PROCEEDINGS OF

International conference on Contemporary Theory and Practice in Construction XVI

Banja Luka, June 13-14, 2024

ЗБОРНИК РАДОВА

Међународне конференције Савремена теорија и пракса у градитељству XVI

Бања Лука, 13-14.06.2024.

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INTERNATIONAL CONFERENCE ON CONTEMPORARY THEORY AND PRACTICE IN CONSTRUCTION XVI

МЕЂУНАРОДНА КОНФЕРЕНЦИЈА САВРЕМЕНА ТЕОРИЈА И ПРАКСА У ГРАДИТЕЉСТВУ XVI

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FOREWORD

It is our great pleasure to write this Foreword to the Proceedings of the International Conference on Contemporary Theory and Practice in Construction, XVI - STEPGRAD. The conference was held on June 13 and 14 at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. As in previous years, the conference STEPGRAD XVI continues a tradition of bringing together researchers, academics, and professionals from all over the world, experts in Civil Engineering, Architecture, Geodesy, and related fields, so this year it brought participants from fourteen different countries The Conference enables the interaction of research students, young academics and engineers with the more experienced academic and professional community to present and to discuss current accomplishments. Their contributions make these Proceedings outstanding. The published papers provide the most recent scientific and professional knowledge in the fields of Computational mechanics, Structural engineering, Building materials, Road planning, Energy efficiency, Urban planning, Architecture, History of architecture, Surveying, Education of engineers, etc.
Almost ninety manuscripts were submitted, while 74 of them were accepted and categorized. Each contributed paper was refereed by the two reviewers. The papers were refereed based on their interest, relevance, innovation, and application to the broad field of Construction. Inviting lecturers this year were dr Ajla Akšamija, professor from the School of Architecture, University of Utah in USA, dr Vlatko Šešov from the Institute of Earthquake Engineering and Engineering Seismology, North Macedonia, dr Marija Nefovska-Danilović, associate professor, from the University of Belgrade and dr Todor Stojanovski from KTH Royal Institute of Technology Stockholm in Sweden.
These Proceedings will furnish the scientists and professionals with an excellent reference book. We trust that it will give an impetus for further studies in all subject areas.
We thank all the authors and reviewers for their valuable contributions. Special thanks go to our sponsors and the members of the Organizational Committee and Working team.

Snježana Maksimović
Miroslav Malinović
Editors

ПРЕДГОВОР

Изузетно нам је задовољство написати овај Предговор за Зборник радова са међународне конференције Савремена теорија и пракса у градитељству XVI – СТЕПГРАД. Конференција је одржана 13. и 14. јуна на Архитектонско-грађевинско-геодетском факултету Универзитета у Бањој Луци. Као и претходних година, конференција СТЕПГРАД XVI наставља традицију повезивања истраживача, наставника и стручњака из цијелог свијета, експерата грађевинарства, архитектуре, геодезије и сродних области, па је ове године окупила учеснике из четрнаест различитих земаља.
Конференција је омогућила интеракцију студената, младих инжењера и научника са искуснијим члановима академске и стручне заједнице у циљу дискусије о савременим тенденцијама у градитељству. Њихов допринос је учинио овај Зборник изузетним. Објављени радови пружају увид у актуелно научно и стручно знање из рачунске механике, инжењерских конструкција, грађевинских материјала, саобраћајница, енергетске ефикасности, урбанизма, архитектуре, историје архитектуре, геодезије, образовања инжењера, итд.
Од скоро деведесет достављених рукописа, 74 је прихваћено и категорисано. Сваки рад је био прегледан од стране два рецензента. Критеријуми за одабир радова су били њихова актуелност, значај и допринос широкој области градитељства. Позивни предавачи ове године били су проф. др Ајла Акшамија са универзитета у Ути из Сједињених Америчких Држава, др Влатко Шешов са ИЗИИС института у Сјеверној Македонији, проф. др Марија Нефовска-Даниловић са Универзитета у Београду и др Тодор Стојановски са краљевског технолошког института КТН у Шведској.
Овај Зборник радова ће послужити као корисна референца стручњацима и истраживачима те смо сигурни да ће пружити подстицај за даља истраживања у предметним областима.
Захваљујемо свим ауторима и рецензентима на њиховом изузетном доприносу. Посебну захвалност упућујемо нашим спонзорима те свим члановима Организационог одбора и Радног тима.

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01

Review paper
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INNOVATIONS IN ARCHITECTURE: RESEARCH, DESIGN AND TECHNOLOGY

Abstract

Architectural designers are currently faced with many challenges—technological changes, environmental and economic impacts, necessity to innovate and raise the bar in building performance, and the paradigm shift in architecture with the wider adoption of advanced computational design and fabrication techniques. This paper focuses on innovations in architecture, relationships between scientific research and design, and advanced building technologies. Several research projects are presented, including use of virtual and augmented reality for design, smart facade systems for generating heating/cooling and electricity, and regenerated buildings with improved performance.

Keywords: innovations, architecture, research, design, emerging technologies

ИНОВАЦИЈЕ У АРХИТЕКТУРИ: ИСТРАЖИВАЊЕ, ПРОЈЕКТОВАЊЕ И ТЕХНОЛОГИЈА

Апстракт:

Архитектонски дизајнери су тренутно суочени са многим изазовима—технолошким промјенама, еколошким и економским утицајима, потребом да се иновира и подигну границе у перформансама зграда, и промјена парадигме у архитектури са ширим усвајањем напредног дигиталног дизајна и конструкције. Овај рад се фокусира на иновацијама у архитектури, односе између научних истраживања, пројектовања и напредне грађевинске технологије. Представљено је неколико истраживачких пројеката, укључујући кориштење виртуелне и проширене стварности за дизајн, паметне фасадне системе за генерисање гријања/хлађења и електричне енергије и обнова зграда за побољшане њихове перформансе.

Кључне ријечи: иновације, архитектура, истраживање, пројектовање, нове технологије

1. INTRODUCTION

1.1. INNOVATION IN ARCHITECTURE: WHAT AND HOW

The general definition of innovation is that it is the process of introducing changes to methods, services, or products. These changes must be useful and meaningful, adding value to the established norms and contributing to our knowledge. Innovation and technological changes are complementary in nature since innovation relies heavily on scientific research and technological developments. Although the concept of innovation within the context of architectural design is not new, the deliberate use of the word “innovation” in architecture has become widely popular during the last decade [1]. A singular cause for this phenomenon remains elusive. However, a confluence of factors likely contributed, including advancements in building technologies and systems, and the wider adoption of advanced computational design techniques. Additionally, the paradigm shift in design, collaboration, and construction facilitated by Building Information Modeling (BIM) has demonstrably influenced the embrace of innovation.

The core tenet of architectural innovation within the contemporary context lies in the transformation of ideas into tangible or intangible outcomes. These outcomes can manifest as physical structures (buildings), or as the design process itself, an intangible service. Regardless of the form, innovation necessitates the application of novel ideas to generate value and positive outcomes. Figure 1 serves as a visual representation of the interplay between the aspects subject to change (product, service, and process) and the degree of innovation achieved (incremental, radical, or transformational). In the context of architectural design, the “product” encompasses the building itself, the physical space it creates, and the materials or objects used in its construction. The “service” refers to the way users interact with the building and its occupants. Finally, the “process” signifies the design methodology employed to conceive and construct the building, space, or system. All three categories present opportunities for innovative interventions, ranging from incremental improvements to paradigm-shifting advancements. Incremental innovation may affect a singular architectural project or a building typology, while transformational innovation influences the entire profession.

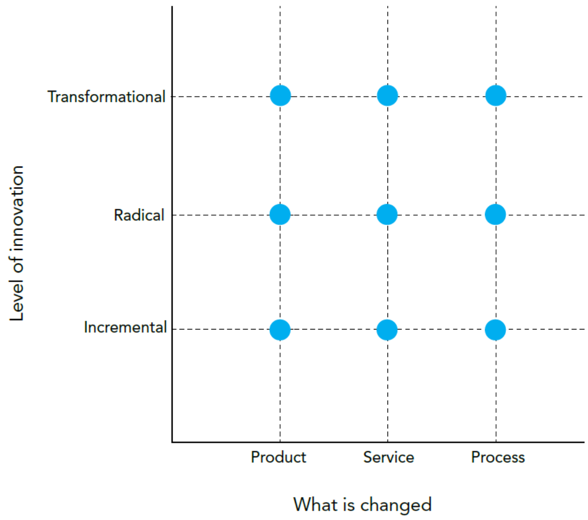


Figure 1. Types and levels of innovation (Source: Author [1]).

Further investigation into the drivers and value propositions for innovation within architectural design is crucial. Innovation serves as a catalyst for organizational progress, impacting efficiency, quality of work, and the improvements of design processes. Architectural innovation necessitates the implementation of novel design strategies and project delivery methods. These innovations, encompassing new design tools, materials, building technologies, and construction techniques, contribute to the creation of buildings that are more responsive to their environment and the needs of their occupants. An integrated model for innovation in architecture is shown in Figure 2, which demonstrates how these different factors influence innovation.

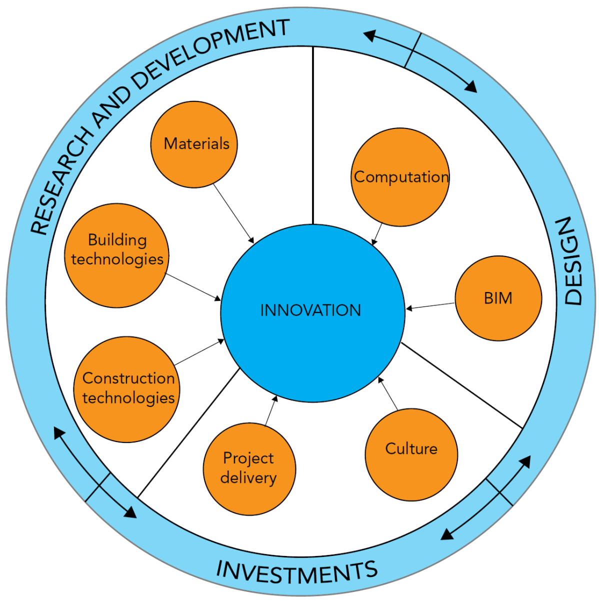


Figure 2. Model for integrating innovation in architecture (Source: Author [1]).

1.2. RELATIONSHIPS BETWEEN RESEARCH AND INNOVATION

The role of research in innovative practices is paramount. Research, within this context, is defined as systematic investigation and creation of new knowledge and applications, utilizing rigorous research methods [2]. Integrating research within the design process is essential for developing new knowledge, solving design and technical problems, overcoming different types of challenges present in the contemporary profession, and improving the design process and architectural work. Research results can be implemented on specific architectural projects but should also be disseminated to the wider design community to improve the knowledge base and architectural profession.

Research and development can bring immense value to any organization for which innovation is important [3]. However, considering the lack of universal models for integrating research with practice, the realities of client requirements, schedules, and budgets, as well as risks and liability—research within the architectural profession is challenging. Organizing and maintaining research departments within architectural design practices can be costly, time-consuming, and risky. Therefore, taking a careful and systematic approach to establishing research departments and defining operational models and relationships between research, design practice, and business performance are essential. It is necessary to balance and determine different priorities, including short-term goals and long-term strategic focus, alignment with firm's motives and values, developing internal capabilities, or collaborating and partnering with external research partners. These following aspects should be considered in integrating research with design practice:

- How to establish the research arm of the firm and its structure and organization.
- What are the connections and relationships between the firm's core values, practice and research?
- What are the long-term strategies and objectives of research vs. short-term actions?
- How to fund research activities and how to mitigate risk and liability issues.
- How to translate results of research efforts into practice.

Figure 3 shows the impacts of research and innovation on revenue, as a direct measure, and value as a measure of all indirect benefits. Investments in research and development require initial capital, but results impact the activities and practices of the firm, influencing design services and methods. Cutting-edge firms and leaders in innovation create a niche market, thus increasing the revenue for their services due to increased market demand. On the other hand, late adopters of innovation do not possess value differentiation. Continuous investment in and implementation of innovative strategies maintains higher revenues for firms whose core values focus on research and development and improvement of design services and methods, as seen in Figure 4.

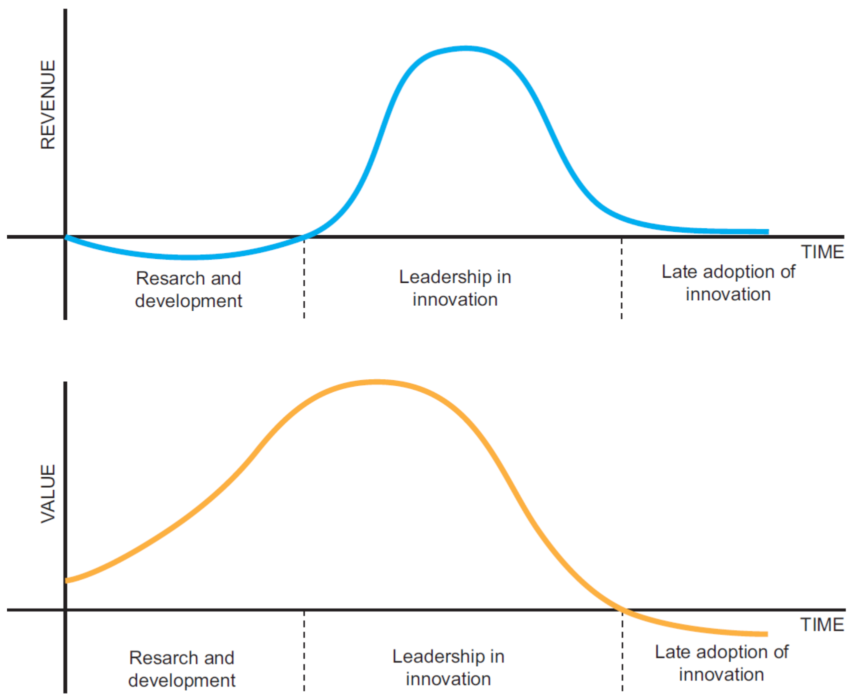


Figure 3. Impacts of investments in research on revenue and value over time (Source: Author [1]).

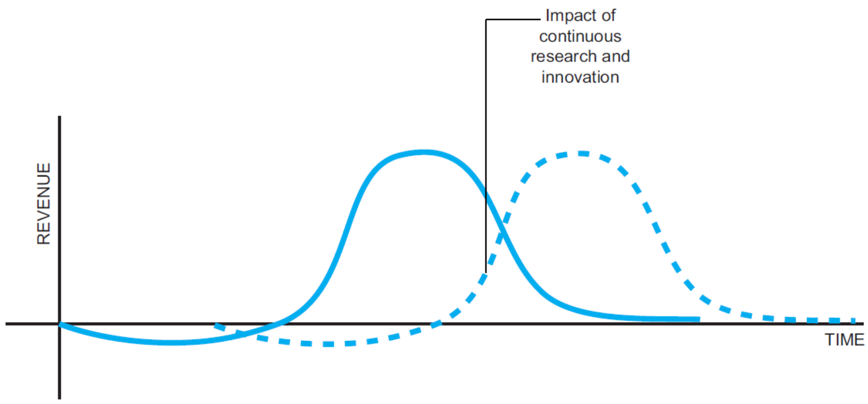


Figure 4. Impact of continuous research and innovation on revenue over time (Source: Author [1]).

2. CASE STUDY 1: AUGMENTED AND VIRTUAL REALITY IN ARCHITECTURAL DESIGN

Augmented reality (AR) and virtual reality (VR) are computer-generated, simulated representations of real or imagined environments, where users can interact with simulated representations using various digital technologies. The similarities between AR and VR technologies are that they rely on digital representations of real or imagined scenes, objects, and environments and utilize advanced 3D modeling and visualization strategies. However, the major differences relate to the level of interaction, where AR can only be “viewed”, and VR can be “experienced”. AR superimposes computer-generated visuals into a real-world environment and utilizes mobile devices, tablets, and computer displays to augment the physical environment with digital projections. On the other hand, VR offers a fully immersive digital environment and uses 3D computer-generated visuals to produce representations of the real world or imagined environments.

AR and VR applications are a promising new direction for architectural design, since improved understanding of architectural design and communication procedures are the primary benefits of these novel technologies [4]. These tools offer exploration of designed environments that is not possible with the traditional forms of representation, since they allow users to immerse themselves, visualize, and explore spaces during different design stages and before construction. However, studies focusing on the integration of these advanced digital technologies in the architectural educational curriculum are limited. Therefore, the primary research objectives of this study were to investigate implementation of AR/VR tools in architectural education and to determine whether these novel digital technologies are beneficial for the educational experience of students [2].

A combination of qualitative, quantitative, and experimental research methods was used, including interviews, qualitative and quantitative surveys, modeling, and experiments. The experiments were conducted during the different stages of the design process and involved three different groups of users. The first experiment analyzed the effectiveness of AR/VR tools (personal assessment by the designer) during the conceptual design, schematic design, and design development. The second experiment investigated the effectiveness of these tools in collaboration and communication between the designer and the “client” during the conceptual design, schematic design, and design development (communication procedures), considering that in the context of architectural education, faculty members are acting as clients. The third experiment involved graduate architecture students, and evaluations were conducted in a group setting (student effectiveness), during the design development phase. These evaluations only included VR applications, since research results indicated that AR tools are most suitable for the early stages of the design process.

Ten different evaluations were conducted to investigate the difference between AR and VR tools, their effects on design and communication protocols during different stages of the design process, and the perspectives of various participants. Each step involved evaluation of the AR or VR building model, shown in Figure 5, which lasted approximately 30 minutes for every participant. These evaluations were followed by a survey (qualitative and quantitative) and interviews (for open-ended questions). In the case of AR, the digital model was visualized within the physical environment by superimposing a 3D digital model in the real environment, and the walk-throughs were conducted by simply rotating a mobile device to visualize different aspects of the model. In the case of VR, each study participant was fully immersed within the VR environment, where they had an opportunity to “experience” the VR model, as seen in Figure 6. This immersive experience included visualization of the VR model (the scale, building geometry, surrounding buildings, building structure, etc.), as well as a walk-through within the site and the building.

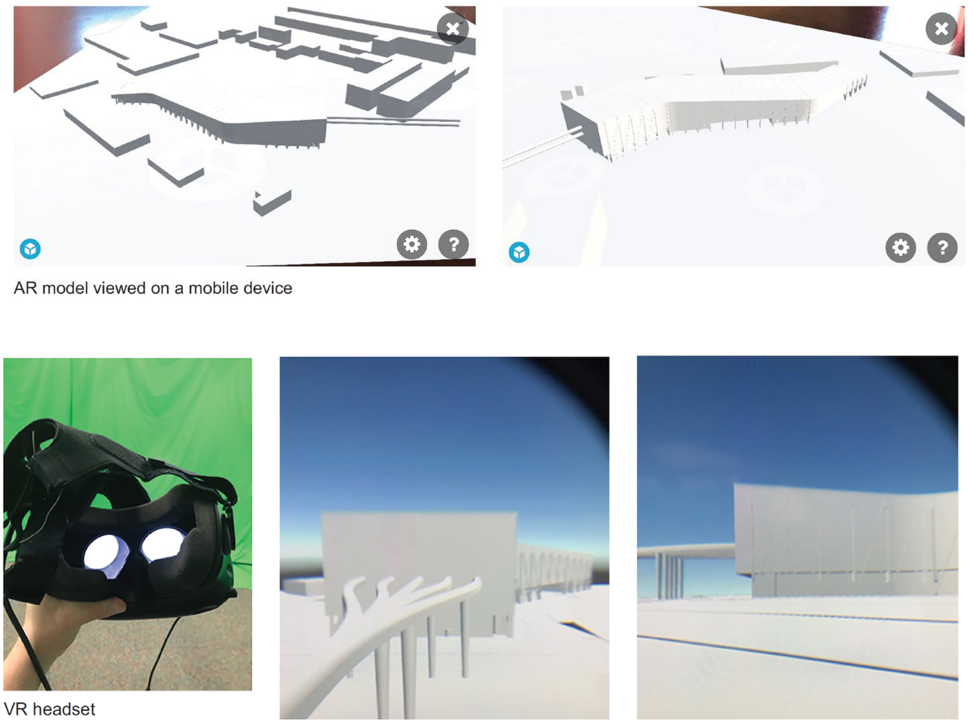


Figure 5. Visualization of the AR and VR model (Source: Author [2]).

Experimental setting for VR experiments

VR experiments

Figure 6. Experimental set-up for VR experiments (Source: Author [2]).

The results of the interactive evaluation showed that AR was beneficial for visualizing the overall site and scale of the building and its relationships to the surrounding context. However, it had limited use for resolving design problems. The results indicated that the AR is useful for understanding the overall building massing and relaying large-scale design ideas to the client. The application of this technology in the early stages of the design process is similar to utilizing physical models, which are very typical in architectural education. The main benefit of AR is that digital models can be created automatically from BIM software and displayed in AR environments, thus saving time and resources compared to building physical models.

The immersive nature of the VR and the ability to experience the building helped to provide an insight as to what would it be like to explore this architectural design in person. From the designer's perspective, the primary benefit of using VR at this stage was the ability to explore and visualize the design, but it was not greatly helpful for making design decisions. The results of the interactive evaluation and communication procedures between the designer and client indicated that the primary benefits of using VR in the conceptual design stage are the ability to explore and visualize the scale of the building, its relationship to the site, the overall form, and movement through the building. The last aspect—the ability to experience the building from the perspective of a building occupant and circulate through the digital model as if moving through the real building—is the most important one, because no other visualization technique offers this capability. The client was more satisfied with the design, workflow, and navigation than the designer, while the designer gave higher ratings for visualization and success, as seen in Figure 7. The results for schematic design evaluations indicated that the designer was more satisfied with the VR model and its effect on design decisions than with the VR model for the conceptual design. The VR model was more developed and included the overall structure, interior partitions, building envelope treatment, and circulation elements (stairs and elevators). Therefore, the immersive experience was more beneficial since it was easier to notice design problems that would be difficult to notice in typical architectural drawings. The final evaluations conducted during the design development implemented the most detailed VR model. The design issues raised during earlier stages were resolved, and the model was updated to reflect these changes. The immersive experience was the most convincing at this stage because it was possible to fully explore all aspects of the VR model (integration of the building with the site and surrounding context, structural systems, building envelope design, circulation, etc.). Figure 7 shows evaluations results for different stages of the design process.

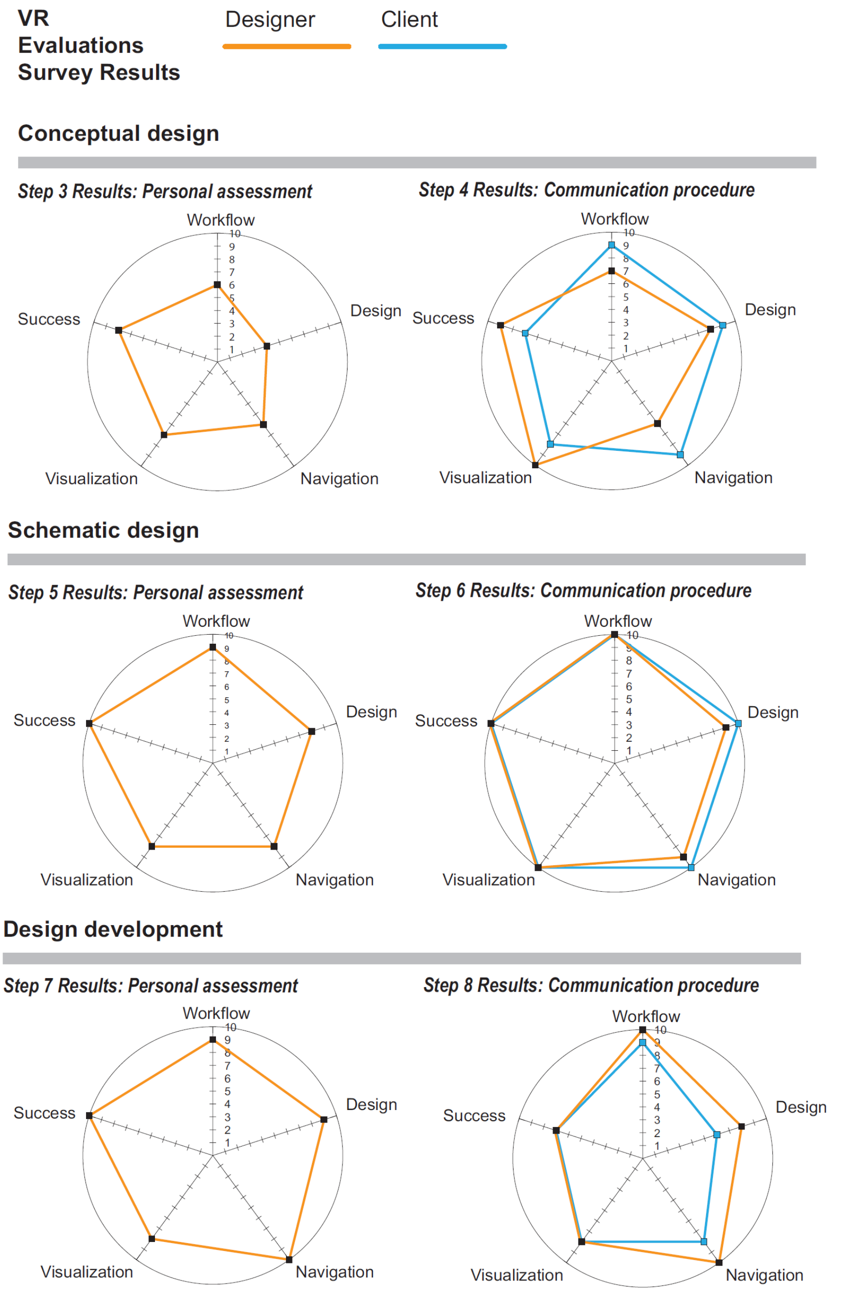


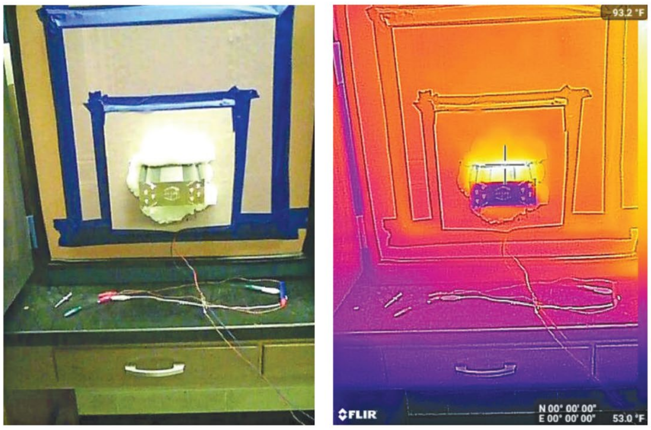
Figure 7. Results of VR evaluations (Source: Author [2]).

The results of the study indicated that AR and VR tools are beneficial for the architectural design process and can advance architectural education. These benefits include improved collaboration, improved communication, investigation of design mock-ups, and possibility to conduct visual, immersive reviews. Specific results of various evaluations indicated that VR and AR tools are useful for visualizing building form, scale, and design elements, as well as understanding movement and circulation through the building. No other design representation method offers such an immersive experience and visualization of design elements nor an ability to move through a digital representation of a building. Therefore, these technologies can greatly benefit spatial cognition, design communication, and visualization of architectural projects.

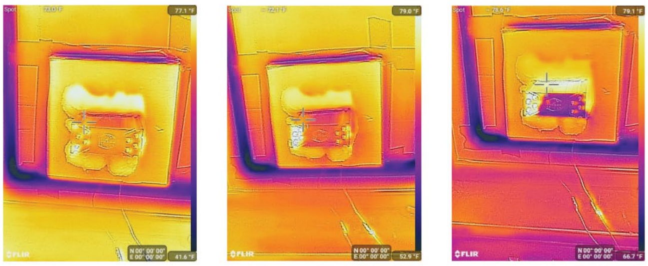
3. CASE STUDY 2: SMART FACADE SYSTEMS FOR ENERGY GENERATION

Smart facade systems can be defined as building enclosures that react to the exterior environment, adapt to environmental changes, regulate their performance and functioning (by self-regulation or by users), integrate smart materials and components, and, in some instances, provide renewable energy for building's operation. Smart facade systems are an important aspect of advanced building technologies that can revolutionize our buildings and significantly improve their performance. This research focused on the development, design, evaluations, and applications of new, intelligent facade systems, which integrate thermoelectric materials [5]-[8]. Thermoelectric materials are smart materials that can produce a temperature gradient when electricity is applied, exploiting the Peltier effect, or generate a voltage when exposed to a temperature gradient, utilizing the Seebeck effect. These types of materials can be used for heating, cooling, or power generation.

Quantitative and experimental research methods, including modeling, simulations, prototyping, testing, and experiments were employed in this research. Initially, two prototypes were designed and constructed. These prototypes were first tested in ambient room conditions to measure the heating and cooling outputs of thermoelectric materials. Then, an experimental study was utilized to physically evaluate heating and cooling outputs of the constructed smart facade prototypes, where a controlled thermal chamber was used to represent different exterior temperatures, and interior temperature was kept constant. Thermal imaging was used to measure the heating and cooling outputs under varying voltage and power supply, as seen in Figure 8. The results were promising and indicated that facade-integrated thermoelectric materials would provide sufficient heating and cooling. The coefficient of performance (COP) was numerically calculated based on the experimental results and compared to conventional HVAC systems [5].



Thermal chamber testing and thermal imagining used for measurements



60°F (16°C) 30°F (-1°C) 0°F (-18°C)

Measurements (heating mode) at 3V, captured with a thermal camera

Figure 8. Experimental set-up (thermal chamber) for measuring heating and cooling potential of smart facade systems (Source: Author [2]).

The next step of the research focused on the design, modeling, and physical prototyping of real facade systems that would integrate thermoelectric materials. Figure 9 shows various facade systems and designs.

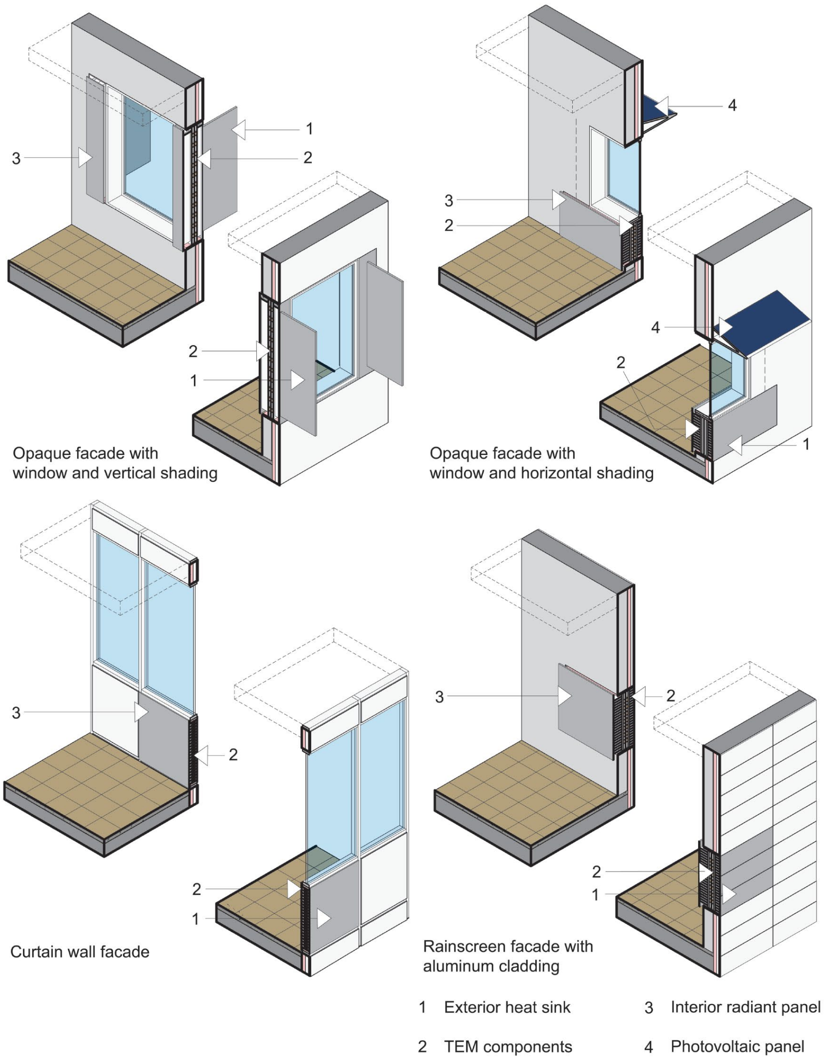


Figure 9. Different smart facade systems that integrate thermoelectric materials for heating, cooling, and power generation (Source: Author [2]).

Table 1. Climate zones used in the energy modeling study of smart facade systems.

Climate zone	City	Zone	Region
1A	Miami, FL	Very hot	Moist
2A	Houston, TX	Hot	Moist
2B	Phoenix, AZ	Hot	Dry
3A	Memphis, TN	Warm	Moist
3B	El Paso, TX	Warm	Dry
3C	San Francisco, CA	Warm	Marine
4A	Baltimore, MD	Mixed	Moist
4B	Albuquerque, NM	Mixed	Dry
4C	Salem, OR	Mixed	Marine
5A	Chicago, IL	Cool	Moist
5B	Boise, ID	Cool	Dry
6A	Burlington, VT	Cold	Moist
6B	Helena, MT	Cold	Dry
7	Duluth, MN	Very cold	N/A
8	Fairbanks, AK	Subarctic	N/A

The last part of the study investigated the heating and cooling potentials of these novel systems for conditioning commercial office spaces. Computational Fluid Dynamic (CFD) simulations were conducted under various exterior environmental conditions to determine interior temperature distribution and the necessary wall coverage with thermoelectric components. Energy modeling was conducted for a single office space, as well as a whole large-scale commercial building, to determine energy saving potentials. Simulations were conducted for fifteen different climate zones in the United States, as seen in Table 1. Figure 10 shows energy modeling results for various climates, indicating energy savings associated with these innovative facade systems compared to conventional HVAC systems.

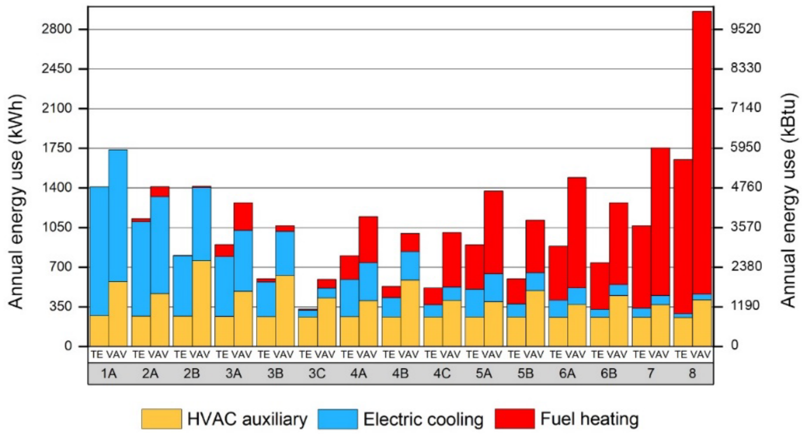


Figure 10. Annual energy use comparison of smart facades with thermoelectric material vs. conventional VAV system for various climate zones (Source: Author [8]).

The results of this research indicated that thermoelectric materials are promising smart components that can be used in facade assemblies for heating and cooling purposes, controlling buildings' interior environments. This is an independent system that does not require moving parts or harmful substances and solely relies on the temperature difference between the interior and exterior environments to operate. Maintenance of these advanced systems would be easier than the conventional HVAC systems because they can be treated as individual components. Furthermore, they can be used as a personalized system which occupants of each space within the same building can use based on personal thermal comfort preferences.

4. CASE STUDY 3: REGENERATIVE DESIGN OF EXISTING LABORATORY BUILDINGS

Existing buildings are the largest contributors to global energy use and greenhouse gas emissions [9]. Recent research shows that energy use in existing buildings can be significantly reduced through proper retrofitting strategies [10], and that retrofitting is one of the main approaches in realistically reducing a significant percentage in carbon emissions [11]. A specific building typology, scientific research laboratory buildings, pose specific challenges for energy-efficient retrofits. The most pronounced challenge is their disproportionate demand and utilization of energy since these buildings typically consume significantly more energy per area than other building types, such as office or residential buildings. This high energy demand is associated with increased ventilation requirements, equipment loads and plug loads. Another challenge is that not all research laboratory buildings have similar mechanical and operational needs, and retrofitting comes down to a case-by-case approach [12].

This case study investigated design strategies for achieving a high-performance retrofit of an existing higher-education laboratory building, located in a cold climate [12]. The primary objective was to evaluate current state and potential retrofit strategies to improve building performance of this building. Research methods included analysis of archival data and empirical data, and computational software modeling and simulations. Using original construction drawings and current state photographs, a full BIM model was developed for analysis and energy simulations. Also, actual energy consumption data was collected for a period of three years. Building's formal and spatial qualities were analyzed and the building's response to environmental conditions was evaluated using performance simulations. Next, thermal and moisture resistance performance of a typical facade system was evaluated. Lastly, a whole-building energy simulation was conducted to evaluate current building performance, and simulation results were compared to the actual energy consumption data. Results were then used to inform proposed retrofit solutions, spatially and formally. Energy simulations of retrofit design were then conducted and evaluated to assess improvement in building performance. Lastly, potential renewable sources of energy were evaluated to reduce the environmental impact of the building and produce on-site renewable energy.

The site plan of the investigated building is shown in Figure 11. The original building was built in 1947, and the addition was built in 1964. Both buildings have their elongated east facades facing the main street. The original building is a two-story, flat-roofed, brick faced building with a central, limestone architrave entrance and tall, metal framed windows. The addition building is a four-story, flat-roofed, also brick faced building characterized by ribbon storefront glazing along the main level and the top story. Levels 2 and 3 do not have any windows, and the only daylight comes from the windows located at the far ends of interior corridors. The addition building also includes a single-story central volume that serves as the main entrance and provides a connection to the original building. The fan shaped volume also includes a lecture hall.

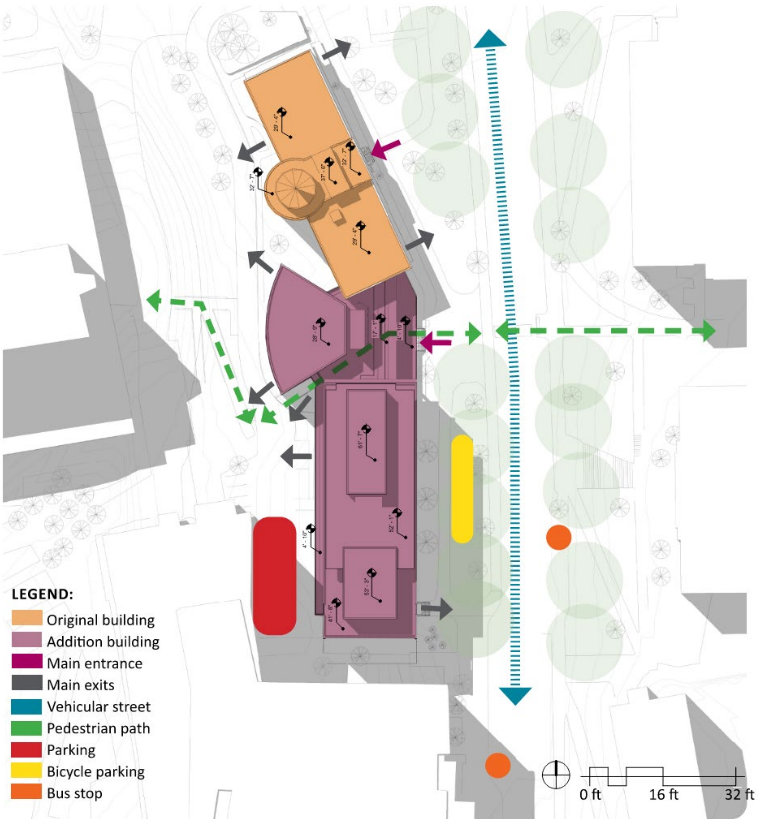


Figure 11. Site plan of the analyzed building (Source: Author [12]).

The building program is composed of primarily research laboratories and administrative spaces, which branch off the central corridor to the east and the west of each floor level, without a particular pattern at both the original and the addition buildings, as seen in Figure 12. Laboratories and office spaces are segregated into separate spaces without visual transparencies between these functions, and the general size of these types of spaces is irregular. Current practice encourages larger laboratories that implement visual transparencies to encourage collaboration, flexibility to allow for adaptions to space function in the future, and decentralization and clustering of energy systems by program function to balance energy needs. These aspects were considered in proposed retrofit design strategies, which influenced the proposed reconfiguration of floor plans and interventions at the building facades. This resulted in an addition of significant building area and volume, which were later included and accounted for in whole-building energy simulations. Figure 13 shows retrofit design strategies.

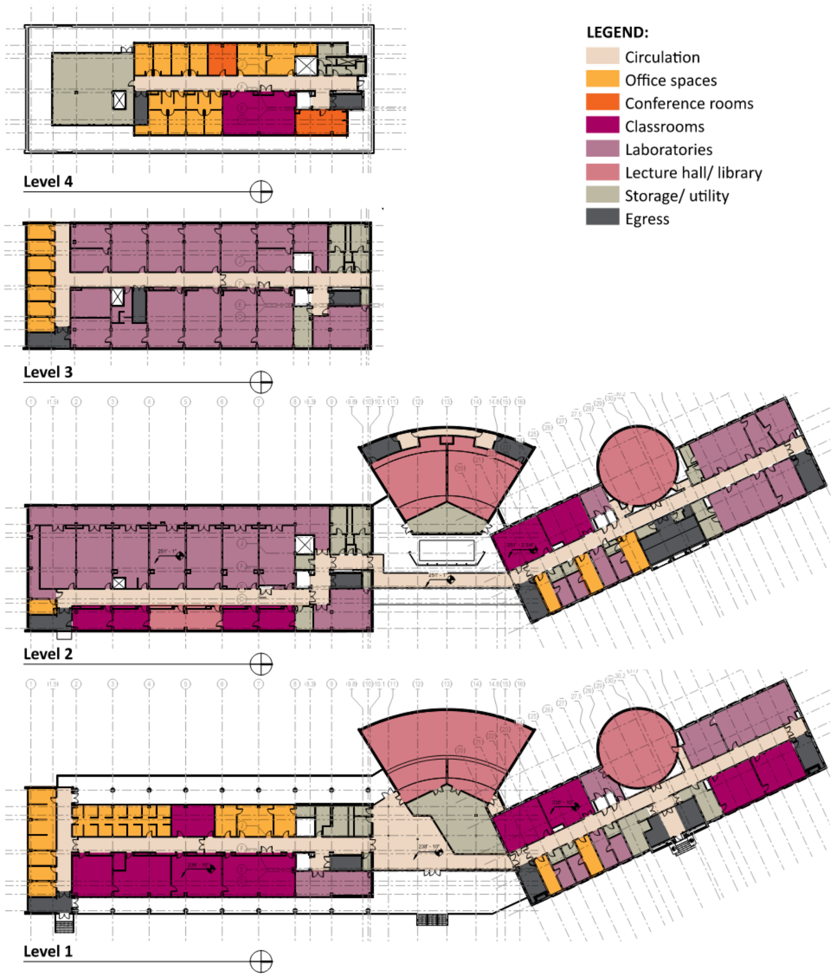


Figure 12. Original spatial organization of the analyzed building (Source: Author [12]).

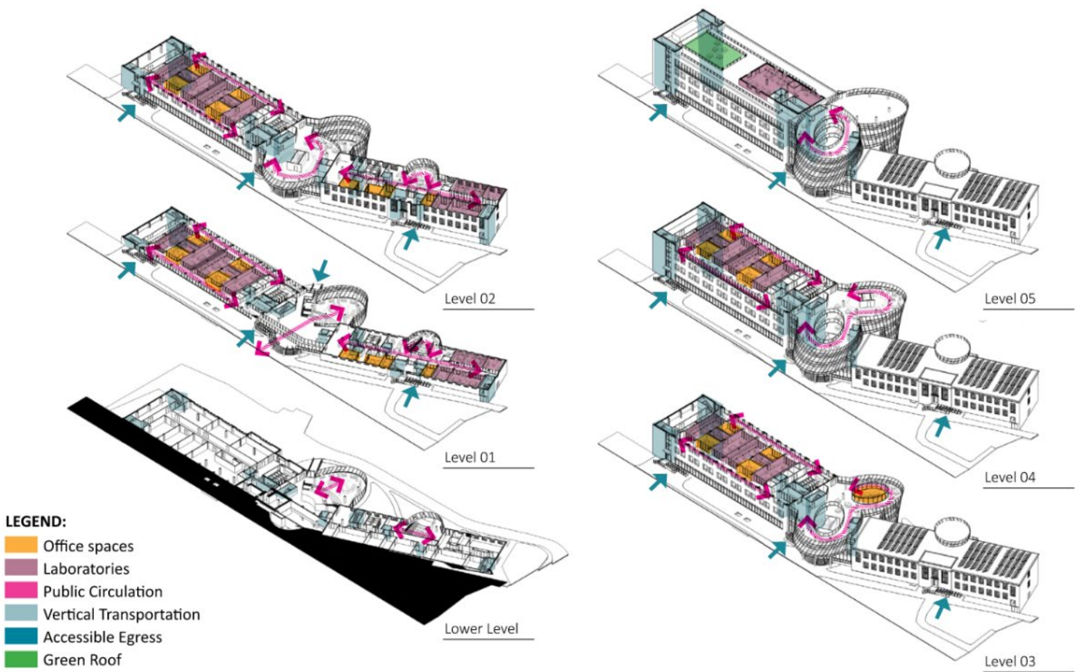


Figure 13. Retrofit design strategies for the analyzed building (Source: Author [12]).

Whole-building energy modeling was conducted, and Figure 14 indicates results for the current building, retrofit design and comparison to actual energy consumption data. The building's actual annual electricity and steam consumption data was collected and averaged over three years (2017, 2018 and 2019).

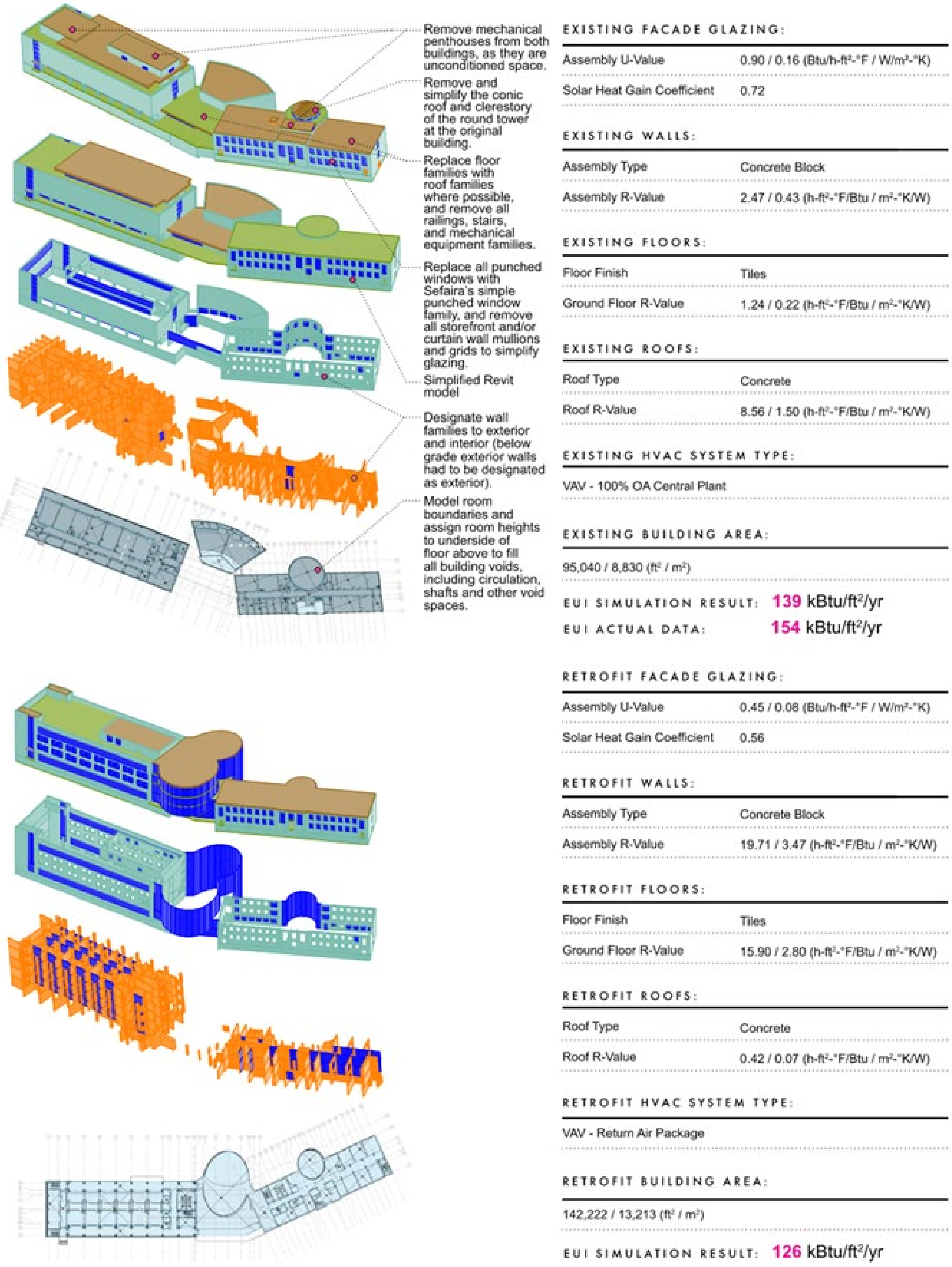


Figure 14. Energy consumption of the current building (modeled and actual) vs. retrofit design (Source: Author [12]).

Typical original window details of the original building and addition building indicated a rather simple technology, utilizing painted aluminum, non-thermally broken frame profiles, aluminum spacers, and single layer, clear glazing of slightly different thicknesses, respectively. Similarly, typical solid, exterior wall sections at both buildings indicated few layers and no insulation in their brick veneer and concrete masonry unit (CMU) frame assemblies. Figure 15 illustrates the typical solid and glazed facade systems at the addition building, as well as retrofit strategies. Solar wall cladding system was considered, since it acts both as an additive air insulation layer and as a heat harvesting, passive, double skin facade system that could be applied to existing facades. Choice to integrate this technology was a result of the existing condition, where the embodied energy of the existing concrete and brick layers dictated that these layers remain as part of the assembly, and that the complete lack of insulation dictated that additional facade layers were necessary and would have to be applied either on the exterior, or on the interior of the existing facade. Thus, a choice was made to treat the existing facade layers as structure, and to insulate and reclad on the exterior.

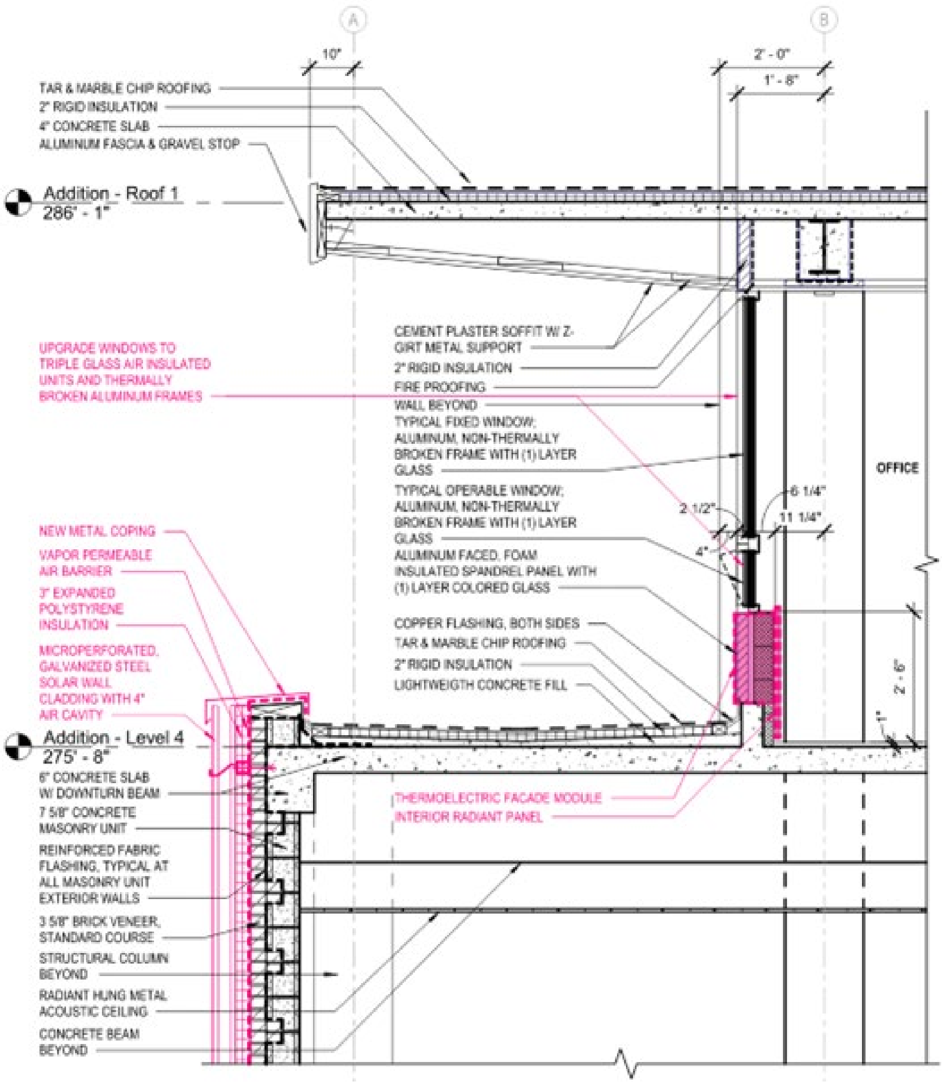


Figure 15. Typical exterior wall for the addition building, indicating existing facade components (in black) and retrofit design strategies (in color) (Source: Author [12]).

Final research results showed that the existing building drastically underperforms in all evaluated criteria. Building enclosure at both buildings, whether solid or glazed, severely underperformed in terms of thermal performance and moisture resistance due to minimum thermal resistance and lack of any insulation. Such underperformance in a predominantly cold climate poses significant challenges for a potential retrofit process, as the building skin would have to be either built up on the exterior or interior sides of the enclosure. Moreover, the interior program and spatial organization was segmented and scattered, without any visual transparencies or inviting program for the public and users to socialize, and several floors of occupied science laboratories and offices did not have any windows. Additionally, egress and accessibility were insufficient. Such state would also pose significant challenges for potential retrofit process, as the interior spaces would require a deeply invested intervention and reconfiguration, which may result in needing to provide additional building area to accommodate additional public, interdisciplinary, and casual program in addition to likely having to significantly enlarge and equip existing laboratories to current standards.

Primary passive retrofit strategies included improvements in building enclosure, specifically adding insulation and water drainage to the exterior walls and insulation and thermally broken components to window systems. Thermal performance of the proposed solid facade system, a solar wall and double skin facade, showed significant improvements. Thermal performance of the proposed glazed facade systems (triple, air insulated glazing units with a thermally broken frame) also showed significant improvements. Integrated retrofit design strategies, shown in Figure 16, resulted in an overall 13% reduction in energy consumption, despite a 67% increase in retrofit building area (an addition of a large 5-story atrium between the two existing buildings).

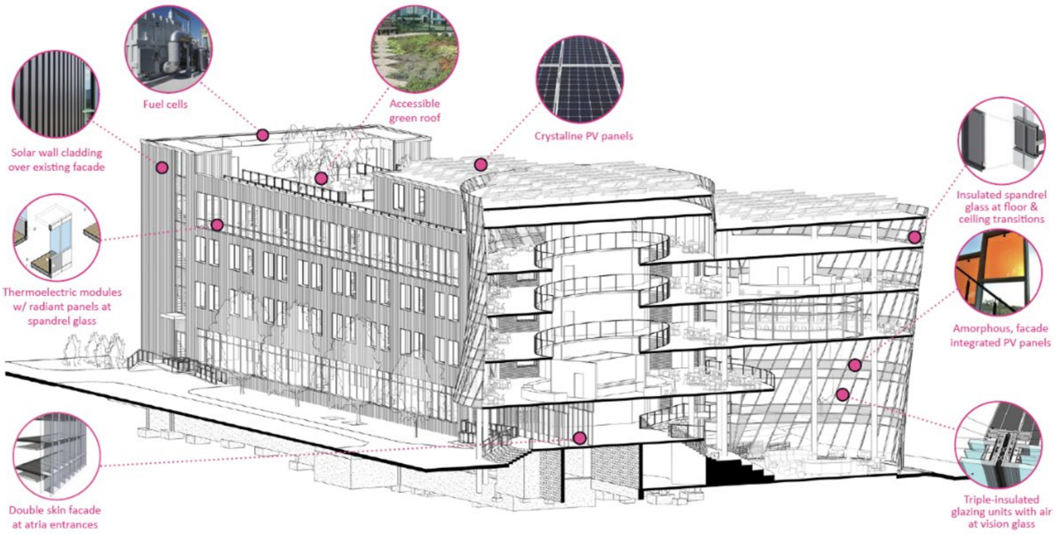


Figure 16. Integrated regenerative retrofit design, illustrating combined passive and active strategies (Source: Author [12]).

Overall results, for a building typology that heavily relies on energy intensive mechanical systems, show that the sequential process of analysis methods and simulations used in this case study helped to inform retrofit decisions as a reiterative process. It helped quantitatively maximize on passive strategies to lower the overall energy consumption before considering active systems. Regenerative design of existing buildings, aimed to improve their performance and reduce energy consumption, requires integration of building performance analysis procedures during the design process.

5. CONCLUSION

This paper discussed innovations in architecture, particularly focusing on design methods, integration of research, and advanced building technologies. It also presented three distinct case studies: research on advanced digital technologies (AR and VR), development of smart facade systems and regenerative design of existing buildings. Research is an integral part of innovation, and as such, it is necessary to discover new knowledge, improve our understanding of the architectural design process and its results, find new methods for design, collaboration, and construction, investigate the impacts of architecture on the environment and people, and ultimately improve the built environment. Historically, most architectural research came from academic and research institutions, rather than architectural practice. But this is changing, and many architectural firms are realizing the need to invest in research and the necessity of conducting research. This is due to many challenges that the contemporary architectural profession is facing, such as climate change, urbanization, depletion of natural resources and environmental concerns, societal transformations, and the changing economy. On the other hand, technological advancements, new materials and building technologies, developments in architectural digital technologies, and new fabrication methods are creating a paradigm shift in architecture and requiring architects to understand how emerging technologies are influencing their work. Therefore, research is essential to understand the effects of these changes and to improve the teaching, learning, and practice of architecture.

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02
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URBAN MORPHOLOGY AND CITY INFORMATION MODELING (CIM) – COMPUTATIONAL URBAN DESIGN IN THE PLANNERS' OFFICE OF THE FUTURE

Abstract

City Information Modelling (CIM) seeks to evolve Building Information Modelling (BIM) into urban planning and design practices that are today dominated by Geographic Information Systems (GIS). The design toolbox in GIS software does not relate to urban design elements (streets, sidewalks, buildings, lots, etc.) or urbanist parameters. Urban designers must use geometric design elements from GIS (lines, polygons, and points) that do not correspond to their practices and three-dimensional (3D) understanding of cities. This paper explores the CIM framework thought evolution of the architects' and the planners' office, the history, and new trends in digitalisation of urban planning and design from a perspective of urban designer and morphological structure of cities.

Keywords: urbanism, urban design, urban morphology, city information modeling, computational urban design,

УРБАНА МОРФОЛОГИЈА И ИНФОРМАЦИОНО МОДЕЛИРАЊЕ ГРАДА (ЦИМ) – КОМПЈУТЕРСКИ УРБАН ДИЗАЈН У КАНЦЕЛАРИЈИ БУДУЋНОСТИ ГРАДСКИХ ПЛАНЕРА

Сажетак

Информационо моделирање града (ЦИМ) настоји да еволуира Информационо моделирање зграда (БИМ) којима данас доминирају Географски информациони системи (ГИС). Пакет алата за пројектовање у ГИС софтверу не подржава елементе урбаног дизајна (улице, зграде, парцеле, итд.) ни урбанистичке параметре. Урбани дизајнери морају да користе геометријске елементе дизајна из ГИС-а (линије, полигоне и тачке) који не одговарају њиховој пракси и тродимензионалном (3Д) разумевању градова. Овај рад истражује мисаону еволуцију ЦИМ оквира канцеларије архитеката и планера, историју и нове трендове у дигитализацији урбаног планирања и дизајна из перспективе урбаног дизајнера и морфолошке структуре градова.

Кључне ријечи: урбанизам, урбанистички дизајн, урбана морфологија, информационо моделовање града, компјутерски урбан дизајн

1. INTRODUCTION

With the new developments in Information and Communication Technology (ICT), and the increased processing power, storage capacity, and communication bandwidth, as well as accelerated digitalization of organizations and companies, businesses and services, the vision of ubiquitous computing (Weiser, 1991) becomes closer to reality today [1]. City Information Modeling (CIM) seeks to digitalize urban planning and design practices [2-4]. Digitization is defined as the process of converting analogue data into a digital form, and ultimately into binary digits. Digitalization describes diverse sociotechnical phenomena and processes of adopting and using ICT technologies [1]. Urban planning and design processes are dominated by Geographic Information Systems (GIS) and Computer Aided Design (CAD) software. GIS and CAD software developed in the 1960s with a two-dimensional (2D) drawing board and design toolbox of geometric elements (points, lines, arcs, polygons, etc.) that has not changed much as data structure and design capabilities. Urban planners and designers remain reluctant to digitalization [4]. Urban planners typically negotiate development projects in various constellations of actors and stakeholders. They typically are not GISers and CADers, but they use the inputs of GIS experts and spatial analysts (GISers refer to technical professionals that use GIS for spatial analyses). GIS and CAD work perfectly for creating maps of cities and urban plans with streets, buildings and plots as polylines and polygons, for spatial database, or for 2D spatial and morphological analyses [5-6], but GIS and CAD cannot represent the hierarchical morphological structure of urban design elements (streets, sidewalks, buildings, lots, etc.) and their interactions in three dimensions (3D).

Urban designers as practitioners must deliver drawings and illustrations of cities and develop design codes or guidelines at various stages of planning and urban design. Masterplans are the standard deliveries to communicate urban design, but urban designers have the unique competence to analyse the experiential qualities of cities in 3D [7]. Furthermore, many urban designers use sketching and the typical computer mouse as interface works differently than the pencil or pan in the hand. Faced with a choice between GIS and CAD, they often return to hand drawing and sketching, and they combine images, diagrams, and maps from diverse software packages to illustrate the experiential qualities, to analyse and to design cities. Urban designers understand cities through types and typologies [6, 8-13]. Types are abstractions about urban forms, or the representative exemplars or prototypes. Society creates types of streets, buildings, neighbourhoods, cities, etc. (even types of spaceships, space colonies, etc.) to simplify communication and promote values [14]. A type packs much information into one icon: a set of architectural or environmental attributes; a set of rules for construction and for organization of space; a set of behaviours and defined roles that take place within it; and a set of qualities it should exhibit [15-16]. Urban morphologists describe cities as a hierarchy of design elements that create types: streets and their layout, plots and their aggregation in blocks, buildings, and land uses [5, 13]. Urban morphology inferences and interprets types of buildings, streets, neighbourhoods etc., whereas urban design invents types and prescribes interventions using types [17]. Urban designers typically turn typologies into design guidelines or Form-Based Codes (FBCs) [6, 12, 18-23] often with morphological methods.

This paper explores the history and new trends in digitalization of urban planning and design from a perspective of urban designer and morphological structure of cities [5, 13]. It described a framework for City Information Modelling (CIM) as evolution of Building Information Modelling (BIM) into urban planning and design that is today dominated by GIS and CAD. The paper furthermore looks at the evolution of the architects' and the planners' office. CIM is conceived as a digital tool in the planners' office of the future that will address the needs of urban designers for morphological hierarchical understanding of cities in 3D. BIM apps replaced CAD software in the architects' office because BIM standardized around the floor plan as a drawing board and a design toolbox closely aligned to the design elements in architectural practices (walls, windows, doors, furniture, etc.). In the BIM apps, architects arrange architectural elements on a floor plan. GIS software does not have a design toolbox that relates to urban design elements (streets, sidewalks, buildings, lots, etc.) or urbanist parameters such as Floor Space Indexes (FSI), Open Space Indexes (OSI), etc. or the morphological structure of cities (hierarchy of streets, lots, and building). To adapt to the GIS and CAD apps, urban designers must use design toolboxes with geometric design elements (lines, polygons, points, etc.) that do not correspond to their practices and three-dimensional understanding of cities. By presenting the CIM framework and its morphological theories, this paper aims to inspire a debate about digitalization of urban planning and design inspired by morphological research and theory and to contribute to increased use of digital tools among urban planners and designers.

2. DIGITALIZATION IN URBAN PLANNING AND DESIGN AND SMART SUSTAINABILITY

Digitalisation in urban planning and design is intertwined with cities and sustainability. In the concept of sustainable development, the urban challenge includes world cities with global reach that draw resources from distant lands, with enormous aggregate impacts on the ecosystems of those lands. Agenda 2030 sets an action plan with sustainable development goals (SDGs) and targets. The mission of SDG 11 is to make cities and human settlements inclusive, safe, resilient, and sustainable. European Commission acknowledges Agenda 2030 in the European Green Deal that highlights climate neutrality, energy and resource efficiency, smart and sustainable mobility, circular economy and preserving and restoring ecosystems and biodiversity and targets disruptive innovation and digital technology as enablers for greater sustainability. Sustainable urbanism addresses the urban challenge in sustainable development with innovative urban design emphasising the human scale and the liveable city, the physical form, and experiential qualities contextualised in world cities shaped by globalisation and virtual-physical existence [23-37]

Digital technology and sustainable development meet in the paradigm of smart sustainability. Smart sustainability inspires and explores the development of smart-sustainable neighbourhoods, digitalization of urban infrastructure and development processes, as well as collaborative experimentation with digital technologies [38]. The aspects of smart sustainability include smart cities and digitalization of urban planning and design practices. The smart city narratives range from embedding hardware and software in the physical city to the effects of computation on the physicality of the city [29]. The smart city has existed as the "informational city" [23], "invisible city" [25], "city of bits" [30], "computable city" [27], "programmable city" [35], etc. The smart city has a physical appearance (hardware such as cables, chips, sensors, robots, and so on), an invisible programming and computing domain (codespace as backend) and a perceptual virtual frontend as apps and social media (so-called cyberspace or metaverse). The digitalization of urban planning and design practices can be understood as digitization of cities (turning analogue data into a digital form and developing data structures as backend) and developing software for urban planners and designers that can be used in urban planning and development as frontend. There are a variety of professionals within urban planning and design that work with sustainability (within or out of the digitalization processes) that have specific digitization and digitalization needs. Strategic planners produce and negotiate visions, frame problems and challenges usually at larger scales from neighbourhood to metropolitan areas. They create policy documents with sustainability goals to be reached typically in long term. The ongoing paradigm in strategic planning is collaborative, communicative, or participatory planning that revolves around information, communicative rationality, and action, consensus building and collaboration among actors and stakeholders [39] discusses three collaborative, communicative or participatory planning streams. For theorists and practitioners of consensus building (e.g. Judith Innes) consensus must be won through negotiation and mediation between interests (and types of information). For collaborative theorists (e.g. Patsy Healey) consensus is potentially inherent in the act of communication between stakeholders. Radical urbanists and architects (e.g. Leonie Sandercock) argue that the aim is not consensus at any price, but empowerment of the most disadvantaged in society. Strategic planning can be applied for any visionary or futuristic thought including cities and strategic urban planners typically do collages of images (in 2D design software) and write documents (in word processors). Physical planners and urban designers focus specifically on the physical form of cities, and they draw plans either in GIS, CAD, or BIM. Physical planners work with zoning or density of development in 2D by arranging land uses at a scale of lots or neighbourhoods (and CAD and GIS fulfill their needs). Urban designers focus on physical form in 3D and experiential qualities of urban space, at a street, city block or neighbourhood design level [7]. There are also landscape architects, transport planners and traffic engineers, mobility managers, etc. that work with cities. In the different practices and needs for professional software, GIS emerges as an integrating framework to share and work with urban data. GIS and spatial analyses are (smart city) digital tools to address sustainable urbanism. To understand the necessary level of GIS expertise for a specific interdisciplinary research project, Ricket [40-41] identify three roles of GISers: 1) use of GIS as a Tool, 2) employing a GIS Toolmaker for commissioned applications or 3) a GIScientist for developing and programming new forms of spatial analyses (Figure 1), but there are also many urban planners and designers that are nonGISers. There are limitations in applying GIS and spatial analysis. Spatial analysis is not particularly useful in analyzing urban planning processes or causal understanding (graphs and topologies) beyond the specifications of identified problems [42]. There is also a drift between GISers or nonGISers. Many public authorities and private business have GIS divisions that deal with spatial data and land cadastres (GISers of various sorts as shown on Figure 1), that sit separately from city planners and urban designers (predominantly nonGISers) that negotiate development and draw plans. The GIS divisions seek to address the challenges associated with processing large datasets and spatial data infrastructure of the municipalities, and the urban planners focus on planning processes and urban development. There is a need to bridge the gap and reach out to nonGISers with a new kind of software.

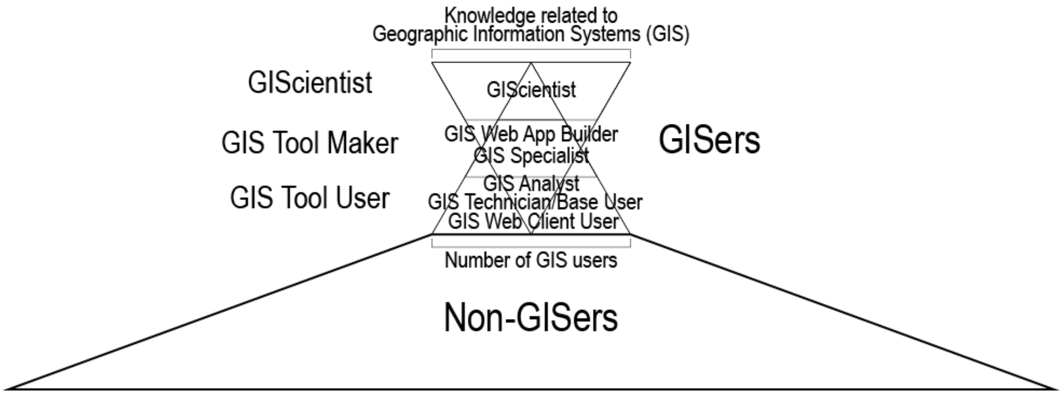

Figure 1. The GISers (the top of the figure is drawn by Ricket, et al. 2020) are just a technical segment of the professionals involved in urban planning and design. There are GIS departments in public authorities or private businesses and planning consultancies. Typically, GISers (as well as CADers and BIMers) are technicians that sit separately, whereas most urban planners and designers are typically nonGISers (many are not even GIS Tool Users as shown above) and they belong to separate departments.

3. THE DEVELOPMENT OF DIGITAL TOOLS FOR URBAN PLANNERS AND DESIGNERS

To understand the dominance of CAD and GIS in today's urban planning and design, and BIM in architecture it is important to look at the history of software and the process of digitalization of the architect's and urban planner's office. The vision for the (digital) office of the future was laid by Vannevar Bush's paper "As we may think" as the concept of "memex". A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility (memex includes all the converging aspect in ICT today, the personal computer, smart communication device and artificial intelligence). It is an enlarged supplement of human memory or "an extended mind" [43-44]. The extended mind includes various portable, wearable, or tangible devices and interfaces, transparent technologies and various apps and online worlds (Internet, social media, etc.) building a cyberspace or metaverse. Some devices, interfaces and virtual representations work smoothly, e.g. the software for word processing is widely used. Human society experienced digital transformation towards virtual paper and keyboard input. Keybords and typewriting are so widespread today that many children prefer typing over handwriting. But architectural professionals, urban planners and designers who previously drew by hand, with T-squares and triangles, did not experience a complete digital revolution. They adapted to a new way of thinking about architecture and cities. The use of digital tools such as CAD and GIS software in urban planning and design is linked with technical knowledge for doing spatial analysis and individual preferences to use computers (of CADers, BIMers, and GISers). Even though architectural professionals, urban planners and designers are trained in CAD, BIM and GIS, there is a misfit between urban planning and design practices and available software. The computers feel peripheral to cities, urban planning and design and the conceptual frameworks of CAD and GIS coerce urban planners and designers in thinking in geometric and database terms that are very limited representationally. CAD and GIS changed very little from their origins in the 1960s.

Digitalization is driven by technological revolutions as Informational Technologies (IT) and Communication Technologies (CT) develop and intertwine with society [1]. IT and CT developed and merged in the 1990s with the expansion of the Internet and spread in society with smart phones in the 2000s. The origins of ICT are much earlier, and CAD was one of the first applications of IT.

After World War 2, the Advanced Research Projects Agency (ARPA) and National Aeronautics and Space Administration (NASA) supported pioneering research on ICT. The Internet (or networking computers) experiments started in the 1960s when J. C. R. Licklider became director in ARPA. Inspired by Vannevar Bush, J. C. R. Licklider conceptualized “human-machine symbiosis” [45] and he coined the term “computer-aided”, describing theoretically systems for computer-aided planning and design. As director at ARPA, J. C. R. Licklider supported, financed, and supervised research on “human-machine symbiosis” systems, or Human Computer Interaction (HCI). Ivan Sutherland [46] using a grant from ARPA demonstrated Sketchpad, the first Computer Aided Design (CAD) system at Massachusetts Institute of Technology (MIT) as a human-computer communication system using the TX-2 computer at MIT Lincoln Laboratory. Timothy E. Johnson presented Sketchpad III in 1963 too, as a CAD system that could create 3D designs. The computational models and computer graphics concepts from Sketchpad for representing points, lines, arcs, and surfaces remain until today. In the same time Douglas Engelbart (known as the “father of the computer mouse”) also financed by ARPA and NASA developed HCI theories, hardware, and software for “computer-aided working space” or “human augmentation” in the (digital) office of the future. Douglas Engelbart envisioned the office of the future in the 1960s as a working station, a terminal that links to a mainframe computer. While in Sketchpad the human designer communicated with the computer with light pen on the screen that acted as electronic drawing board, Engelbart used a keyboard and computer mouse with a pointer. In Sketchpad, there was a design toolbox with lines, arcs, and surfaces as hardware complement, whereas Engelbart instead of a design toolbox offered programming classes for anything that was displayed on the screen. Similar direction of graphical pursued the RAND cooperation with the GRAIL (GRAphical Input Language) on the Linc minicomputer (that is considered as a predecessor of the personal computers today). GRAIL was an interactive software-hardware system that utilized visual programming for elements displayed on the screen. It allowed a human to write on a two-dimensional surface with a stylus and the system recognized the text and the diagrams written on the tablet automatically.

In the 1970s, the pioneering efforts to create hardware-software systems for “human-machine symbiosis” and “human augmentation” converged in the innovations and developments in PARC (Palo Alto Research Center) that was established by Xerox to digitize photocopying and printing. Office automation became the buzzword used to describe the computer augmentation of office functions in the 1970s. Psychological research into human interaction with computers gave rise to the field of HCI by the research in PARC. Robert W. Taylor, who like Licklider and Sutherland directed ARPA’s center for computer research became a director in PARC in the 1970s. Taylor recruited a new generation of computer scientists and programmers and fashioned a prototype for ITC working environment in PARC that will shape Silicon Valley until today. Taylor recruited visionaries as Alan Kay, Charles P. Thacker, Charles Simonyi, etc. and created a cozy and informal working environment that revolved around ubiquitous computing, personal computers (Xerox Alto) and local area networking (Ethernet), mouse-driven Graphical User Interface (GUI), virtual paper and word processing, and the desktop paradigm through object-oriented programming (Smalltalk language). Alan Kay promoted the desktop metaphor as files, folders and windows in the experimental Xerox Alto inspired by Engelbart’s mouse and GRAIL’s display elements. Charles Simonyi developed the concept of virtual paper and Bravo, the word processor that became crucial for the widespread use of Microsoft Office. The desktop paradigm mainstreamed with Apple’s computers and Microsoft’s Windows software in the early 1980s. It is a dominating paradigm that is built over the x86 architecture that was developed by Intel in the 1970s and miniaturized over the years. The widespread diffusion of personal desktop computers with a computer mouse at the end of the 1970s and 1980s (e.g., Apple II, Apple III, and Apple Lisa and x86 series processors by Intel) rendered both the light pen, stylus, and AI obsolete in architectural practices (only until recently when tablets reemerged). By the late 1970s, the computer industry promoted a vision for automating office work, not for stand-alone personal computers, but as office automation systems for networked workstations. The personal computer with the keyboard and mouse became the standard. The CAD systems for architectural systems that established in the 1980s and 1990s (for example Autodesk’s AutoCAD) as well as the Building Information Modelling (BIM) software from the 1990s and 2000s (Graphisoft’s ArchiCAD and Autodesk’s Revit) remain dominant and unchanged conceptually. Unlike Sketchpad or GRAIL, they revolve around Engelbart’s mouse pointer and Xerox Alto’s office desktop metaphor. Autodesk AutoCAD was released in 1982 and it made it possible to draw architectural projects with lines, arcs, and dimensions with a computer mouse. The mouse and pointer, as well as grid and snap functions recreated the drawing board of architects with the T-square in a digital form. AutoCAD dominated architectural design practices until the emergence and spread of BIM software, namely ArchiCAD (initially developed for Apple Lisa in 1984 and transited to Windows in the mid-1990s) and Autodesk Revit (in the 2000s). The difference between ArchiCAD and AutoCAD was that ArchiCAD used building elements as walls, slabs, doors, windows and so on as 2D symbols on a plan and created various 3D representations (including sections, elevations, architectural details, axonometries and perspectives). ArchiCAD digitized the architectural famous handbook Architects' Data (often called Neufert, by its author Ernst Neufert) in its building elements that do not show only the 2D symbol, but also the spaces needed to operate (e.g., furniture elements in kitchens or bathrooms). ArchiCAD like AutoCAD worked as digital drawing boards, but the difference was that ArchiCAD created sections, elevations, architectural details, axonometric views, and perspectives automatically from the 2D symbols on the plan. In AutoCAD, architects draw sections, elevations, and architectural details manually and they use elevations to create 3D visualizations. However, neither ArchiCAD nor AutoCAD used hand props for sketching as pencils or triangles on the grid and snap digital drawing board. BIM software like ArchiCAD created a plan arranging drawing board that links to the GRAIL display elements paradigm, but this cannot be applied in a context of urban design drawing board and the GDL (Geometric Description Language) never became popular among architects (in a way that visual programming add-on Grasshopper alleviated the 3D modeler Rhino in the digital architect community). The Geographic Information Systems (GIS) software developed two representations: discrete objects (attribute databases for object supported by the vector graphics in CAD) and continuous fields (raster graphics). The GIS software, like CAD, was established with the desktop computer with computer mouse and keyboard. It experienced the commercialization of CAD. AutoCAD launched Autodesk into leading CAD software company from the 1980s until today and ArcGIS similarly put ESRI in a dominating position. Like CAD, GIS has an editor with geometric elements (points, lines, and polygons) and it is widely used for drawing 2D masterplans.

City Information Modelling (CIM) starts with Geographic Information Systems (GIS) and brings a perspective of city planning and urban design as a specific niche of consumers of GIS software and spatial media. GIS cannot represent morphological structure with interactions between elements or typologies. CIM problematizes GIS as data structure, by conceptualising a more complex data structure than raster and vector data. CIM like BIM should store information about cities in a hierarchical morphological structure of streets, lots, and building (as well as interactions street-lot, lot-lot, lot-building, street-building). The hierarchy in BIM is standardized as Industry Foundry Classes (IFC) data. IFC data shows a graph of all building elements in a room or on a building story as a numbered list. The GIS data structure includes geometric elements and shapes as classes defined by integers (as geospatial coordinates) and linked to a database with integer and string variables (raster data is integrated in the map as array of integers). There are two directions of CIM research. Gil (2020) reflects CIM in a context of digital tools for urban planning and design as convergences with GIS, BIM and CIM. The first direction of CIM argues for creating information models that derives from GIS and CIM software that generates urban designs (inspired by the shape grammars of George Stiny) [47] and the second stream develops CIM software as digital tool for urban designers based on practices [2-4]. Within the second direction the emphasis is also on drawing boards and morphogenesis of digital tools where GIS is dominating the practices, but also not fully integrated in city planning and urban design. In parallel, Kitchin [39] discusses 3D spatial media and advancements to 3D GIS.

There are additional computational conceptualisations and data structures for hierarchical 3D modelling from the geospatial and geoinformatics branch and from video games and animated movies that use the concept of "scene graphs" in 3D modelling. The Open Geospatial Consortium (OGC) is an international organization that emerged in the 1990s and developed open-source GIS software as an alternative to commercial packages such as ArcGIS by ESRI. OGL compiles a list of standards for geospatial data. Geography Markup Language (GML) and City Geography Markup Language (CityGML) utilizes markup to create a hierarchical (morphological) structure of geography and cities [48-52] with syntax inspired by HTML (HyperText Markup Language) and XML (Extensible Markup Language). XML is a markup language without predefined tags to use. Geographic Markup Language (GML) utilizes generic geometric elements (points, lines, and polygons defined by gml:coordinates) to create 3D geometry and assign textures. CityGML defines feature classes and attributes (e.g. CityObject/Building/BuildingPart/lod1Solid/Polygon/Surface). The hierarchy of the urban elements is created in the markup code with xlink:href. The 3D geometry of the city is represented at various Levels of Detail (LOD0 to LOD4). CityGML uses generic city objects and generic attributes that can be extended with additional attributes within the markup code hierarchy. The generic elements are Building, CityFurniture, CityObjectGroup, LandUse, Relief, Transportation, Vegetation and WaterBody [50] and they do not correspond to the morphological structure of cities. Secondly, the markups for the object in CityGML are very long and the parameters of the objects are lost in the extensive description of classes. CityJSON emerged as a more concise alternative to CityGML. CityJSON is a data exchange format for digital 3D models of cities and landscapes that is a JavaScript Object Notation (JSON)-based encoding of CityGML. The aim of CityJSON is to offer an alternative to the GML encoding of CityGML, which can be extensive and complex to read and manipulate. CityJSON aims to be easy-to-use, both for reading datasets and for creating them. CityJSON is designed with programmers in mind with JavaScript being concise and popular programming language particularly for browser content and the Internet. The third popular standard of OGC is 3D Tiles that link to development of WebGL and glTF for video games in the 2010s. WebGL is a JavaScript framework designed for rendering interactive 2D and 3D graphics within web browsers. It creates possibilities to develop 2D and 3D video games in browsers, but it also allows to model architecture and cities. glTF is the standard file format for 3D scenes and models (as scene graphs). WebGL and glTF were developed and are maintained and updated by the Khronos Group, a consortium of IT companies that work with computer graphics. 3D Tiles is a standard for 3D geospatial datasets such as point clouds, buildings, and photogrammetry. Built on glTF and other 3D data types, 3D Tiles is a streamable, optimized format designed to tap the potential of 3D geospatial data. 3D Tiles is maintained and updated by Cesium, a private company. WebGL, glTF and 3D Tiles are all JSON based frameworks. There is also Universal Scene Description (USD) framework for interchange of 3D computer graphics data that was adopted by nVIDIA, the giant in production of computer graphics processors or Graphical Processing Units (GPU). USD was developed by Pixar as format to exchange 3D data for animated movies from various sources and it borrows syntax from LISP (an abbreviation of "list processing"). USD uses definitions such as "def Xform "Parent"" and "def Mesh "Child1"" within in large brackets {} to create a scene graph of objects (meshes, forms, cameras, animation paths, etc.) in a 3D scene. LISP creates hierarchical data structure by placing objects/classes in brackets. Every object/class in the brackets is a subordinate e.g. (parent (child)). To define a morphological structure of cities, the syntax would be: city1(neighborhood1(street1(lot1(building1, building 2…))))).

The digital tools for urban planning and development emerged in the 1960s and since the 1990s, computers are widespread in public administrations and businesses that work with urban development (as in any office work). In the architect's office, the drawing board, T-square, and triangles, were replaced by computers with large screens, CAD and BIM apps (often supported by 2D and 3D modelling software), a mouse and a keyboard as Douglas Engelbart envisioned the office of the future in the 1960s. One difference is that Engelbart's idea was to have working stations, interfaces that link to a mainframe computer/cloud as ICT system. Today in the offices there are personal computers that are networked and sometime use cloud services to network teammates, but the processing is decentralized in many microcomputers (as architects grew accustomed to individualized CAD and BIM apps, often off the cloud). In the planner's office the computers are mostly used for preparing documentation and word processing, and the GIS software is typically used in the land cadastre and GIS divisions of public authorities and municipality. Architects and urban designers can sit in planner's offices and use CAD, BIM, and GIS software to draw masterplans, but the apps need to be adapted to the practices, or the urban design solutions must fit the conceptual frameworks and data structure of points, lines, and polygons (that works just for 2D masterplans).

4. BEYOND THE MASTERPLAN

Urban designers as practitioners must deliver drawings and illustrations of cities and develop design codes or guidelines at various stages of planning and urban design. They conventionally use traditional design skills like hand drawing or creating scale models and many urban designers remain reluctant to digitization because it is more difficult to draw with a mouse. The mouse behaves differently on the screen. Small quick movements speed the movement of the cursor, whereas pencil in the hand has a uniform movement speed. The grab of the mouse is not as precise as pencil and paper. Urban designers collaborate with public authorities, private developers, and citizens on coordination meetings, planning workshops and design charrettes, sit around a table, sketch, cut cardboards, make scale models of buildings, and place them on the map. The knowledge and expression of urban designers is diagrammatic [53]. Urban designers not only mix imagery, typologies, diagrams, and mapping in analysing and designing cities, but they develop representations and notations. Kevin Lynch created mental maps with urban elements. Gordon Cullen devised notations and symbologies to describe the experience of urban space. Jan Gehl, [54-55] inspired by proxemics research [56-57] illustrated personal spaces with images at various distances and developed diagrams for analysing human perception between buildings (accentuating street profiles). Street frontages as collages of building façades are also typically analysed by urban designers [58-61]. Urban designers in practice commonly combine theories and representations for urban analyses.

Following these eclectic traditions of urban designers, the CIM framework seeks to go beyond the masterplan and complement it with additional drawing boards that includes a 2D distorted representation of street space surrounded by street profiles and street frontages. Figure 2A shows the hierarchical structure of cities: streets and their layout, plots and their aggregation in blocks, buildings, and land uses as building utilization [13]. Figure 2A highlights the visually perceivable elements in the morphological structure and Figure 2B shows the corresponding representations (plans, street frontages or building elevations and street profiles that become axonometries). Urban designers shift between the building view conventionally described with urban sketches or photographs (Figure 2C1) and a top view of maps and master plans (Figure 2C2). The Italian typo-morphological tradition analyses the city as a network of routes and streets and typologies of buildings (including building plans and façades, [8]). The buildings and plots adjacent to routes and streets on plan create a townscape in three dimensions as an envelope viewed from above revealing the building façades (Figure 2C3). The 3D-to-2D diagrammatic projection of the urban (space) envelope creates an urban experience of a flâneur standing on the street corner observing an aural townscape in 360 degrees. The urban envelope allows an analysis of the interaction between the streets and squares with the surrounding buildings and the design of these interactions. The street frontage or the façade of the city block (called also pertinent strip, [8]) becomes an additional fundamental (edge) element of urban form (complementing the building footprint). Research in urban morphology focuses on elements as objects that are bounded with polygons (building and plots) or extend along axes (streets) while transitional edges such as sidewalks, urban façades, fences, etc. can be permeable, invisible, or dislocated (buildings by setback). These edges as transitional spaces between morphological elements often define the experiential character of urban space.

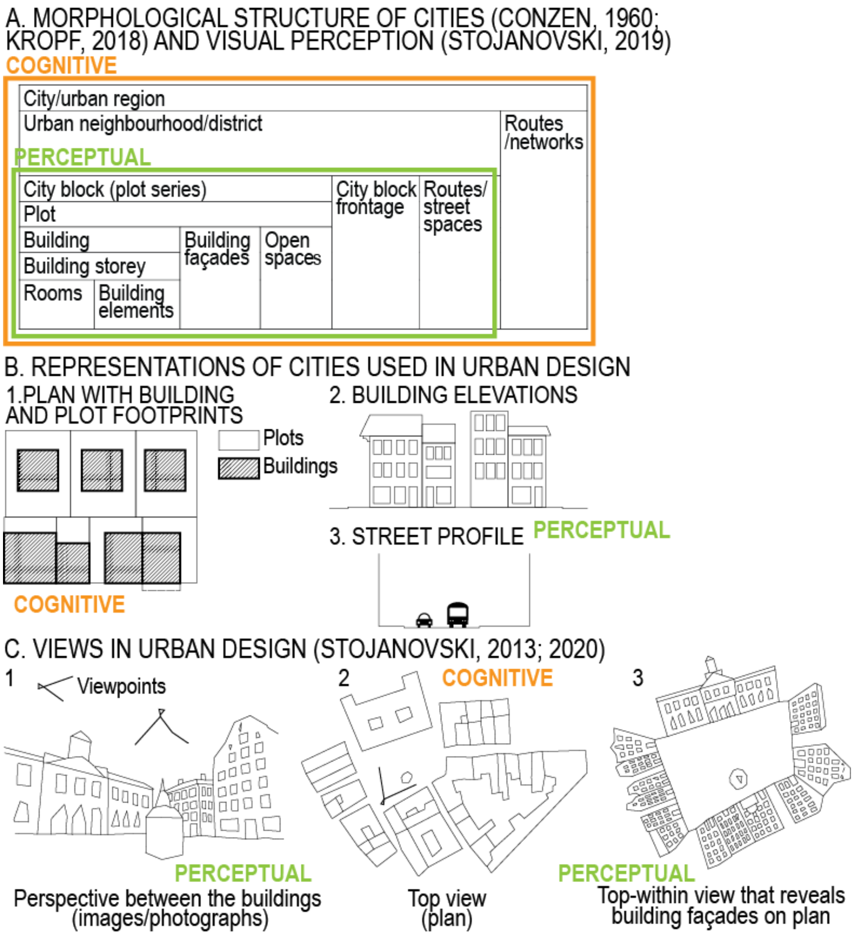

Figure 2. From cognitive maps to perceptual urban (space) envelopes.

Masterplans are the standard to communicate urban design. Figure 3A shows a typical masterplan with conventional zoning and land uses. The drawing boards for plans are tables with T-squares and triangles in the architectural studio or a digital window with drawing aids in CAD and GIS. To complement masterplans, urban designers develop design codes and guidelines, based on building or street typologies (Figure 3B). The design codes and guidelines reduce the emphasis on land uses, which often change rapidly, and emphasize the forms of buildings and streets, which are more rigid and long-lasting. They range from strict codes that regulate architectural details to advisory guidelines aiming to educate planners, design consultants and developers about good design principles or specific design objectives [21]. Figure 3C conceptually illustrates the urban envelope as an assembly of building façades and street profiles describing visual townscapes as aural projections and a design board for urban designers complementary to the master plan. It can be used to design street segments in Figure 3C1, intersections (nodes) in Figure 3C2 or squares (public space surrounded by buildings) in Figure 3C3. City Information Modelling (CIM) software is currently programmed based on the urban envelope conceptualization to enable the design or redesign of townscapes [2-4]. The CIM software will utilize cadastral maps from GIS and masterplans to create urban envelopes depicting townscapes procedurally in interaction with actors and stakeholders. Computer technology allows for the visualization of townscapes by the automatic creation of 3D city models from GIS data and cadastral maps (referred to as procedural modelling). CIM is conceived as an addition to GIS and the software includes a toolbox with morphological and typological elements described in FBCs, design codes and guidelines. Urban designers typically focus on street frontages by creating collages of building façades, showing images, or analysing movement on sidewalks [59-62], or the spaces between the buildings (Gehl, [55-56], uses diagrams of humans in a street profile). The urban (space) envelope allows work with building and street types as a (digital) drawing board and it combines two representations of urban spaces, the street frontage and street profile in one drawing board (Figure 2C).

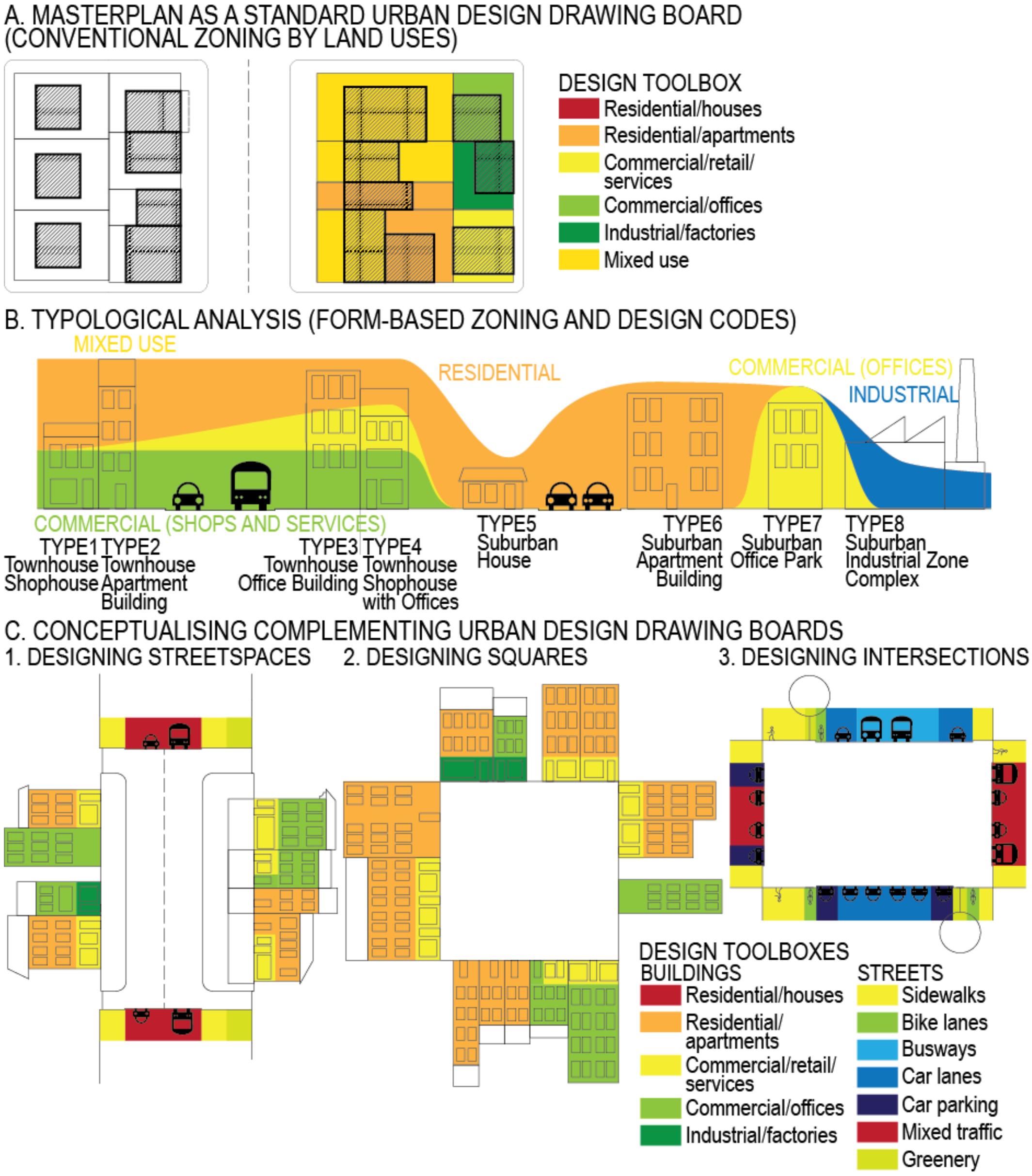

Figure 3. Beyond masterplans- Urban (space) envelopes complement urban design drawing boards.

5. THE PLANNERS' OFFICE OF THE FUTURE (CONCLUSIONS)

Hardware and software intertwine with buildings, streets, even human bodies, seeking to digitalize society and create "smart homes" and "smart cities". CIM framework thought evolution of the architects' and the planners' office, the history, and new trends in digitalization of urban planning and design from a perspective of urban designer and morphological structure of cities. The CIM software aims to contribute to increased use of digital tools among urban planners and designers. The smart city has many names ("informational city", "invisible city", "city of bits", "computable city", "programmable city", etc.) and similarly the architects, urban planners and designers can be "digital", "augmented", "automated", etc. However, urban planners and designers remain reluctant to digitalization similarly as historical cities are rigid to smart technologies. Almost every city has smart city or sustainable neighborhood experiment and many fail to reach digitalization and sustainability goals facing the established urbanist practices and rigidity of historical urbanity (Cugurullo, 2021, refers to these urban experiments as "Frankenstein urbanism"). The digital tools for urban planners and designers such as CAD and GIS, unlike the smart sustainable experiments that seek to intertwine the newest ICT in cities, they rely on proven IT concepts from computer graphics and databases to keep a dominant position. They suffice to draw 2D masterplans. The new generation of hierarchical urban models such as CityGML, CityJSON, 3D Tiles, etc. and new conceptualizations in video games and animation movies such as WebGL and glTF, UDC, etc., offer a great opportunity to develop a new generation of CIM if they integrate morphological theory and develop software for design of urban environments in 3D. The standards first need to align their hierarchy of urban elements in 3D with morphological theory. Without software that utilizes CityGML, CityJSON, 3D Tiles, etc. and links to the cadastral data and GIS it will be impossible to influence urban designer practices. In the end, digitalization must incorporate sustainability concerns in cities and allow to integrate models that assess environmental, economic, and social aspects and contribute to sustainable development.

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03
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HUMAN-INDUCED VIBRATIONS OF CROSS-LAMINATED TIMBER FLOORS

Abstract

This paper discusses vibration serviceability assessment of cross-laminated timber (CLT) floors induced by human activities, with special emphasis on vibrations induced by walking. In the first part current design criteria for vibration serviceability check of timber and CLT floors were analyzed in line with the more general vibration performance-based approach applicable to any floor structure regardless of the material used. The second part focuses on the ongoing research achievements in the design of vibration resistant CLT floors carried out at the Faculty of Civil Engineering, University of Belgrade. In addition, challenges for future research were formulated as well.

Keywords: vibration servceability, pedestrian dynamic load, CLT, walking frequency, hybrid floors

ВИБРАЦИЈЕ МЕЂУСПРАТНИХ КОНСТРУКЦИЈА ОД УНАКРСНО ЛАМЕЛИРАНОГ ДРВЕТА ИЗАЗВАНЕ ЉУДСКИМ АКТИВНОСТИМА

Сажетак

У овом раду анализирана је процјена вибрација међуспратних конструкција од унакрсно-ламелираног дрвета, које су изазване људским активностима, са посебним акцентом на вибрације изазване ходањем. У првом дијелу, приказане су тренутно коришћене методе за процјену вибрација дрвених и CLT међуспратних конструкција, као и општија метода заснована на евалуацији нивоа вибрација, која се може примијенити у анализи било које међуспратне конструкције, без обзира на материјал од кога је направљена. У другом дијелу рада, дат је приказ резултата истраживања у области развоја CLT међуспратних конструкција отпорних на вибрације, које се спроводи на Грађевинском факултету Универзитета у Београду. Поред тога, формулисани су изазови у будућем истраживању.

Кључне ријечи: гранично стање употребљивости на вибрације, пјешачко динамичко оптерећење, CLT, хибридне међуспратне конструкције

1. INTRODUCTION

Nowadays, almost 40% of the global carbon emissions come from the construction sector: 30% from operational carbon associated with energy used to operate the building, and 10% from embodied carbon generated during the production, transport and construction of building materials [1]. This rate is expected to grow drastically: recent studies have indicated that carbon emission from building materials and processes will be responsible for almost half of the carbon emission by 2050. To meet the goals of the Paris Agreement, construction sector needs to reach net-zero carbon emissions by 2050, while new buildings will have to be net-zero carbon starting from 2023, [2]. Moreover, during the next 40 years the total building floor area is expected to double by approximately 230 bn m^2 of new floors. Considering all the points mentioned above, the key question is how to fulfill the demands of the global real estate market while also attaining net-zero carbon buildings. One of possible pathways to reduce embodied carbon in civil engineering is using renewable materials such as wood.

Due to the limited size and mechanical properties of the raw timber material, its traditional use remains widespread for housing and low-rise buildings. However, after decades of dominance of concrete and steel civil engineering structures, a significant shift in the construction sector emerged in the 1990s with the invention of cross-laminated timber (CLT). CLT is a plate-like engineered wood-based product assembled of several (usually odd) thin layers arranged and glued in a crosswise manner, Figure 1. Its outstanding strength, stiffness and aesthetic appeal, combined with high level of prefabrication, construction speed and good fire resistance, position CLT as a highly competitive alternative to traditional building materials like concrete and steel. This has been confirmed through a wide range of applications on residential, public, and commercial multi-story buildings across Europe and North America over the past decade, in which key load-bearing structural elements – walls and floors were made entirely of CLT. Typically, the width of CLT panels ranges from 2.5 to 3 meters, while the length can extend up to 20 meters. Panels are connected together on site using fasteners and self-tapping screws, forming multi-panel floor structures.

CLT is a lightweight material having a high stiffness-to-weight ratio. CLT floors possess enough stiffness to span relatively large distances. However, due to their low weight, CLT floors may exhibit excessive vibrations induced by human activities such as walking, running or jumping. While these vibrations may not cause structural damage, they can lead to discomfort for occupants or malfunctions in vibration-sensitive equipment [3]. Consequently, vibration serviceability has become a growing concern in the construction industry, governing the design of lightweight long-span floors in modern buildings. This implies that the shape and dimensions of the floor are dictated by vibration requirements rather than strength considerations. Although extensive research has been conducted on this issue in the past few decades, the focus has predominantly been on floors made of concrete and steel-concrete composites, resulting in the development of relevant design guidelines [4-7]. These guidelines exploit the vibration performance approach which suggests vibration serviceability (VS) assessment based on the evaluation of the vibration response level in terms of acceleration or velocity. On the other hand, provisions in Eurocode 5 refer to vibration performance of traditional timber joist floors having fundamental frequency greater than 8 Hz [8]. Recently, several studies have been carried out to address the most important factors affecting the vibration performance of CLT floors, [9], [10]. It has been shown that CLT floors exhibit different behavior from traditional lightweight timber joist floors. Based on experimental data, in the Canadian CLT Handbook an empirical method for VS assessment has been proposed by relating the fundamental frequency and static deflection of the CLT floor, [11]. The method is simple but has limited ranges of applicability. Moreover, both Eurocode 5 and CLT Handbook limit the fundamental frequency of traditional timber floors and CLT floors to 8 Hz respectively, to avoid resonant vibration response. Recent studies have shown that the cut-off frequency between the low frequency floors having resonant response and high frequency floors having transient response is even 14Hz [12]. This clearly confirms that CLT floors may have strong dynamic response in both low and high frequency range. In addition, existing empirical design methods do not account for other design considerations that can significantly affect the vibration response of CLT floors, such as additional floor mass, orthotropic behavior of CLT, inter-panel connections, damping, different types of boundary conditions, amongst others. Consequently, they can lead to cost-ineffective floor solutions in terms of spending more material to improve vibration performance, which is unacceptable from the carbon emission standpoint.

Figure 1. A 5-ply CLT panel

Recent studies have confirmed that design methods for vibration of both CLT and traditional timber floors need updating, including more reliable calculation methods for vibration response assessment, such as vibration performance-based methods [13], [14].

This paper aims to present research achievements in the design of vibration-resistant CLT floors subjected to human-induced dynamic loading, with specific emphasis on the ongoing work at the University of Belgrade, Faculty of Civil Engineering (FCEUB).

After the introduction section, Section 2 describes fundamentals of dynamic of modelling of walking force models. Section 3 deals with different approaches used for VS assessment of CLT floors, while research developments within the ongoing research project at FCEUB were presented in Section 4. Finally, Section 5 summarizes conclusions and further research directions.

2. HUMANS AS SOURCE OF FLOOR VIBRATIONS

To prevent excessive floor vibrations and discomfort of human occupants in buildings, reliable and accurate prediction of floor vibration is necessary in the design stage. This involves consideration the following key aspects of VS assessment:

- **vibration source** - dynamic load induced by human activities,
- **vibration path** - the floor structure and its modal properties (natural frequencies and mode shapes, modal mass and damping),
- **vibration receiver** - humans or vibration sensitive equipment.

Floors occupied by people are subjected to dynamic loads induced by human activities such as walking, jumping or running. Given that walking is the most common human activity, particular attention will be devoted to it.

Extensive experimental research has shown that a pedestrian in normal walking makes about 1.5 to 2.5 steps per second. This means that the frequency of normal walking - f_p ranges from 1.5 to 2.5 Hz (on average around 1.8 Hz). Dynamic force is quasi periodic, while its Fourier spectrum exhibits peak amplitudes corresponding to f_p (first harmonic), $2f_p$ (second harmonic), $3f_p$ (third harmonic), $4f_p$ (fourth harmonic) and $5f_p$ (fifth harmonic) as can be seen in Figure 2. The strongest peak corresponds to the frequency of the first harmonic which is equal to the walking frequency. In addition, amplitudes in the Fourier spectrum can be detected in the frequency range up to 50Hz.

As a result of the total lack of available walking force models that can describe the full amplitude spectrum of the measured walking force signals, two different mathematical models of walking-induced dynamic force were developed in recent studies. The first is the harmonic walking force model proposed to evaluate vibrations of low-frequency floors that can exhibit resonant vibration response, Figure 3 (left). The second model is based on impulses used to evaluate vibration response of high-frequency floors, that can exhibit transient response, Figure 3 (right). More details on the force modes will be given in the next section.

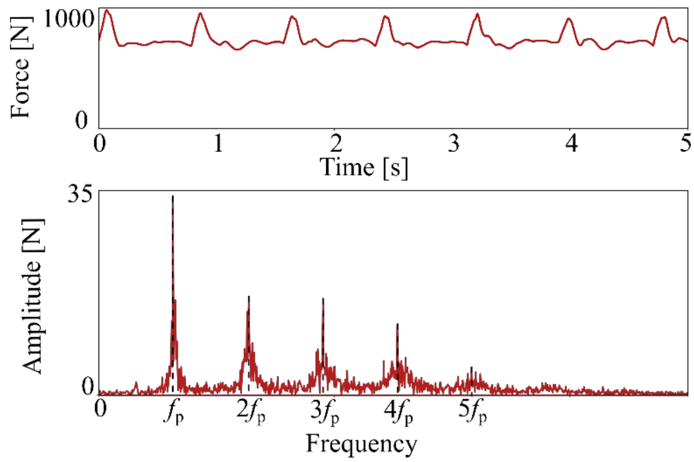


Figure 2. Time and frequency domain signal of a measured vertical force generated by walking

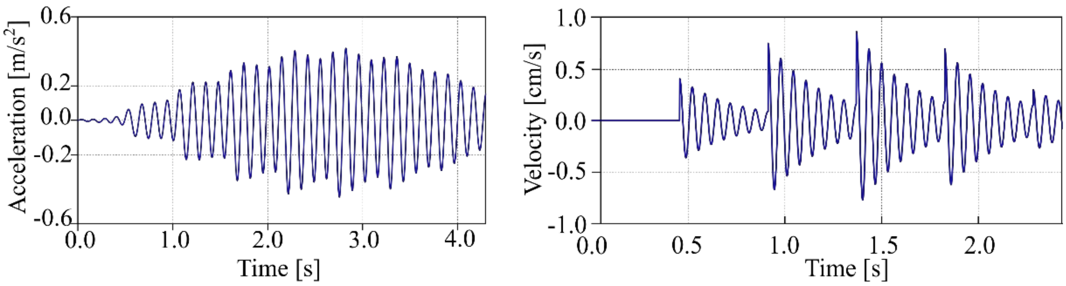


Figure 3. Vibration response of low-frequency floor (left) and high-frequency floor (right)

3. EMPIRICAL METHODS FOR VS ASSESSMENT OF CLT FLOORS

Popular design criteria for vibration serviceability check of timber floors restrict excessive vibrations by limiting the fundamental frequency, static deflection [15], or by relating the fundamental frequency and static deflection [8], [11]. Most of them are empirical methods, formulated based on data collected through experimental studies. Basic idea behind these methods is, when used correctly, they simplify VS assessment procedure and avoid dynamic modelling. In this section two most commonly used design methods in engineering practice will be elaborated.

3.1. CLT HANDBOOK METHOD

According to the Canadian CLT Handbook [11], the vibration-controlled span of a CLT floor is calculated as:

$$L \leq 0.11 \frac{\left(\dfrac{EI_{eff}}{10^6}\right)^{0.29}}{m^{0.12}} \tag{1}$$

where EI_{eff} is the effective bending stiffness in the major strength direction for a 1-m wide panel (Nm^2), while m is the linear mass of CLT for a 1-m wide panel (kg/m). Although simple, this empirical approach has a limited range of applicability. It was derived from experimental testing conducted on single-span bare CLT panels supported on walls. Furthermore, the reliable estimation of vibration performance can be obtained only in cases where floor layouts closely match those to which expression (1) was calibrated.

As can be seen from Equation (1), estimation of vibration performance depends on the bare panel properties, without considering additional mass, damping, floor layouts and different support conditions, as well as dynamic load induced by building occupants. Moreover, according to the handbook, CLT floors are characterized as high-frequency floors having fundamental frequency greater than 9 Hz, i.e. they exhibit only transient-like vibration response due to each footfall, with peak values mainly governed by the stiffness and mass of the floor. Such approach assumes that only high-frequency floors can have good vibration performance. However, high-frequency floors can exhibit vibration serviceability issues as well. Consequently, this frequency limitation is unacceptable from the ecology and carbon emission perspective.

3.2. HAMM'S DESIGN METHOD

Based on a comprehensive study carried out on approximately 100 timber floors including 38 mass timber floors, Hamm et al. [16] proposed design procedure for VS assessment of both traditional timber joist and CLT floors. The procedure is applicable to floors with fundamental frequency greater than 4.5 Hz and requires classification of the floor into one of three floor classes as given in Table 1. Moreover, the cut-off frequency f_{lim} is introduced to distinguish between low and high frequency floors. Both low and high frequency floors should meet the stiffness criterion in terms of deflection due to a 2 kN point load calculated as:

$$w = \frac{2l^3}{48EI_l b_w} \leq w_{\lim} \tag{2}$$

where l is the floor span, EI_l is the bending stiffness in the longitudinal direction (including the screed stiffness), while b_w is given as:

$$b_w = \min \begin{cases} b_{ef} = \dfrac{l}{1.1}\sqrt[4]{\dfrac{EI_b}{EI_l}} \\ b \end{cases} \tag{3}$$

In Equation (3), b is the floor width, while EI_b is the effective bending stiffness in the transverse direction. Deflection limit values are given in Table 1.

For low frequency floors, additional criterion is introduced in terms of acceleration induced by dynamic harmonic force with walking frequency equal half or third the fundamental frequency of the floor. Maximum resonant response of the floor is calculated as:

$$a = \frac{F_{dyn}}{2M\varsigma} = \frac{0.4F_n}{2M\varsigma} \leq a_{\lim} \tag{4}$$

where:

ς is the modal damping ratio,

M is the modal mass,

F_{dyn} is total dynamic force that includes factor of 0.4 considering that the force on the floor is acting during a limited time and not always in the midspan,

F_n is amplitude of the n^{th} harmonic of the force (F_2 = 140 N, F_3 = 70 N).

3.3. VIBRATION PERFORMANCE-BASED APPROACH

Based on the discussion in the previous section, it is evident that empirical-based methods are unreliable often leading to overestimation of the vibration response and consequently to cost-ineffective floor solutions. Hamm et al. [16] made a step forward introducing additional acceleration criterion but only for low frequency floors.

On the other hand, vibration performance-based approach is well developed and integrated into several design guidelines for VS assessment of concrete and steel-concrete composite floors. This approach is based on the evaluation of the vibration response level which is then compared to a predefined threshold value. Moreover, it accounts for three key components of the VS assessment: vibration source, floor's modal properties and receiver's response to floor vibrations.

The approach is general and based on the modal superposition method for calculation of the footfall induced floor vibrations. To account for arbitrary floor layouts, support conditions, effects of non-structural elements such as partitions, modal properties are determined from the finite element analysis (FEA).

Arup's design guideline [17] offers a model of pedestrian vertical loading that applies to any type of floor structure regardless of the material. Here, the cut-off frequency between the low-frequency floors and high-frequency floors is set to 10.5 Hz. Key features of this guideline will be elaborated in the following sections.

Table 1. Floor classes and corresponding limit values [16]

	Class I	Class II	Class III
Vibration demands	Floors with high demands	Floors with low demands	Floors without demands
Description of vibration perception	Vibrations are not perceptible or only perceptible when concentrating on them. Vibrations are not annoying.	Vibrations are perceptible but not annoying.	Vibrations are clearly perceptible and sometimes annoying.
Type of use	Corridors with low spans, floors in apartment or office buildings	Floors in single-family houses	Floors under non-residential rooms or roof spaces
Frequency criterion	f_{lim} = 8 Hz	f_{lim} = 6 Hz	-
Stiffness criterion	w_{lim} = 0.5 mm	w_{lim} = 1.0 mm	-
Acceleration criterion	a_{lim} = 0.05 m/s^2	a_{lim} = 0.1 m/s^2	-

3.3.1. LOW-FREQUENCY FLOORS

Floors with a fundamental frequency below 10 Hz are likely to develop resonant response induced by one of the first four harmonics of the walking force. In this case, the walking force model is defined as a sum of four harmonics described by a Fourier series:

$$F(t) = W\sum_{i=1}^{4} DLF_i \sin\left(2\pi i f_p t\right) = \sum_{i=1}^{4} F_i \sin\left(2\pi i f_p t\right) \tag{5}$$

where W is the weight of a pedestrian, f_p is the walking frequency, while DLF_i is the dynamic load factor corresponding to the i-th harmonic. The frequency of each harmonic is an integer multiple (i = 1–4) of the selected walking frequency in the range 1.5–2.5 Hz. Design values of the dynamic load factors are given in Table 2.

The guideline suggests that all modes up to 15 Hz can significantly contribute to the vibration response and therefore should be identified and included in the analysis. For a walking frequency f_p, the maximum amplitude of resonant response of the n-th mode to each of the four harmonics i is calculated as:

$$a_{n,i} = \frac{\mu_{e,n} \cdot \mu_{r,n} \cdot F_i}{2M_n \varsigma_n} \tag{6}$$

where:

$F_i = W \cdot DLF_i \quad i = 1,2,3,4$,

M_n is the modal mass,

ς_n is the modal damping,

$\mu_{e,n}, \mu_{r,n}$ are the mode shape values at the excitation (e) and response (r) points in each mode n, respectively.

More details regarding the vibration response calculation can be found in [17]. From Equation (6) it is evident that in resonance, the calculated response is inversely proportional to the floor's modal mass and damping. While reliable estimation of the modal mass can be obtained from the FEA, damping can be reliably estimated only through experimental testing.

Table 2. Dynamic load factors [17]

Harmonic number	Forcing frequency [Hz]	Design value of *DLF*
1	1 – 2.8	$0.41(f\text{-}0.95) \leq 0.56$
2	2 – 5.6	$0.069 + 0.0056f$
3	3 – 8.4	$0.033 + 0.0064f$
4	4 – 11.2	$0.013 + 0.0065f$

3.3.2. HIGH-FREQUENCY FLOORS

Floors with a fundamental frequency greater than 10 Hz are categorized as high-frequency floors, exhibiting a transient response characterized by a rapid decay between two footfalls. The walking model is based on a series of vertical impulses corresponding to each footfall. Design value of a vertical impulse which simulates a single footfall is defined as:

$$I_{eff,n} = 54\frac{f_p^{1.43}}{f_n^{1.3}} \quad [Ns] \tag{7}$$

where f_n is the natural frequency corresponding to the n-th mode shape.
The velocity time history due to a single footfall at a particular location on the floor is calculated as:

$$v_n(t) = \hat{v}_n e^{-2\pi\varsigma_n f_n t}\sin(2\pi f_n t) = \frac{\mu_{e,n}\cdot\mu_{r,n}\cdot I_{eff,n}}{M_n} e^{-2\pi\varsigma_n f_n t}\sin(2\pi f_n t) \tag{8}$$

The procedure developed in the guideline is based on the modal superposition method advocating that all mode shapes with natural frequencies up to twice the fundamental frequency should be included in the vibration response calculation. Finaly, the total response to each footfall is calculated by summing the velocity responses in each mode:

$$v(t) = \sum_{n=1}^{N} v_n(t) \tag{9}$$

3.4. HUMAN PERCEPTION OF VIBRATIONS

Vibrations induced by building occupants may be annoying, causing people's discomfort and affecting usability of a structure. Human perception of vibration is highly subjective. It depends on the vibration amplitude and frequency, exposure time, body posture and direction, [18]. When human perception of vibrations is the primary criterion, the vibration level is assessed based on calculated averages of acceleration or velocity. The root mean square (RMS) is commonly used averaging technique that accounts for changes in amplitude over time and is frequently applied to both transient and resonant vibration responses. An RMS value of a time domain signal *x(t)* calculated over a certain averaging time *T* is defined as:

$$x_{RMS}(t) = \sqrt{\frac{1}{T}\int_0^T x(t)^2\, dt} \tag{10}$$

ISO 10137 standard [3] defines base curves for human perception of vibration with respect to the frequency and the orientation of the vibration relative to the axes of the human body. The baseline curve given in Figure 4 (left) defines the RMS acceleration level corresponding to the vertical z -axis. Apparently, people are most sensitive to vibrations in the frequency range between 4 – 8 Hz, where the baseline RMS acceleration perceptible by humans is equal to 0.005 m/s^2. For frequencies higher than 8 Hz, the RMS threshold value linearly increases. For high-frequency floors for which vibration response is calculated in terms of velocity, human perception is evaluated based on the curve presented in Figure 4 (right), with the RMS velocity level perceptible by humans equal to 10^{-4} m/s.

Acceptable vibration levels are often assessed using the so-called response factor, or R factor, which represents the ratio between the measured (or predicted) vibration level and the corresponding threshold of perception:

$$R = \frac{a_{RMS}}{0.005} \quad or \quad R = \frac{v_{RMS}}{10^{-4}} \tag{11}$$

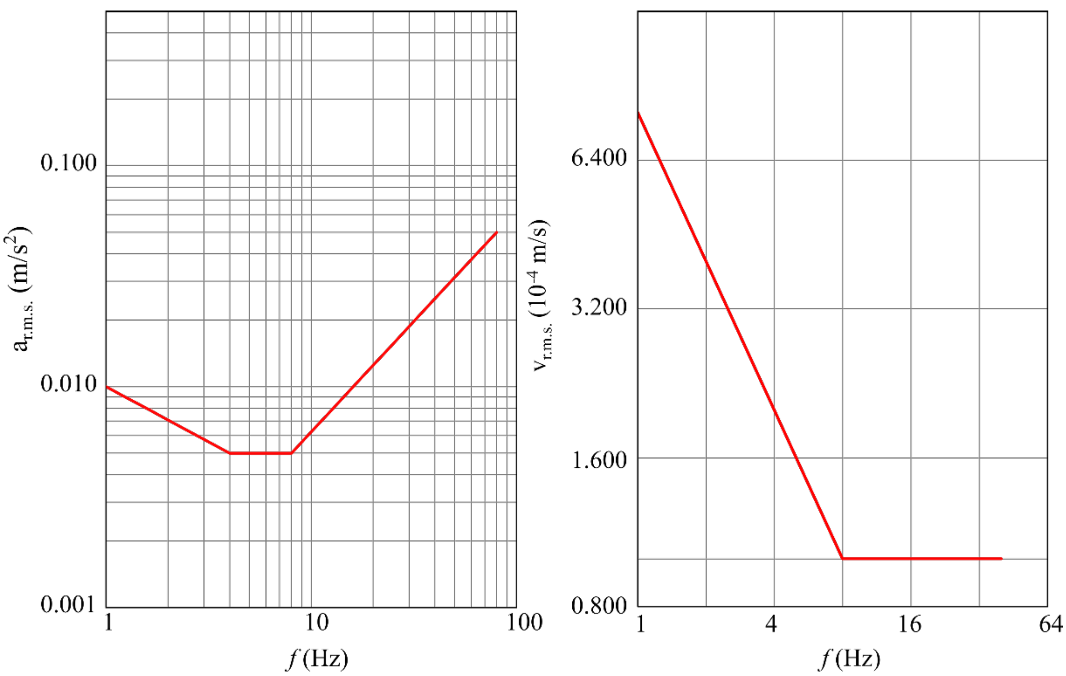


Figure 4. RMS acceleration and velocity baseline curves after ISO 10137 [19]

Table 3. Vibration performance targets according to ISO 10137 [19]

Type of building	Time	R factor
Critical working areas (hospitals, precission laboratories, operating theatres)	Day/Night	1
Residential	Day	2 to 4
	Night	1.4
Quiet office, open-plan	Day/Night	2
General office (schools, offices)	Day/Night	4
Workshops	Day/Night	8

4. ONGOING RESEARCH AT FCEUB

This section deals with selected research in which the author is involved within the ongoing research project at FCEUB. The research focus is on the development of vibration-resistant CLT floor solutions to represent sustainable and cost-effective alternative to the conventional concrete and steel-concrete composite floors through an extensive experimental testing and numerical simulations.

4.1. DEVELOPMENT OF COMPUTATIONAL TOOL FOR EVALUATION OF VIBRATION RESPONSE

Hindu software is a novel computational tool for VS assessment of floors, which is being developed within the research group. It is designed as Python-based software with a user-friendly graphical interface (GUI). Based on the input parameters (floor geometry, modal properties, walking path, walking frequency etc.), it provides quick vibration response calculation and effective visualization of calculated responses [19]. The software is fully functional, but still in the development phase. All numerical simulations that will be presented in the following sections were carried out using the *Hindu* software. Figures 5-6 illustrate some of the key components of the software.

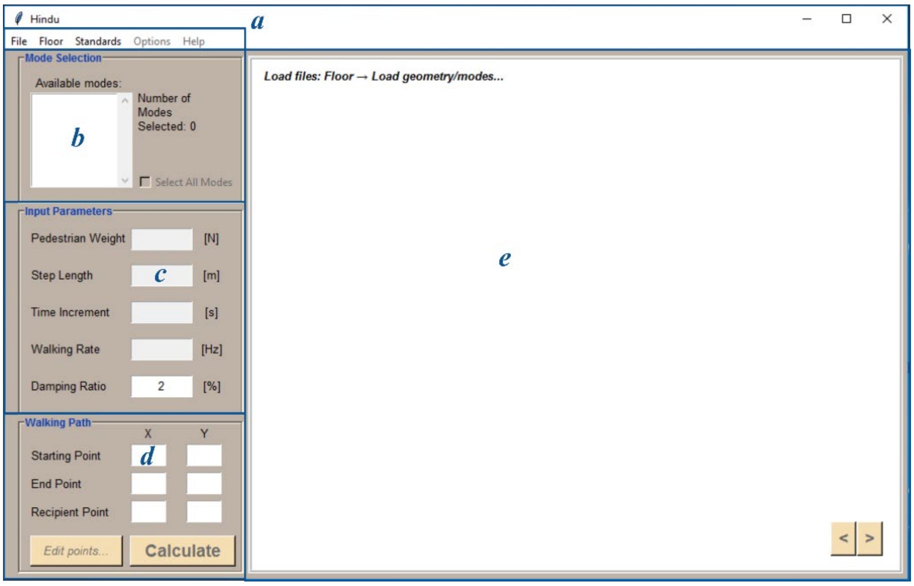


Figure 5. Main window of the Hindu software

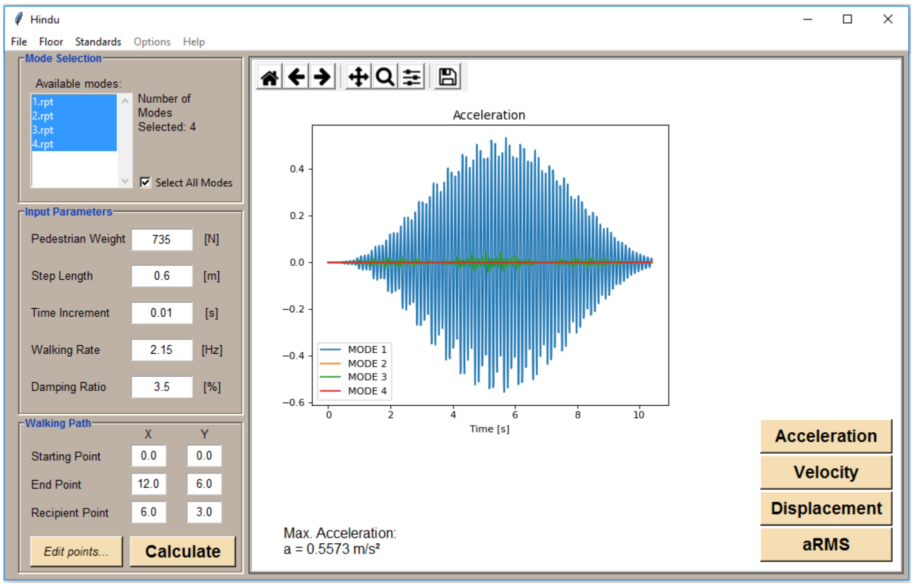


Figure 6. Visualization of the floor response

4.2. INFLUENCE OF INTER-PANEL CONNECTIONS ON VIBRATION RESPONSE

In the current design practice when assessing vibration serviceability, CLT floor is often treated as one-way slab. The influence of the inter-panel connections on the vibration response of CLT floors is neglected, treating a multi-panel floor as a monolith slab or with no inter-panel connections at all, which may result in an overestimation or underestimation of its response to pedestrian-induced vibrations. Consequently, the first focus of the research was to identify to what extent inter-panel connections affect the modal properties and vibration response of CLT floors and how they can be efficiently modelled in the numerical simulations.

Figure 7 illustrates the two commonly used inter-panel connections: half-lap joint and single spline. In numerical simulations, these connections were modelled using an equivalent elastic strip, [20]. Natural frequencies and mode shapes of a square 6m x 6 m CLT floor composed of two 3m x6m panels and simply supported on two parallel edges, are given in Figure 8. Based on the visual inspection of mode shapes and comparing natural frequency values between floors modeled as monolithic slabs and panels with connections, it is evident that the most significant differences occur in modes where modal coordinates are largest along the connection line.

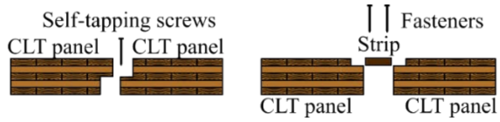


Figure 7. Half-lapped joint (left) and single spline (right) connections of CLT floors

This discrepancy is particularly pronounced when the connection line exhibits dominant movement in relation to the rest of the floor [20]. As the floor is a low frequency floor, vibration response was calculated using Arup's design guideline with walking frequency selected to induce resonant response of the first mode with the third harmonic of the walking force. The response was calculated for two walking paths: walking path 1 in the span direction (parallel to the connection line) and walking path 2 perpendicular to the span direction and connection line. Note that in all calculations the additional mass of concrete topping and non-structural elements including 10% of the live load was 150 kg/m^2. By comparing R factors calculated for floors modeled as monolithic slabs and as panels with connections, it can be concluded that inter-panel connections have a significant impact on the vibration response of CLT floors, Figure 9. Floors with inter-panel connections exhibited larger vibration response, which is especially pronounced for walking path 2. On the other hand, ignoring the inter-panel connections can lead to a notable overestimation of the vibration response. This is because only width of a single panel is accounted for in the vibration response calculation. Given the considerable difference in stiffness between the span and transverse directions, it is justified to employ one-way action in the static analysis of CLT floors. However, such an assumption in dynamic analysis can lead to notable errors. To demonstrate the importance of vibration performance-based approach in the VS assessment of CLT floors, vibration performance of the investigated CLT floor was assessed using the CLT Handbook method. The calculated vibration-controlled span was 5.9 m, which is almost equal to the proposed floor span (6m).

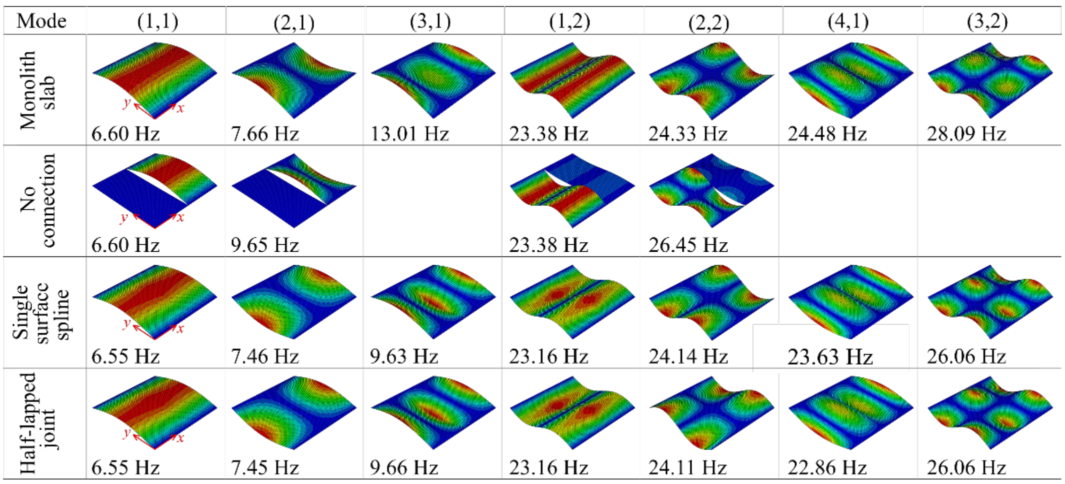


Figure 8. Natural frequencies and corresponding mode shapes of a 6m x 6m square CLT floor considering different inter-panel connections [20]

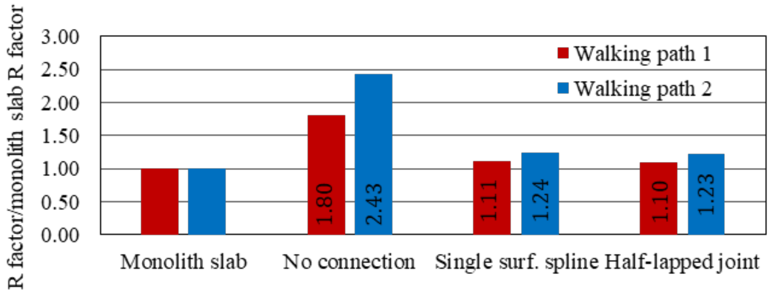


Figure 9. Response factor ratios for different connection models (left) and walking paths (right)

On the other hand, the maximal calculated value of RMS acceleration response according to Arup's design guideline due to dynamic force with walking frequency equal to 2.18 Hz (selected to induce resonance of the first vibration mode with the third harmonic of walking) was 0.197 m/s^2, resulting in the R factor equal to 39, which is far beyond the maximum acceptable value for floors.

4.3. EXPERIMENTAL IDENTIFICATION OF VIBRATION BEHAVIOR OF CLT FLOORS

The focus of the experimental work we conducted is to evaluate modal properties and pedestrian-induced vibration response of bare CLT floors. For that purpose, an extensive experimental testing was carried out at FCEUB. Several floor layouts were selected as shown in Figure 10. Full-scale CLT floors were composed of one, two or three 5-ply 15 cm thick panels. The panels were connected using half-lap joints.

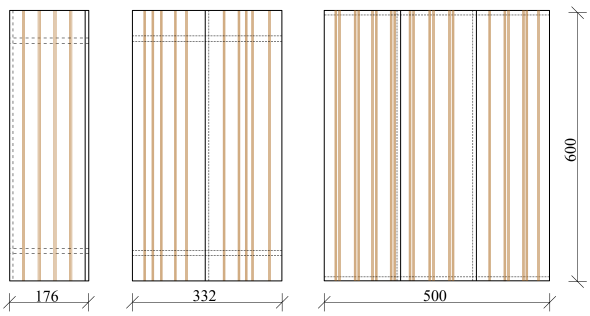


Figure 10. Floor layouts used in experimental testing

4.3.1. MODAL TESTS

First type of experimental testing involves modal tests on single-panel and two-panel CLT plates supported by elastic supports, carried out to define values of the modelling parameters describing the inter-panel connection (elastic properties of the equivalent elastic strip). Random broad-band excitation of panels was generated using rubber impact hammers. Acceleration response was measured using five high-sensitivity accelerometers (Brüel & Kjaer, Naerum, Denmark, type 4508-B, nominal sensitivity 100 mV/g) strategically positioned on the floor specimens. Operational modal analysis was carried out using a commercial platform ARTeMIS Modal Pro [21] to extract modal properties of the investigated floor specimens.

Applying a finite element model updating technique, the initial numerical models were calibrated based on the experimentally identified modal properties (natural frequencies and mode shapes). Timber material properties were then obtained from the single-panel configuration, while elastic properties of the half-lap joint connection were extracted from the two-panel configuration. Finally, verification of the updated parameters was carried out through an experimental testing of three-panel CLT floor simply supported on two parallel edges (SFSF). Comparison of the experimentally extracted modal properties and the modal properties obtained from numerical simulations using the updated parameters is given in Table 4 and Figure 11. The presented procedure can be used as a benchmark for assessment of modelling parameters of inter-panel connection described using an elastic strip from experimental data.

Table 4. Natural frequencies and MAC values of the three-panel CLT floor

Mode	Experiment	Initial numerical model		Updated numerical model	
	f_e (Hz)	f_i (Hz)	Diff (%)	f_u (Hz)	Diff (%)
1	8.4	8.33	-0.82	8.42	0.24
2	10.2	9.96	-2.39	10.10	-1.03
3	14.6	14.91	2.12	14.67	0.50
4	19.6	20.60	5.11	18.94	-3.36

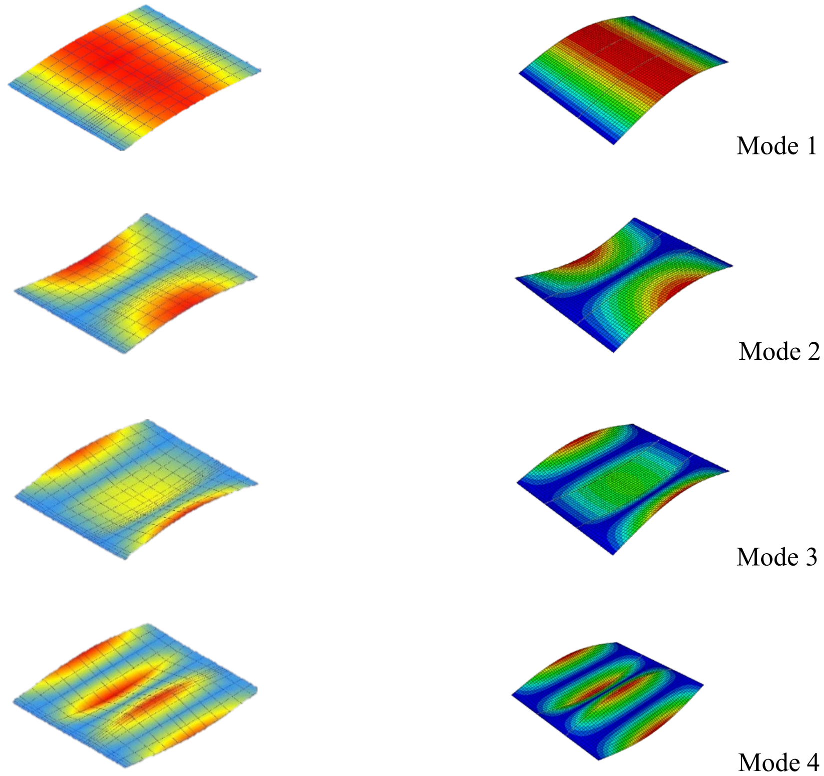


Figure 11. First four mode shapes of a three-panel CLT floor (SFSF) obtained from experimental testing (left) and numerical modeling (right)

4.3.2. WALKING TESTS

Another experimental study we conducted involves the evaluation of the vibration response induced by pedestrians walking on CLT floors. For that purpose, several test subjects were selected to walk with different walking frequencies and along straight walking paths. Walking frequency was controlled by a metronome. Figure 12 illustrates acceleration response and Fourier spectra of the floor layouts given in Figure 10 due to pedestrian walking at frequency of 1.8 Hz. In addition, RMS value of acceleration response is calculated as well over T = 1s averaging time. Although the tested floors have almost identical fundamental frequency (see Table 5), they exhibit different vibration responses. Contribution of vibration modes other than the fundamental in the case of two-panel and three panel floor is evident. Consequently, these modes cannot be neglected in the VS assessment.

As the fundamental frequency of the three-panel floor is 8.3 Hz, walking frequency of a test subject was set to 2.08 Hz to induce resonance with the fourth harmonic of walking force. Resonant response of the floor was calculated using Arup's design guideline as well. The results of both experimental and numerical simulations are given in Figure 13. The floor showed near-resonant response. While the measured and simulated peak acceleration values closely match, there is a notable difference in their corresponding RMS values – equal to 0.39 and 0.67, respectively. Note that the numerically simulated vibration response was calculated assuming 1.5% of modal damping. Increase of modal damping to 2% would result in a decrease of vibration response for even 20%.

4.4. DEVELOPMENT OF HYBRID FRP-CLT FLOORS

The most important aspect of our research study is the development of hybrid CLT floor solutions by applying a novel strengthening technique which includes strategic positioning of fiber reinforced polymer (FRP) reinforcement within the CLT panel to achieve higher strength and stiffness. FRP bars were placed in the grooves in both upper and bottom layers of the panel and bonded by using epoxy adhesive, as illustrated in Figure 14 (left). To identify stiffness and strength of the proposed hybrid solution, static tests were carried out first, as shown in Figure 14 (right). The preliminary analysis of the collected experimental data has shown that FRP reinforcement can significantly improve static performance of CLT panels. The findings report a 28% increase in the ultimate load and an 18% increase in stiffness for the applied reinforcement scheme and reinforcement percentage of 0.87%. In the next phase, vibration simulations were foreseen to identify vibration performance of a full-scale hybrid FRP-CLT floor when subjected to pedestrian footfall loading. Figure 15 (left) illustrates the modal testing of a single hybrid panel with reinforcement percentage of 0.7%. The panel was supported on elastic supports to eliminate any potential influence of boundary conditions on the modal properties. Results of the modal testing were elaborated in Table 6. They demonstrate an increase of natural frequencies of the hybrid panel in comparison to the bare CLT counterpart. The most prominent increase of 22% and 11% was detected for bending modes 2 and 4, respectively.

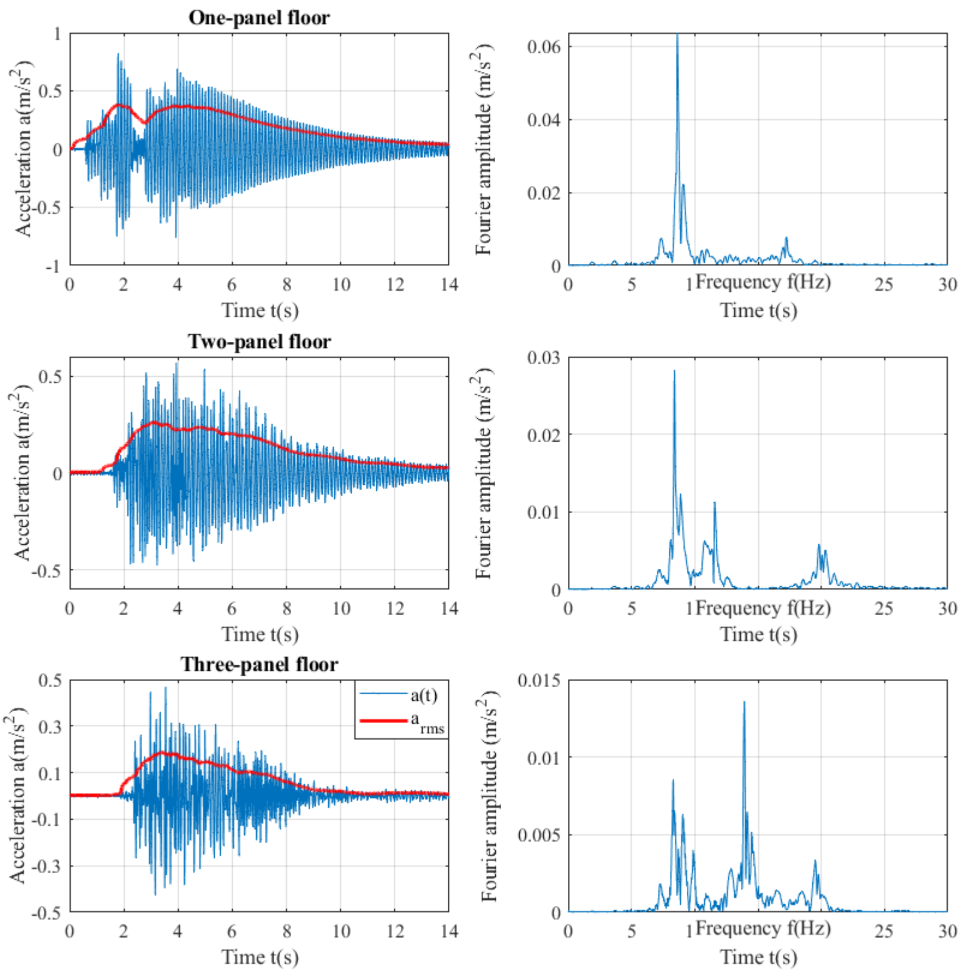
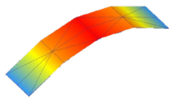
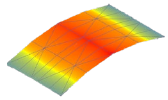
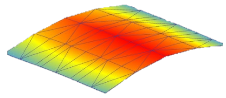
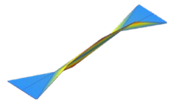
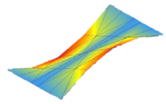
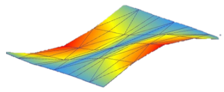
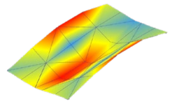
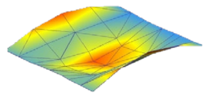
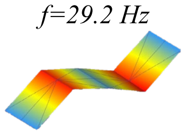
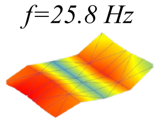
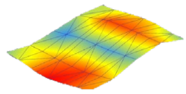
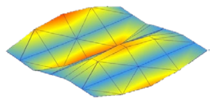


Figure 12. Acceleration time history and Fourier spectra for walking frequency 1.8Hz

Table 5. Natural frequencies and mode shapes of experimentally tested floors

Mode	One-panel floor	Two-panel floor	Three-panel floor
(1,1)	*f=8.6 Hz* 	*f=8.4 Hz* 	*f=8.3 Hz* 
(2,1)	*f=17.6 Hz* 	*f=11.6 Hz* 	*f=9.9 Hz* 
(3,1)		*f=20.3 Hz* 	*f=15.1 Hz* 
(1,2)	*f=29.2 Hz* 	*f=25.8 Hz* 	*f=25.6 Hz* 
(4,1)			*f=19.6 Hz* 

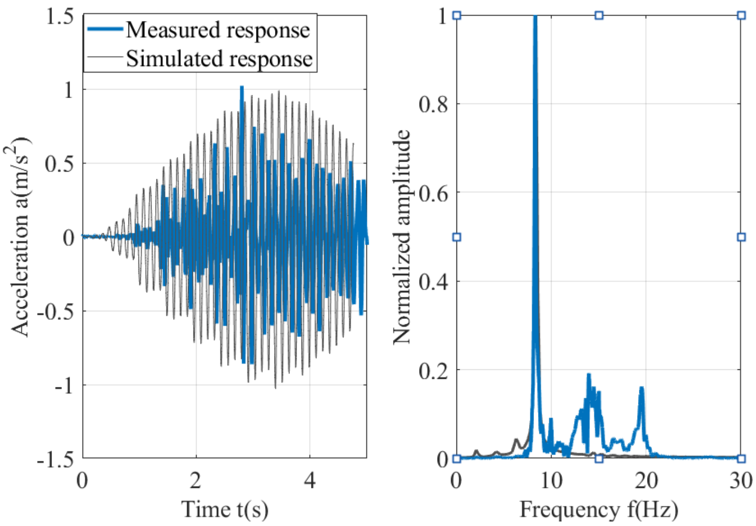
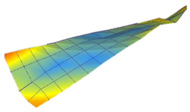
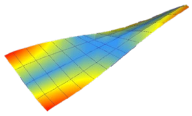
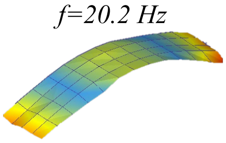
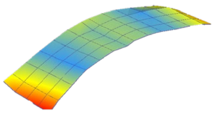
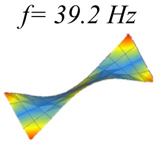
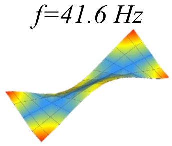
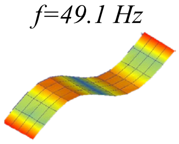
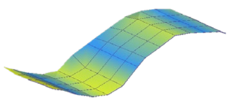


Figure 13. Measured and simulated resonant response of a three-panel floor (f_p = 2.08 Hz)

Figure 14. Hybrid FRP-CLT panel (left), static experimental setup (right)

Figure 15. Modal testing of hybrid FRP-CLT panel

Table 6. Comparison of modal properties of bare CLT and hybrid FRP-CLT panel supported on elastic supports

Mode	CLT	FRP-CLT
1	*f=19.7 Hz* 	*f=21.1 Hz* 
2	*f=20.2 Hz* 	*f=24.6 Hz* 
3	*f= 39.2 Hz* 	*f=41.6 Hz* 
4	*f=49.1 Hz* 	*f=54.5 Hz* 

5. CONCLUDING REMARKS

To meet net-zero carbon emission, contemporary design solutions require minimal use of structural materials. Given that zero-carbon buildings represent one of the key challenges in the 21st century, it is evident that CLT is emerging as a construction material of the future. Although lightweight, CLT floors possess enough stiffness to bridge relatively long spans. However, they often exhibit excessive vibrations when excited by human activities. Consequently, their design is often dictated by vibration serviceability limit state.

The traditional approach for VS assessment of CLT floors based on empirical recommendations is conservative and outdated, resulting in unreliable assessment of vibration performance of CLT floors. On contrary, vibration performance-based approach is a more comprehensive approach, based on fundamental principles of structural dynamics. It enables taking into consideration all pertinent design parameters in the VS assessment of CLT floors such as inter-panel connections, walking path and vibration acceleration or velocity response due to pedestrian-induced dynamic loading amongst others.

Improvements in the computational methods for vibration response calculation of CLT floors subjected to pedestrian-induced loading developed through the ongoing research would help engineers to apply more reliable and efficient procedures in design practice. In addition, novel hybrid floor solution designed as a combination of CLT and FRP reinforcement is promising, offering improved vibration performance of CLT floors.

Future research challenges are related to the application of more sophisticated models of pedestrian-induced dynamic loading, including human-structure interaction and probabilistic-based approach in the VS assessment of CLT floors. In addition, due to many sources of uncertainty in vibration response predictions at design stage (damping being one of the most uncertain among them), a novel approach would involve addressing potential vibration serviceability issues after the floors have been constructed.

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SEISMIC RESILIENCE THROUGH EUROPEAN RESEARCH NETWORKING - CRISIS PROJECT

Abstract

CRISIS project aims at improving the disaster and emergency management through building a harmonized and efficient system for risk assessment of basic services and transport infrastructure in the targeted cross-border region. The main project activities include: (1) Cross-border multi hazard assessment; (2) Needs assessment; (3) Cross- border multi-risk assessment; and (4) Development of cross-border web base platform for risk assessment and management. The main stakeholder of the project is the civil protection and disaster management national authorities in the cross-border region where more than 500.000 inhabitants live, as well as all academic partner institutions that will share the knowledge and strengthen the mutual cooperation.

Keywords: seismic resilience, seismic risk, critical infrastructure, landslide

СЕИЗМИЧКА ОТПОРНОСТ КРОЗ ЕВРОПСКО ИСТРАЖИВАЧКО УМРЕЖАВАЊЕ – ПРОЈЕКАТ "CRISIS"

Сажетак

Пројекат CRISIS има за циљ унапријеђење управљања катастрофама и ванредним ситуацијама кроз изградњу хармонизованог и ефикасног система за процјену ризика основних услуга и саобраћајне инфраструктуре у циљаном прекограничном региону. Главне пројектне активности укључују: (1) Прекограничну процјену вишеструких опасности (2) Процјену потреба (3) Прекограничну процјену вишеструког ризика и (4) Развој прекограничне *web* платформе за процјену и управљање ризиком. Главни носилац пројекта су националне власти цивилне заштите и управљања катастрофама у прекограничном региону, у коме живи више од 500.000 становника, као и све академске партнерске институције, које ће подијелити знање и ојачати међусобну сарадњу.

Кључне ријечи: сеизмичка отпорност, сеизмички ризик, критична инфраструктура, клизиште

1. INTRODUCTION

The European continent is characterized by a history of natural disasters: earthquakes, floods, landslides, draughts, extreme temperatures, forest fires and tempests with extensive economic, social, and ecological consequences that affect human wellbeing and the wellbeing of the society in a long run. These natural disasters often exceed the capacity of countries to manage emergency situations in the aftermath of a natural disaster and call for cross-border and regional cooperation. In addition, the preparedness and prevention level vary from country to country, whereat, achievement of the necessary preparedness level requires existence of a well-coordinated regional and international cooperation that will include recent scientific knowledge in the field of natural disaster risk management.

This paper refers to activities carried out in the frame of project entitled 'Comprehensive RISk assessment of basic services and transport InfraStructure - CRISIS' (http://www.crisis-project.org/). The CRISIS project is supported by the Directorate General for European Civil Protection and Humanitarian Aid Operations, DG – ECHO as part of the European Commission. Project consortium includes five partners: Ss. Cyril and Methodius University in Skopje, Institute of Earthquake Engineering and Engineering Seismology-IZIIS as coordinator and Crisis Management Centre, Government of the Republic of N. Macedonia, Polytechnic University of Tirana, Faculty of Civil Engineering, Albania, Aristotle University of Thessaloniki, Greece and European Centre for Training and Research in Earthquake Engineering – EUCENTRE, Italy, as partners (Fig.1).

The CRISIS project is aimed at improve the management of natural disaster consequences through establishment of a harmonized and efficient system for assessment of the risk pertaining to vital structures and transportation infrastructure in the cross-border region of North Macedonia, Greece, and Albania.

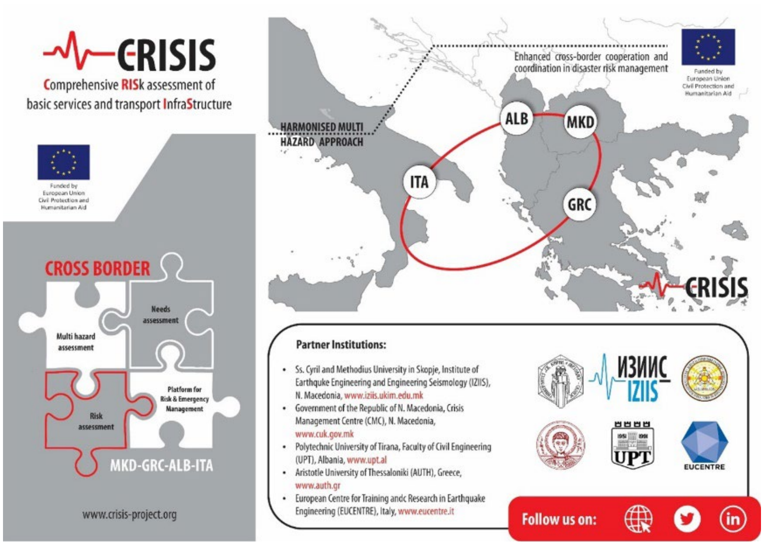

Figure 1. CRISIS Project consortium

2. PROJECT OBJECTIVES

The main objective of the CRISIS project is providing a solid basis for development of a cooperative approach to prevention and preparedness in disaster management in cross-border regions of the neighbouring countries located in the West Balkan region, by means of: (a) Assessment of natural cross-border hazards to basic services and transport infrastructure; (b) Collection, harmonization, and improvement of existing data and tools for risk assessment on critical assets; (c) Development and testing of the methodology incorporated in the web-based platform for rapid screening of vulnerable infrastructure nodes within a region.

Within the project, a comprehensive exposure model has been defined. The model is based on identified relevant goods associated with vital buildings and transportation infrastructure exposed to natural disasters that are relevant for the region of interest. To effectively manage emergency situations, a web platform that will integrate all natural hazards, the exposure model and analysis of different risk scenarios is being developed. The developed methodology and web platform will sustainability contribute to create a network of competent entities and development of disaster management plans in the cross-border regions.

3. MAIN PROJECT TASKS

The project is being realized through 4 main tasks (Fig. 2):

1. Identification of natural hazards in the cross-border region that affect the functioning of vital structures (health care institutions, institutions dealing with emergency situations, educational institutions, etc.) and the transportation infrastructure.
2. Review of existing legislation (EU and regional) related to management of emergency situations and risks. Pros and cons analysis related to management of emergency situations and risks. Pros and cons analysis with the purpose of identify existing omissions and bottlenecks.
3. Assessment of risk pertaining to vital structures and transportation infrastructure as the basis for the definition of key points in the entire system of emergency and disasters management.
4. Development of a geo-referenced web platform that will contain data related to: vital structures and transportation infrastructure in the cross-border region, natural hazards and vulnerability parameters of all elements at risk. This platform should be able to immediately provide information on the hazard, the exposure model and the risk and enable the assessment of possible losses and disruptions of the critical functions.

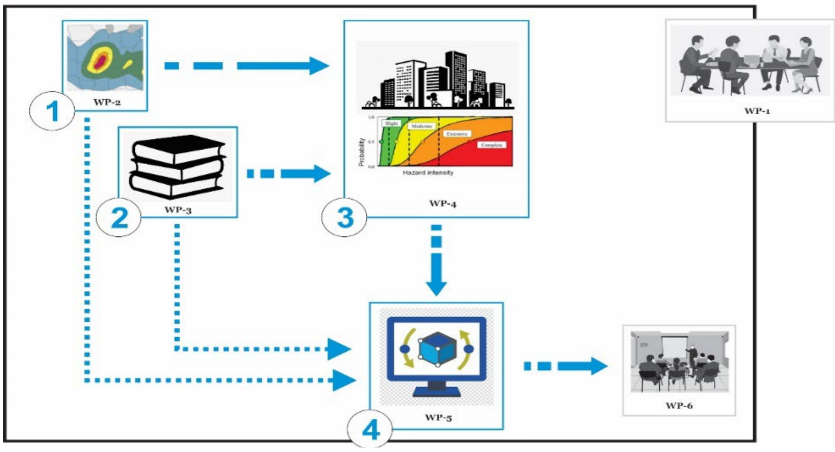

Figure 2. General block-diagram of the project

3.2. METHODOLOGY FOR IDENTIFICATION OF NATURAL HAZARDS

For the identification of hazards in the cross-border region version 2 of the ThinkHazard! screening tool (thinkhazard.org) has been used, developed by the World Bank Global Facility for Disaster Reduction and Recovery (GFDRR - www.gfdrr.org), which enables users to screen project locations for multiple natural hazards, Fraser et al. (2017). ThinkHazard! translates technical hazard data describing hazard intensity, frequency, and susceptibility in scientific parameters. The hazard metrics is: very low, low, medium and high. The hazard classification is used to communicate hazard to users who are not expert in natural hazards but require hazard information for project planning and disaster risk management purposes. The four hazard levels (very low, low, medium and high) are derived from hazard maps, which present the spatial distribution of hazard intensity (e.g., flood depth, ground shaking) at a given frequency or return period.

3.2.1. IDENTIFICATION OF NATURAL HAZARDS AT THE CROSS-BORDER REGION

The classification of the hazard levels for all the different hazards included in *ThinkHazard! (*with the exception of volcano, tropical cyclone, tsunami, and coastal flood) are shown in Table 1. The selected municipalities extracted from the full list of municipalities of the cross-border region are taken into account.

Table 1. Classification of the hazard levels of the municipalities of the cross-border region

Municipality	Earthquake	Landslide	Wildfire	Extreme heat	Water scarcity	River flood	Urban flood
Filiates	High	High	High	Medium	Low	High	Medium
Konitsa	High	High	High	Medium	Low	Very low	Low
Pogoni	High	High	High	Medium	Low	Very low	Low
Florina	Medium	Low	High	Medium	Low	Low	Medium
Kastoria	Medium	Medium	High	Medium	Low	Very low	High
Bitola	Medium	Medium	High	Medium	Low	High	High
Bogdanci	Medium	Medium	High	Medium	Low	High	High
Centar Zupa	Medium	Medium	High	Low	Low	High	Low
Debarca	Medium	Low	High	Low	Low	Low	High
Debar	Medium	Medium	High	Low	Low	High	Low
Bulqize	Medium	High	High	Low	Low	High	High
Delvine	High	High	High	Medium	Very low	Very low	High
Devoll	High	High	High	Low	Low	Low	High
Diber	Medium	High	High	Low	Low	High	High
Dropull	High	High	High	Low	Low	High	High
….	….	….	….	…..	…..	…	….

As far as earthquake is concerned (Fig.3), the whole cross-border region is characterized by medium to high earthquake hazard. High level of earthquake hazard is concentrated at the western part of the cross-border region, covering a significant area of both Grece and Albania of the cross-border region, while North-Macedonia is characterized by medium seismic hazard level.
Regarding landslide hazard (Fig. 4), the hazard levels at the cross-border region range between very low and high. High landslide hazard level is observed at the western part of the cross-border region, with the whole of the Albanian part being characterized with high hazard level.
The earthquake and landslide hazard are considered as the most crucial types of hazards for critical infrastructure in the cross-border region.

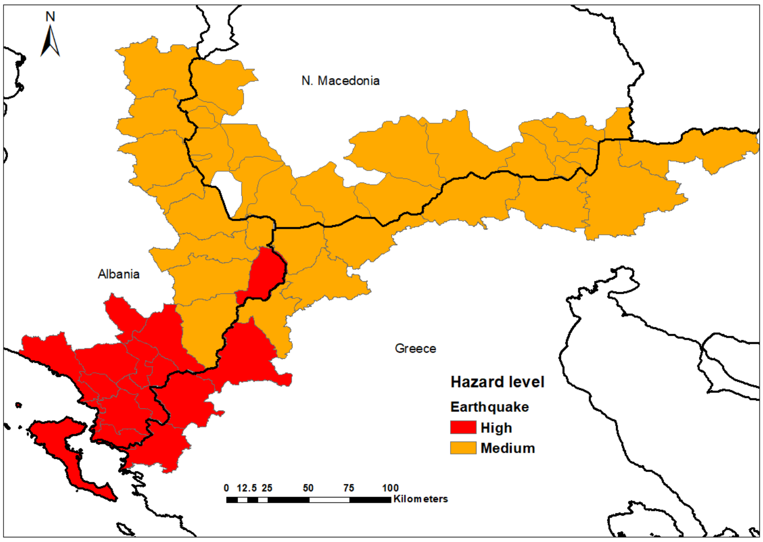

Figure 3. Spatial distribution of earthquake hazard levels at the CBR

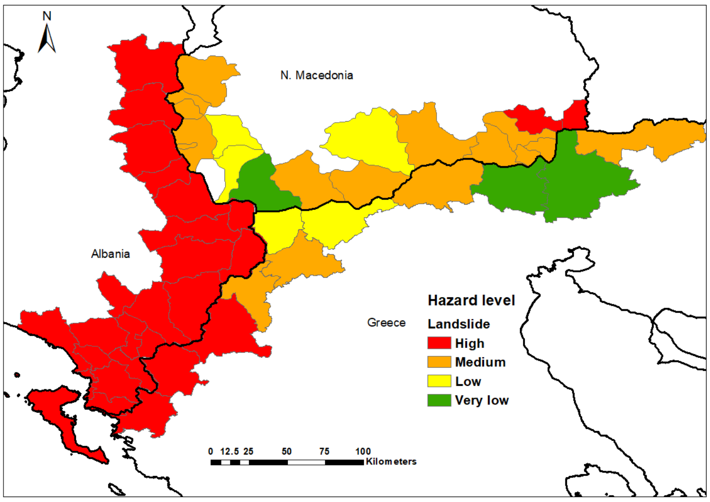

Figure 4. Spatial distribution of landslide hazard levels at the CBR

3.2.2. EARTHQUAKE HAZARD AT THE CROSS-BORDER REGION

For a more comprehensive presentation of the earthquake hazard at the cross-border region, the 2013 European Seismic Hazard Model (ESHM13) was used, Woessner, J. et al. (2015), which resulted from a community-based probabilistic seismic hazard assessment supported by the EU-FP7 project “Seismic Hazard Harmonization in Europe” (SHARE, 2009–2013) Giardini, D. et al. (2014). The ESHM13 is a consistent seismic hazard model for Europe and Turkey which overcomes the limitation of national borders and includes a through quantification of the uncertainties. Figure 5 illustrate the spatial distribution of the mean Peak Ground Acceleration (PGA) at the cross-border region for a reference rock condition, i.e. Eurocode 8 Type A with an average shear wave velocity vs_{30} = 800 m/s, for a 475-year respectively, obtained from ESHM13. Results are provided for sites equally spaced at 10 km. For T=475 years, PGA ranges between 0.21 and 0.45g. Results for T=975 years return period due to space limitation are not presented here. The regions where the highest levels of PGA are observed are the western coasts of the cross-border region to the Ionian Sea, as well as the island of Corfu. It should be noted that these PGA values refer to rock-site conditions and are expected to be amplified if local site conditions are considered.

3.2.3. LANDSLIDE HAZARD AT THE CROSS-BORDER REGION

A landslide susceptibility map subdivides the terrain into zones with differing likelihoods that a landslide may occur. Landslide susceptibility assessment can be considered the initial step towards a landslide hazard and risk assessment, but it can also be ‘end product’ in itself that can be used in land-use planning and environmental impact assessment.

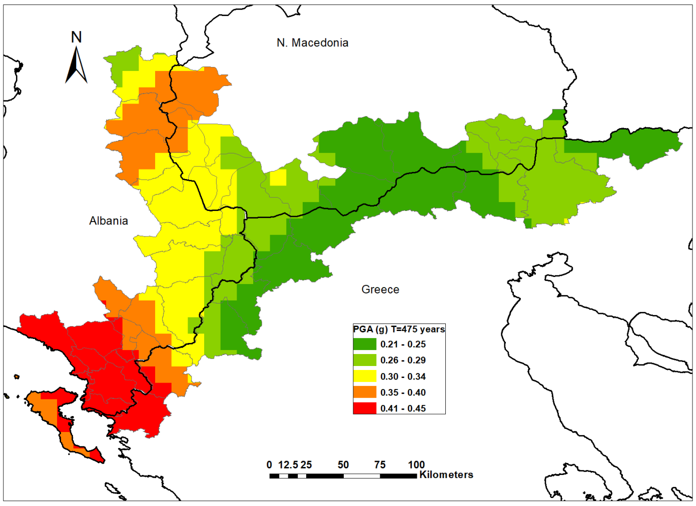

Figure 5. Spatial distribution of PGA at the cross-border region for a reference rock condition (Vs_{30} = 800 m/s) and for a 475-year return period

The landslide susceptibility map of the cross-border region is presented based on the Pan-European Landslide Susceptibility Map version 2 (ELSUS v2, Wilde, M., et al. (2018)), Figure 6. The map can be viewed at scales up to 1:200,000 as determined by the cell size of 200 × 200 m and should not be enlarged to greater scales.

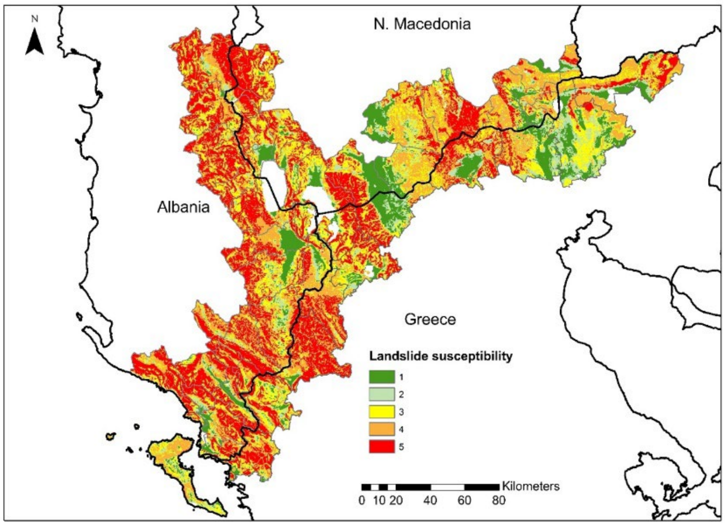

Figure 6. Landslide susceptibility of the cross-border region (where landslide susceptibility 1 = very low; 2 = low; 3 = moderate; 4 = high; 5 = very high)

The methodological approach for the elaboration, validation and classification of ELSUSV2 is the same as the previous version called ELSUS 1000 reported by Günther, A. et al. (2014). More specifically, a semi-quantitative method is used, combining landslide frequency ratios information with a spatial multi-criteria evaluation model of three thematic predictors: slope angle, shallow subsurface lithology and land cover. A landslide susceptibility index (LSI) for each model zone is computed based on the specific weight of these three thematic predictors for ‘plain’ and ‘mountainous’ model zones.

3.3. EVALUATION OF CREDIBLE SCENARIOS

3.3.1. EARTHQUAKE SCENARIOS

Evaluation of credible earthquake scenarios that may seriously affect basic services and critical infrastructure in cross border region is of the outmost importance. Scenarios are defined primarily on available seismological and seismo-tectonic data for the region of interest (databases ESHM13). For that purpose, 11 real earthquakes that have struck in the cross-border region and its vicinity were selected, as well as 9 seismogenic faults, considering the spatial distribution, level of seismic hazard and frequency of the earthquakes (see Fig.7). Although the parameters related to the selected earthquakes from SHARE European Earthquake catalogue slightly differ in relation to the parameters given in the official national earthquake catalogues, to keep a harmonization pattern, the parameters are not modified.

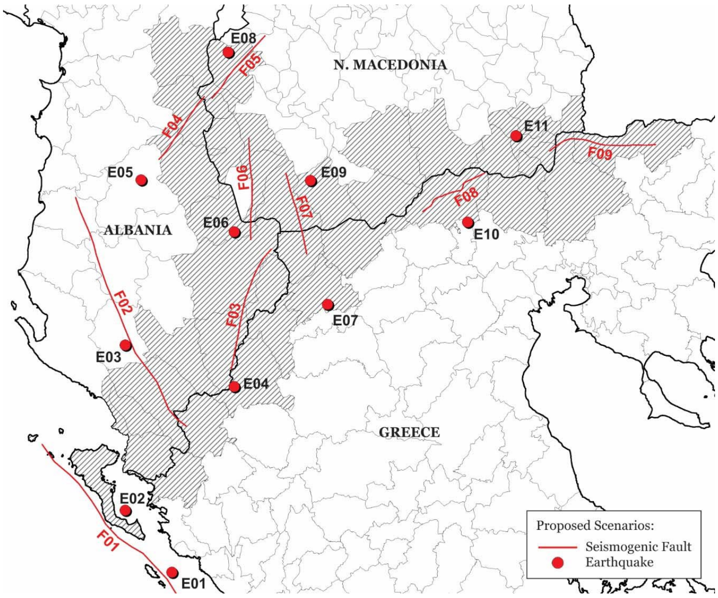

Figure 7. Spatial representation of earthquake scenarios

3.3.2. LANDSLIDE TRIGGERING SCENARIOS

Based on its scope and objectives, the earthquake as a triggering effect to cause landslides is taken into consideration to produce landslide hazard maps in terms of permanent displacements caused by different earthquake scenarios. Earthquake induced land sliding of a hillside slope occurs when the static plus inertia forces within the slide mass cause the factor of safety to temporarily drop below 1.0. The value of the peak ground acceleration within the slide mass required to cause the factor of safety to drop to 1.0 is denoted by the critical or yield acceleration a_c. Two seismic scenarios are defined with return periods equal to 475 years (magnitude M=6) and 975 years (magnitude M=7) based on ESHM13. To define the PGA value at surface, the V_{30} map proposed by US Geological Survey (earthquake.usgs.gov/data/vs30/) is used to categorize the ground type based on EC 8. The final product of the landslide hazard zonation is presented by digital maps of expected permanent displacements for the pre-defined earthquake scenarios (Fig. 8). The presented approach for the cross-border region is a simple tool which is used to recognize the hazardous areas, where limited available geotechnical and seismological datasets exist.

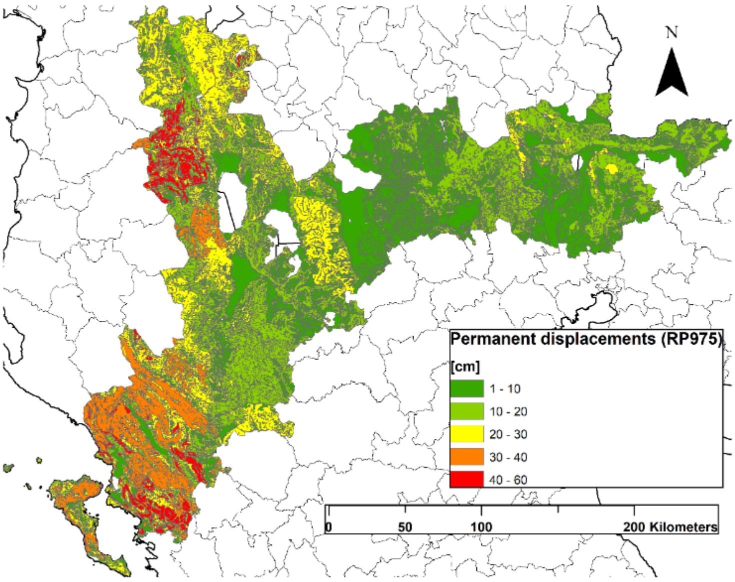

Figure 8. Spatial distribution of permanent ground displacement, seismic scenario of 975 years return period

4. CONCLUSIONS

The paper presents main findings and results achieved within the CRISIS project (project on going). Identification of natural hazards and most credible risk scenarios in the cross-border region between N. Macedonia, Albania and Greece that affect the functioning of basic structures and transportation infrastructure were presented.

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ANALYZING ZONES FOR STANDING: ENHANCING VIBRANCY DURING PUBLIC EVENTS

Abstract

This study examines how parts of the public space that offer the possibility for standing contribute to vibrancy during public events. The aim of the paper is to investigate how different arrangements of temporary structures affect the positions of potential zones for standing and, therefore, the vibrancy of public spaces. Using Trg Slobode (Liberty Square) in Novi Sad as a case study, it investigates the connection between space for standing and staying and spatial dynamics during public gatherings. The paper emphasizes the key factors that shape the perception of lively space and point out the importance of its adaptability. These findings enhance understanding of functioning of public spaces during events, stressing the importance of creating vibrant environments that cater to visitors' diverse needs.

Keywords: vibrancy, public events, temporary structures, spatial layout.

ИСТРАЖИВАЊЕ ДИНАМИКЕ ПРОСТОРА ЗА СТАЈАЊЕ: ПОВЕЋАЊЕ ЖИВАХНОСТИ ТОКОМ ЈАВНИХ ДОГАЂАЈА

Сажетак

Овај рад испитује како дијелови јавног простора који пружају могућности за стајање доприносе живахности током јавних догађаја. Циљ је истражити како различити распореди привремених структура утичу на позиције потенцијалних мјеста за стајање и, самим тим, на живахност јавних простора. Користећи Трг слободе у Новом Саду као студију случаја, истражује се веза између простора за стајање и просторне динамике током јавних окупљања. Рад истиче кључне факторе који обликују перцепцију живахности и указују на важност прилагодљивости простора. Ова сазнања унапрјеђују разумијевање функционисања јавних простора током догађаја, истичући важност стварања живописних окружења која задовољавају различите потребе посјетилаца.

Кључне ријечи: живахност, јавни догађаји, привремене структуре, просторни распоред.

1. INTRODUCTION

To create the sense of vibrancy and urbanity in a public space, the presence of users is crucial, especially if they gather around the main area. Encouraging people to pause and spend time in urban spaces has multiple positive effects, including fostering vitality and diversity. The unique and unpredictable aspects of these spaces add to their value. Therefore, it's important to appreciate these differences by enhancing people's engagement. This fosters the prosperity of urban life and helps create a lively atmosphere in public spaces. As underscored by Ben Rogers, the greater the diversity and vibrancy of urban spaces, the more society tends towards equity, prosperity, and democracy. This assertion is deeply rooted in the fundamental definition of public space as an open, accessible, and democratic environment [1].

Standing in public spaces provides individuals with the chance to observe their surroundings and the ongoing activities in those communal areas. It is a universal phenomenon for people in cities worldwide to enjoy observing what's going on in shared spaces.

Engaging in public spaces is pivotal in shaping social dynamics and cultivating a positive ambiance. When individuals have the chance to stand and linger in public areas, the likelihood of spontaneous interactions and meaningful connections with others significantly increases. Given that "people attract people," it is more likely that cities with vibrant public spaces will attract citizens, tourists and other visitors [2]. This phenomenon can be attributed to the inherent sociability of individuals, as they naturally gravitate towards forming connections. The innate human desire for interpersonal interaction further underscores the importance of such opportunities in our social fabric, even despite the increased interest in virtual encounters.

Opportunities for encounters and daily activities in urban public spaces create possibilities for interpersonal contacts and relationships in public discourse, providing people with the opportunity to engage in communication and experience the activities of others in various forms [3]. By offering these opportunities, public spaces meet the innate needs of their users, enriching social life with vibrancy and dynamism. According to Cattell et al., engaging in social interactions within open urban spaces has the potential to offer respite from the monotony of daily routines, foster a sense of community, provide opportunities for maintaining established social connections or forging new ones, and positively influence people's tolerance levels and overall mood [4].

In connection with standing in public spaces and the vibrancy of these areas, Gehl's distinctions in degrees of contact intensity become particularly relevant [5]. When individuals stand in public spaces, they engage in a modest level of contact – a basic form of interaction. This act of standing can serve as a potential starting point for more profound connections, contributing to the overall vibrancy of the public space.

Standing provides opportunities for encountering others, observing their behavior, and listening to the surrounding activities. These interactions, even at a modest level, become integral components of the vibrancy of public spaces. Moreover, standing serves as a means of maintaining already established contacts, fostering a sense of community and continuity in the dynamic environment.

Public spaces, where people stand and interact, act as not only sources of information about the external world but also as wellsprings of inspiration and stimulating experiences. The diversity of contacts, from casual encounters to more profound connections, contributes to the richness and vitality of the public space, aligning with Gehl's insights on the varying degrees of contact intensity within the realm of social interaction [5].

Jane Jacobs asserted that urban planners and designers often fail to grasp that individuals are drawn to the presence of others. Instead, they tend to plan and design with the assumption that city residents seek scenes characterized by emptiness, order, and silence. Contrary to this assumption, she concluded that nothing could be further from the truth, asserting that places designed on such principles tend to be monotonous and uninspiring [6].

The motivations of people visiting public spaces are varied, yet consistently, a prevailing factor is the joy derived from observing others - their behaviors and activities [6]. Standing not only offers individuals the chance to immerse themselves in the events but also allows them to relish the ambiance alongside fellow visitors, potentially playing a role in shaping the unique identity of the place.

In the 1970s, William H. Whyte postulated that a public space becomes urban and invigorating when there are approximately 16.6 pedestrians within the observer's visual field [7]. This theory was empirically tested in small Norwegian towns, confirming that a scene with 14 to 20 people standing in the square creates the perception of an urban, stimulating public space (Figure 1). Gehl and Svarre expanded upon this experiment, directing 20 participants to stand around the square's perimeter, while the remaining participants evaluated the impact on the square's vibrancy (Figure 2) [8]. The assessments indicated a significantly lower perception of vibrancy when participants were positioned farther from the center.

Figure 1. Participants of the experiment in the middle of the square.

Figure 2. Participants of the experiment around the perimeter of the square.

Gehl and Svarre's experiment serves as the foundational inspiration for our research. This paper initiates an examination of the dynamics of spaces for standing by means of thorough analysis, concentrating on the shifts in position and configuration stemming from diverse arrangements of temporary structures during public events. The overarching objective is to evaluate the influence of these variations on the vibrancy of public spaces. The study focuses on the main square in Novi Sad, known as Liberty Square. An array of events hosted here directly influences the Square's vitality and dynamism, shaping its ambiance and appeal.

Leveraging parametric design tools allows us to gather insights into the spatial capacity for accommodating individuals during public events. Nevertheless, simply pinpointing these surfaces does not furnish an understanding of the vibrancy within the public space. Consequently, this paper introduces a method that has been devised to assess and distinguish the degree of vibrancy within public spaces, building upon prior theoretical research.

2. METHOD

The method is based on empirically confirmed research, which suggests that greater separation from the center is interpreted as a reduction in vibrancy, while closer proximity is thought to enhance overall vibrancy.

The first step involves defining the boundary of the event space and determining the positions of the temporary structures. After that, attention is directed to defining access spaces and passageways between temporary structures to ensure efficient flow. These spaces are characterized by a low probability of being used for observation or participation in activities due to their primary function as access points to temporary structures or roads. Through the determination of access distances for each temporary building and adjacent passages, the spaces for standing are defined and demarcated.

Within predetermined boundaries, the event space is divided into concentric circles, with each circle assigned a numerical value that indicates liveliness in that particular area (circular segments shown in Figure 3). Upon scientific analysis, it was found that vibrancy diminishes from the center to the periphery. Consequently, a value of 1 was assigned to the central circle. Due to the absence of a universally accepted methodology for measuring the vibrancy of a space, this study proposes to convert the qualitative data into a mathematical formula as follows:

$$\text{Vibrancy Level Value (VLV)} = 1 - \frac{\text{Distance from the Center}}{\text{Radius of the Public Space}} \tag{1}$$

This formula facilitates the incorporation of the distance from the center as a key factor in assessing the vibrancy across various sections of a space, and it can be further fine-tuned and adjusted to suit the unique characteristics of diverse spaces. The parameters and methodologies established in this manner are adaptable to address the specific requirements and features of a given public space.

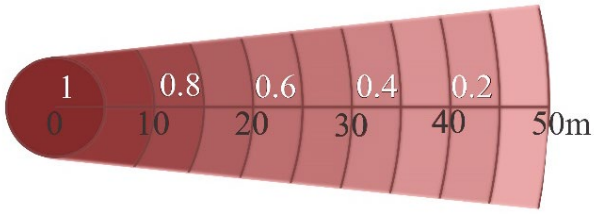


Figure 3. A visual depiction illustrating the correlation between vibrancy levels and their respective distances from the cfienter of a public space within a radius of 50 m.

Successive circles incrementally expand by 5 m in radius, culminating in a totacl of 10 circles with a final radius of 50 m as shown in Figure 3. Each of the ten concentric circles designated for spatial analysis delineates a zone with a distinct level of vibrancy, where the numerical vibrancy value decreases proportionally with the expanding distance from the center. Utilizing this model, the central circle, boasting a radius of 5 m, has been pinpointed as the area exhibiting the highest vibrancy, denoted with a value of 1. This central zone is deemed optimal for activities that demand heightened visitor interaction and engagement. The gradual enlargement of these circular zones corresponds to a diminishing level of vibrancy, ultimately reaching a value of 0.1 for the outermost circle. These outer circles are well-suited for activities requiring less engagement and provide ample space for visitors to unwind and relax.

These concentric circles overlap with the designated standing zones, allowing spaces for standing to span various vibrancy zones. Areas of zones smaller than 3 m^2 are automatically excluded from the calculation and are not depicted in the geometrical representation. This is because they are deemed insufficient for accommodating a group of people, which is a fundamental requirement for achieving the effect of lively space. The computed overlapping area for each zone is subsequently multiplied by the corresponding Vibrancy Level Value. The cumulative values derived from this calculation, based on the chosen arrangement of temporary structures, are then totaled. The resultant output is validated by recognizing that a higher value for a specific configuration of temporary structures signifies a more advantageous spaces for standing in terms of vibrancy. The described procedure is shown as a flowchart diagram in the Figure 4.

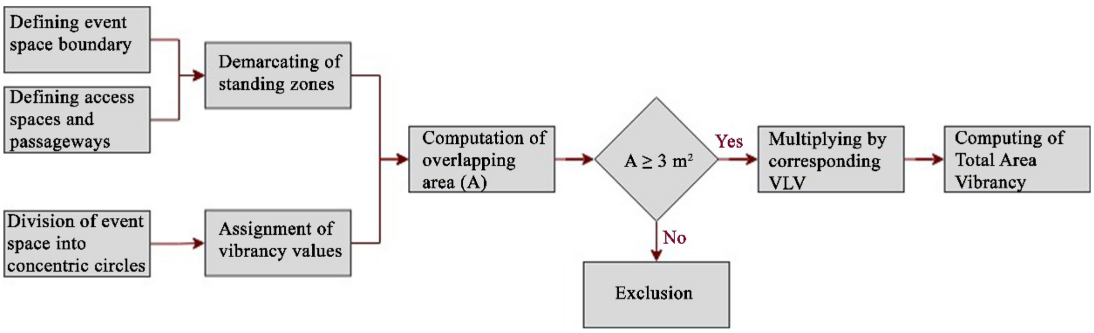


Figure 4. Flowchart diagram of the overall computational workflow

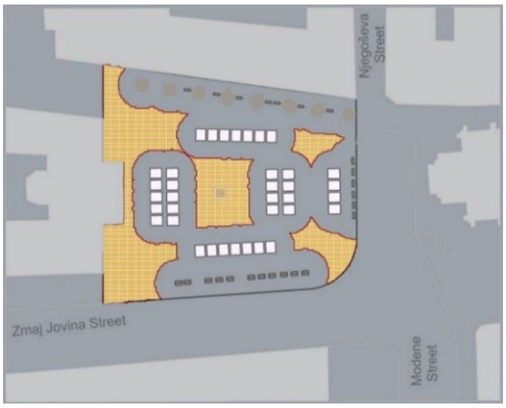
Analyses are performed using Grasshopper within the Rhinoceros.The workflow begins by importing a 2D model of the event space from AutoCad into Rhinoceros, ensuring an accurate representation of the physical dimensions and layout. Once the model is prepared, it's imported into Grasshopper for analysis. Grasshopper's parametric workflows are then utilized to define parameters and conduct calculations for vibrancy scores. After executing the analysis, Grasshopper generates visualizations and facilitates iterative design exploration. Finally, the refined design and analysis results are exported back to Rhino for documentation and presentation.

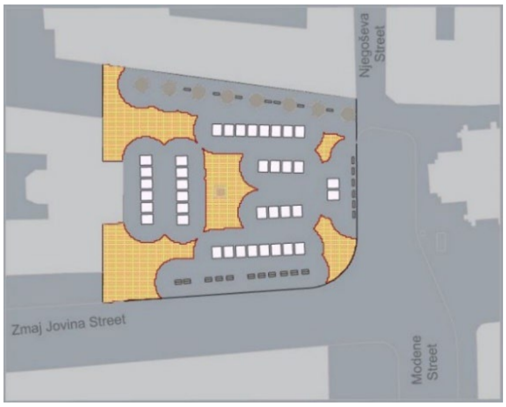
This approach empowers organizers to strategically design the event layout, optimizing spatial utilization and elevating the overall visitor experience. Furthermore, this methodology ensures a harmonious distribution of activities throughout the event, providing visitors with the flexibility to select zones that best resonate with their interests and engagement preferences.

3. RESULTS

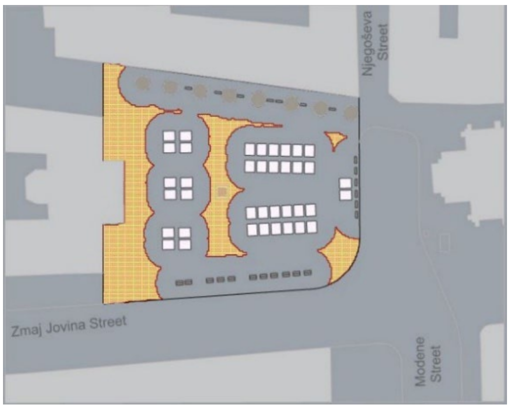
The described approach was implemented at a specific public venue: Trg slobode (Liberty Square) in Novi Sad. Four distinct arrangements of temporary structures were utilized as realistic settings for applying this method during a public event. These four layouts employ space in distinct ways: Layout 1 combines linear and group arrangements, Layout 2 follows a linear format, Layout 3 adopts a group layout comprised of a single type of group containing 4 temporary structures, and Layout 4 employs two dominant groups - one comprising 12 temporary structures and the other consisting of 4 temporary structures (Figure 5). Consistency was maintained across each arrangement, with 36 temporary structures sharing identical base dimensions (2.5 m width and 3 m length).

The border of the analyzed area was defined based on the long-standing practice of setting up temporary structures in a certain part of the Square. A dimension of 50 m was taken as the radius of the public space, based on the dimensions of the Square and the defined border of the analyzed area. A distance of 2 m was allotted on each side of the temporary structures to designate space for standing. Figure 5 illustrates the geometry of the resulting zones for standing.





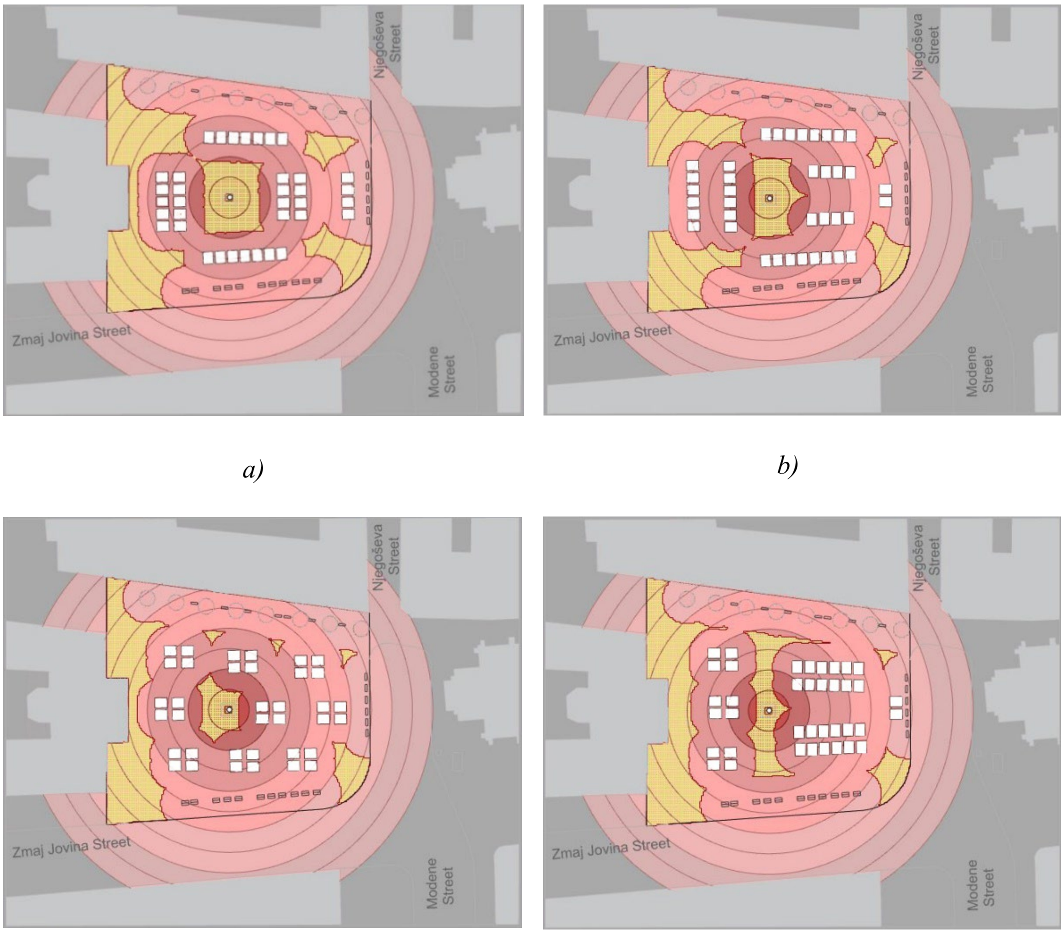
a) *b)*



c) *d)*

Figure 5. Display of the spatial configurations of standing areas for the following layouts of temporary structures:a) Layout 1 b) Layout 2 c) Layout 3 d) Layout 4

The method described, utilizing concentric circles, was applied to the standing surfaces obtained, as illustrated in Figure 6. This involved multiplying the overlapping area of the standing zone and the specific circular ring by its corresponding vibrancy rating.



a) *b)*

c) *d)*

Figure 6. *Application of the method utilizing concentric circles on standing surfaces for the following arrangements of temporary structures: a) Layout 1 b) Layout 2 c) Layout 3 d) Layout 4*

The outcome of multiplying the overlapped area by the vibrancy rating was computed for each ring. These individual results were then summed up across all rings within a layout. As a result, four total area vibrancy values were generated for the four layouts, as depicted in Figure 7.

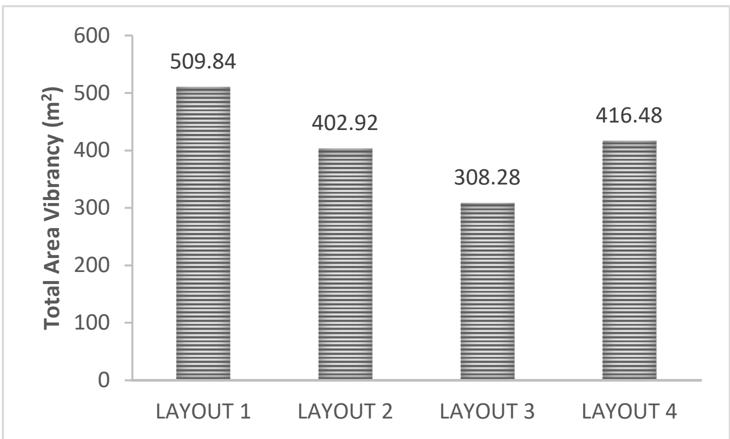


Figure 7. A graph showing the calculated total area vibrancy for each arrangement of temporary structures

These results depict the vibrancy scores achieved by implementing different configurations of temporary structures. Layout 1 attained the highest total area vibrancy score of 509.84 m^2, suggesting that this arrangement generated the most vibrant and lively atmosphere. In contrast, Layout 3 obtained the lowest score of 308.28 m^2, indicating a comparatively less lively environment. The disparity between these scores underscores the importance of considering layout configurations in enhancing vibrancy levels.

Layouts yielding higher vibrancy scores, such as Layout 1, may offer valuable insights into best practices for creating engaging and lively spaces. On the other hand, layouts with lower scores may prompt further analysis to identify factors inhibiting vibrancy and potential areas for improvement. Overall, the vibrancy analysis aids in understanding the impact of layout configurations on the perceived vibrancy of spaces, facilitating informed decision-making in design and planning processes.

4. DISCUSSION

In contrast to existing studies on vibrancy in public spaces [2, 9, 10, 11], our approach is distinguished by the examination of the impact of different layout configurations of temporary structures on vibrancy levels. In the expansive literature on urban vibrancy, little attention has been paid to the specific impact of temporary structures and their arrangement. Even those dedicated to temporary structures often explore the wider field of temporary urban interventions and their impact on urban vibrancy and regeneration.

The research conducted by Gehl and Svarre underscored urban design's role in nurturing vibrant public spaces, emphasizing factors such as pedestrian-friendly environments, diverse activities, and social interaction [8]. While Gehl and Svarre's work offers valuable insights into fundamental principles of urban vibrancy, its focus predominantly centers on permanent urban features rather than temporary structures. Conversely, our study contributes to this discourse by directing attention to temporary interventions, increasingly employed in urban spaces for diverse events and activities. Through the examination of various layout configurations of temporary structures, we provide specific insights into how these ephemeral elements may augment or diminish vibrancy levels in public spaces.

Nonetheless, it is imperative to acknowledge the limitations of our study relative to existing research. For instance, our investigation was confined to a specific public venue and temporary structure arrangements in Novi Sad. Although this confinement facilitated a precise analysis within a controlled environment, it may constrain the generalizability of our findings to other contexts. Furthermore, while our vibrancy analysis methodology yielded substantive quantitative data, its refinement and validation through comparative studies and interdisciplinary collaboration could be advantageous.

In summary, while our study furnishes valuable insights into the nexus between layout configurations of temporary structures and vibrancy levels, it serves as a point of departure for further exploration and refinement. By assimilating insights from extant research and embracing interdisciplinary methodologies, future investigations can deepen our comprehension of vibrancy in public spaces and engender more efficacious urban design and planning strategies.

5. CONCLUSION

The values obtained from this analysis should not be regarded as absolute or definitive. However, they hold significance when comparing results across various spatial arrangements for several reasons. Utilizing these values enables an assessment of the efficiency of one layout relative to others. This aids in making well-informed decisions and identifying best practices.

The limitations of the described method include challenges in accurately determining the center of public space, particularly when this central position lacks strict geometric definition. Additionally, the standing areas and configurations of temporary structures have not been subjected to verification or real-world testing by visitors, thus remaining theoretical concepts. Furthermore, they encourage further research that would take into account the impact of specific temporary structures on attracting a larger crowd to their surroundings, thus including the key factors influencing gatherings.

In light of these limitations, it becomes evident that there is ample room for refinement and expansion in future spatial analyses. By incorporating a more comprehensive understanding of crowd behavior and spatial dynamics, future analyses can offer even greater insights and utility for urban planning and design endeavors.

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06
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APPLICABILITY OF THE "TYPOLOGY OF RESIDENTIAL BUILDINGS IN BOSNIA AND HERZEGOVINA", AT A MUNICIPALITY OR CITY LEVEL, CASE STUDY - SINGLE-FAMILY HOUSES IN THE CITY DERVENTA

Abstract

In order to make correct estimates of energy consumption for heating, reduction of energy consumption, and CO_2 emissions by applying energy efficiency measures, it is necessary to know the structure and characteristics of the building stock. The Typology of residential buildings in Bosnia and Herzegovina identified the structure and characteristics of residential building stock through different periods at the level of Bosnia and Herzegovina. This paper analyses the differences between national and city or municipal typology. Conducted analysis for the City Derventa, shows that in the case of single-family houses, the application of national instead of local typology can result in certain deviations in the estimation of energy consumption, savings, and CO_2 emissions.

Keywords: single-family houses, typology, energy consumption, energy efficiency

ПРИМЈЕНЉИВОСТ ТИПОЛОГИЈЕ СТАМБЕНИХ ЗГРАДА У БОСНИ И ХЕРЦЕГОВИНИ НА НИОВУ ОПШТИНА ОДНОСНО ГРАДОВА, СТУДИЈА СЛУЧАЈА – СЛОБОДНОСТОЈЕЋЕ КУЋЕ У ГРАДУ ДЕРВЕНТА

Сажетак

Да би се направиле исправне процјене потрошње енергије за гријање стамбеног сектора, смањења потрошње енергије и емисије CO_2 примјеном мјера енергетске ефикасност потребно је сто реалистичније познавати структуру и карактеристике стамбеног фонда. „Типологија стамбених зграда Босне и Херцеговине“ идентификовала је карактеристике стамбених објеката на нивоу државе Босне и Херцеговине по појединим периодима изградње. Овај рад анализира разлике између националне и локалне типологије. Проведена анализа на примјеру града Дервента, показује да у случају слободностојећих кућа, примјена националне умјесто локалне типологија може довести до одређених одступања у процјенама потрошње, уштеде енергије и емисије CO_2.

Кључне ријечи: слободностојеће куће, типологија, потрошња енергије, енергетска ефикасност

1. INTRODUCTION

Buildings are responsible for about a third of global energy consumption and a quarter of CO_2 emissions [1]. In the European Union (EU), buildings are the largest consumers of energy (40% of total final energy consumption in 2012), and are responsible for 36% of the emissions of CO_2. Some research showed that about 58.44% of the total energy in Bosnia and Herzegovina is used in the residential sector [2]. Increasing energy efficiency in the building sector is fundamentally important for decreasing energy consumption, fossil fuels consumption, and greenhouse gas (GHG) emissions, and of course, gives the possibility of using renewable energy sources on a much larger scale. In order to create different scenarios for the reconstruction of the building sector, and planning of the necessary investments, it is very important to have data about the structure and characteristics of residential building stock at the local, regional, entity, and national levels. Local, regional, and national typologies are very valuable tools for those types of analyses.

The Typology of residential buildings in Bosnia and Herzegovina was created as a result of a two-year scientific research project (2014-2016) [3], and presents the classification of existing residential buildings according to the type and period of construction until 2014. It contains a calculation of the energy need for heating buildings, building structures, thermo-technical systems for heating, and domestic hot water systems, as well as a proposal of measures for improving architectural and construction building parts and measures for improving heating systems and domestic hot water systems for 29 selected typical buildings, in accordance with the methodology of the European project TABULA.

Typologies provide insight into the most important characteristics of buildings but also contain a lot of data for numerous further scientific research projects (e.g., the National Typology of residential buildings in Serbia [4] was used in the papers [5] - [7], the Typology of residential buildings in Bosnia and Herzegovina in papers [8] – [11], etc). In [5], a comparative analysis of residential indoor air pollutant concentration change is presented through different mitigation scenarios by implementing building physical and thermal retrofit measures for existing Belgrade and Niš housing stock up to 2050. For modelling the overall residential stock, appropriate data from [4] (i.e., building construction, building age, etc., and thermal i.e., heating system, envelope thermal performances, etc.) were used.

Ćuković – Ignjatović et al, [6] investigated the potential for improving the energy performance of multifamily housing blocks connected to the district heating system. The national Typology of residential buildings in Serbia [4] was used as a tool for assessment of current building performance and savings through different retrofit scenarios.

The reduction of energy demand in the residential building sector by a bottom-up simulation model through three different scenarios was analysed in [7]. The bottom-up simulation model was developed based on the national Typology of residential buildings in Serbia [4] as an input.

Gajić at all, [8] analysed the potential savings of the energy need for heating the existing single-family houses in the residential stock in urban and rural areas of Bosnia and Herzegovina, based on data from [3].

The representative shape factors of residential houses and buildings in Bosnia and Herzegovina were analysed in [9]. The paper is based on the data from the Typology of residential buildings in Bosnia and Herzegovina [3].

Kadrić, et al, [10] performed a comparison of methodologies for calculating the energy demands of residential buildings from the national typologies of Bosnia and Herzegovina [3] and Serbia [4]. In addition, the comparison of the data obtained from the two national typologies and the necessary corrections were proposed that would enable a more accurate assessment of energy consumption for heating in the residential sector of the two countries.

Gvero et al. [11], analysed the urban air pollution caused by the emission of PM10 from small household devices and abatement measures in one part of the Banja Luka city area. For prediction and quantification of the influence of the household’s appliances, the results of the project the Typology of residential buildings in Bosnia and Herzegovina were used.

The Typology of residential buildings in Bosnia and Herzegovina is also used for the preparation of the Integral Building Renovation Strategy in Bosnia and Herzegovina until 2050 [12].

According to [3], the number of buildings of single-family housing (97.63%) compared to collective housing (2.37%) is significantly higher. Also, 73.71% of the gross surface area of residential space belongs to single-family houses. From this percent, almost 90% (i.e. 90.42% according to the gross surface of residential space) of single-family houses were built in the period 1971-2014.

In the absence of other data, the Typology of residential buildings in Bosnia and Herzegovina [3] is used today to assess the energy characteristics of the building stock in most municipalities and cities in Bosnia and Herzegovina.

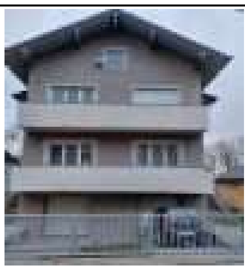
Having in mind that the national typology was created as a result of a comprehensive analysis of the building stock at the national level, this paper attempts to answer whether the data from [3] are applicable at the local (municipality or city) level, where the building stock is much smaller. Single-family houses built in the period 1971-2014 were selected for this analysis because they are the most represented type of building in Bosnia and Herzegovina and in the City Derventa.

2. ANALYSES AND DISCUSSION

The Typology of residential buildings in the City Derventa [13] was created within the framework of the INER project (Intelligent energy management and promotion of renewable energy sources) within the framework of INTERREG IPA as a result of two-year research (2020-2022). The Typology of the City Derventa contains data about typical buildings, building envelope construction, energy calculations, heating and hot water preparation systems, possibilities for improving energy efficiency with the aim of reducing energy consumption for two scenarios (standard and improved scenario), etc. according to the type and period of construction of building stock.

According to the 2013 Census, the City Derventa has 27,404 inhabitants and 13,748 housing units [13]. A significant increase in the number of residential buildings in the City Derventa began in the 1960s of the 20th century and was caused by industrialization, which required a large workforce. In the City Derventa around 14,500 building units were destroyed or damaged as a result of the last war. In the first post-war years, the majority of multi-family buildings and single-family houses underwent partial renovation. The matrix overview of characteristic single-family houses in the period 1971-2014, from the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina is given in Table 1.

Table 1. Matrix overview of characteristic single-family houses in the period 1971-2014, from the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina

	The “Typology of residential buildings in the City Derventa” [13]	*The “Typology of residential buildings in Bosnia and Herzegovina” [3]*
1971-1980		
1981-1992		
1992-2014		

The data about the net area of heating space, heated space volume, and shape factor of the characteristic buildings in booth typologies are presented in Table 2, and the heat transfer coefficient (U values) of the basic elements of the envelope are presented in Table 3. As can be seen from Table 1, the net area and heating volume of characteristic single-family houses in the City Derventa, by period of construction, are higher than in the national typology.

Table 2. The area of heating space, heated space volume and shape factor of the characteristically single family houses in the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina

Types	*Periods*	*Typology*	*Net area of the heated spaces*	*Heated space volume*	*Shape factor -f_0= A/V ratio*
Building category	*Built in*		*m^2*	*m^3*	-
Single family houses (SH)	*1971-1980*	*Derventa*	*165.6*	*558.9*	*0.802*
		Bosnia and Herzegovina	*67.8*	*149.2*	*1.04*
	1981-1992	*Derventa*	*125.22*	*374.40*	*0.93*
		Bosnia and Herzegovina	*101.4*	*250.2*	*0.83*
	1992-2014	*Derventa*	*168.42*	*499.2*	*1.04*
		Bosnia and Herzegovina	*121.1*	*298.7*	*0.92*

As it can be seen from Table 2, the shape factor of the characteristic single-family house in the City Derventa in the construction period 1971–1980 is smaller than the shape factor of the characteristic single-family house in the national typology. The opposite situation is in the construction periods of 1980–1992 and 1992–2014. The heat transfer coefficients of characteristically single-family houses, (Table 3) according to the construction periods considered, are generally similar in both typologies. A few significant differences are noticeable in the construction period 1981–1992, where the coefficients of characteristically single-family houses in the City Derventa, in most cases, are higher than in the national typology.

Table 3. Heat transfer coefficient (U values) elements of envelope of the characteristically single family houses in the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina

Types	*Periods*	*Typology*	*U external wall*	*U windows*	*U ground floor*	*U floor construction to unheated attic*
Building category	*Built in*		*W/(m^2K)*	*W/(m^2K)*	*W/(m^2K)*	*W/(m^2K)*
Single family houses (SH)	*1971-1980*	*Derventa*	*1.664*	*3.00*	*3.38*	*2.522*
		Bosnia and Herzegovina	*1.64*	*3.00*	*3.63*	*1.75*
	1981-1992	*Derventa*	*1.612*	*2.9*	*3.22*	*2.36*
		Bosnia and Herzegovina	*0.5*	*2.93*	*0.43*	*0.34*
	1992-2014	*Derventa*	*0.517*	*2.85*	*0.693*	*2.98*
		Bosnia and Herzegovina	*0.52*	*2.85*	*0.578*	*0.34*

Energy calculation (annual energy need for heating, delivery energy, primary energy, and emission of CO_2) of characteristic single-family houses by different periods of construction is presented in Table 4, and was carried out according to appropriate rulebooks [14] – [16]. The identified typical heating systems and the system for preparing domestic hot water, as well as their efficiency, are identical in both typologies. For the purposes of this analysis, energy calculations for all characteristic single-family houses were performed using the same meteorological data (the "North Zone" [14]) as in the national typology.

Table 4. Energy characteristic of single-family houses by different period of construction from the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina.

Types	Periods	Typology	Specific energy need for heating $Q_{h,nd,cont}$ (continuous heating, annual)	Specific energy need for heating $Q_{h,nd,interm}$ (intermittent heating, annual)	Specific delivered energy for heating $E_{h,del,interm}$ (annual)	Specific primary energy for heating $E_{prim,interm}$ (annual)	Specific emission CO_2 (annual)
Building category	Built in		kWh/(m^{2}a)	kWh/(m^{2}a)	kWh/(m^{2}a)	kWh/(m^{2}a)	kg/(m^{2}a)
Single family houses (SH)	1971-1980	Derventa	349.69	263.35	526.7	589.90	35.70
		Bosnia and Herzegovina	484.58	381.59	763.19	854.77	51.73
	1981-1992	Derventa	347.51	247.91	495.82	555.32	33.61
		Bosnia and Herzegovina	176.45	135.93	271.86	304.47	18.43
	1992-2014	Derventa	224.04	162.71	325.42	555.32	22.06
		Bosnia and Herzegovina	149.89	127.61	255.25	285.86	17.30

According to Table 4, the specific energy consumption (need, deliver, and primary) and CO_2 emissions of characteristically single-family houses in the City Derventa are higher in two construction periods (1981–1992 and 1992–2014) and lower in one construction period (1971–1988). Obviously, differences in energy consumption are mostly caused by the difference in the shape factor of characteristically single-family houses and less by the difference in the values of the U values of the envelope elements. These differences are not negligible, as shown in Figure 1, and amount from 21.27% in the case of energy need for heating (intermittent heating) and CO_2 emissions (construction period 1992–2014) up to 45.17% for the same parameters in the construction period 1981–1992.

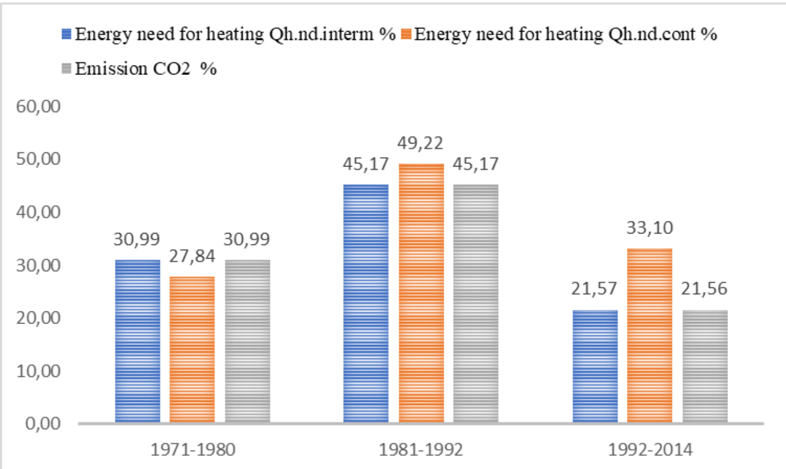


Figure 1. Difference in energy need for heating and emission CO_2 of single-family houses by different period of construction from the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina"

As already mentioned, energy calculations for all characteristic single-family houses in the City Derventa were performed using the same meteorological data as in the national typology. Taking into account that average monthly temperatures for the City Derventa prescribed by [14] are higher than those for the "North Zone," the identified difference in energy consumption (Figure 1) will be less expressed for the characteristic single-family houses in the construction periods 1981–1992 and 1992–2014 and more for the construction period 1971–1980.

The values of the heat transfer coefficient (U value) elements of the envelope of characteristically single-family houses and energy needs for heating after implementation of the first set of standard improvement measures are presented in Table 5. As can be seen from Table 5, the use of data from national typologies for the estimation of energy savings by implementation of the first set of standard improvement measures, instead of data from the local typology, would also lead to wrong estimations, although now these differences are much smaller and are in the range of 3.35% for the period of construction in 1992–2014 to 29.99% for the construction period 1971–1980. In this case, it is also important to stress that calculations with local meteorological data would cause the correction of the obtained results in the same way as already mentioned. At the City level, these differences will be further increased due to the differences in the surfaces of the characteristic single-family houses in different typologies.

Table 5. Heat transfer coefficient (U values) elements of envelope and specific energy need for heating (annual) of the characteristically single-family houses after implementation of the first set of standard improvement measures in the Typology of residential buildings in the City Derventa and the Typology of residential buildings in Bosnia and Herzegovina

Types	*Periods*	*Typology*	*U external wall*	*U windows*	*U floor construction to unheated attic*	*Specific energy need for heating $Q_{h,nd,interm}$ (annual)*
Building category	*Built in*		*W/(m²K)*	*W/(m²K)*	*W/(m²K)*	*kWh/(m²a)*
Single family houses (SH)	*1971-1980*	*Derventa*	*0.285*	*1.60*	*0.289*	*93.89*
		Bosnia and Herzegovina	*0.32*	*1.60*	*0.33*	*134.11*
	1981-1992	*Derventa*	*0.28*	*1.60*	*0.289*	*90.51*
		Bosnia and Herzegovina	*0.22*	*1.60*	*0.19*	*72.71*
	1992-2014	*Derventa*	*0.284*	*1.60*	*0.28*	*89.02*
		Bosnia and Herzegovina	*0.22*	*1.60*	*0.18*	*86.04*

3. CONCLUSION

In order to make correct estimates of energy consumption for heating in the residential building sector, reducing energy consumption and CO_2 emissions by applying energy efficiency measures in a municipality or city, but also at the entity and state level, it is necessary to know the structure and characteristics of the building stock as realistically as possible. Strategic planning is much easier if exist appropriate typologies of residential buildings at different levels. Conducted analyses show that if the data from the national typology in local communities were used, for the purposes of implementing energy efficiency measures, reducing emissions of CO_2, etc., in the case of single-family houses, it could lead to wrong estimates at the local level.

Table 4 and Figure 1 indicate, that the assessment of the energy characteristics of building stock at the municipality or city level, in the case of single-family houses should be based on local typologies (if they exist). Otherwise, the national typology can be used but taking into account its limitations caused by local characteristics of building stock.

Local typologies should also contain data about energy consumption calculated using local meteorological data. This would further improve the estimation of consumption and potential energy savings and, of course, cause additional differences between the calculated energies in local typologies and national typologies.

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APPLYING CONTEMPORARY PRINCIPLES FOR PRESERVING CULTURAL HERITAGE: A CASE STUDY OF THE MILITARY KITCHEN IN BELGRADE FORTRESS

Abstract

The main research problem relates to the possibilities of applying contemporary principles of cultural heritage preservation in practice. Its examination is the focus of teaching in cultural heritage preservation at the Faculty of Architecture in Belgrade. In the case study of the Military Kitchen within the Belgrade Fortress, and through the development of student conceptual solutions for its revitalisation, the possibilities for translating the guidelines for preserving cultural heritage from their theoretical to practical dimensions were examined. Designing sustainable solutions for the preservation and integration of cultural heritage in the contemporary context indicates real possibilities for the simultaneous respect of the preservation principles of cultural heritage and the fitting of contemporary architectural expression.

Keywords: cultural heritage, Belgrade fortress, Military Kitchen, contemporary principles

ПРИМЕНА САВРЕМЕНИХ ПРИНЦИПА ОЧУВАЊА КУЛТУРНОГ НАСЉЕЂА: СТУДИЈА СЛУЧАЈА ВОЈНЕ КУЈНЕ У ОКВИРУ БЕОГРАДСКЕ ТВРЂАВЕ

Сажетак

Главни истраживачки проблем односи се на могућности примјене савремених принципа очувања културног насљеђа у пракси. Његово испитивање у фокусу је наставе у области очувања културног насљеђа на Архитектонском факултету у Београду. На студији случаја Војне кујне у оквиру Београдске тврђаве, а кроз развој студентских идејних решења за њену ревитализацију, испитане су могућности за превођење смјерница за очување културног насљеђа из њихове теоријске у практичну димензију. Осмишљавање одрживих рјешења за очување и интегрисање културног насљеђа у савремени контекст, указује на реалне могућности за истовремено поштовање принципа очувања културног насљеђа и уклапање савременог архитектонског израза.

Кључне ријечи: културно насљеђе, Београдска тврђава, Војна кујна, савремени принципи

1. INTRODUCTION

1.1. DEVELOPMENT OF CONTEMPORARY PRINCIPLES ON THE PRESERVATION OF CULTURAL HERITAGE

Cultural heritage has been a subject of people's interest since ancient times, primarily through the relationship of generations to the past. However, it took many centuries to understand the need for the protection of cultural monuments and cultural heritage, and therefore, the formation of methodologies for an organised and more efficient approach to its preservation [1]. The gradual evolution in the approach to the protection of cultural heritage can be traced from the first half of the 20th century, which marked the development of international charters and organisations dealing with the protection, presentation and promotion of cultural heritage globally. The formation of organisations such as: The International Council on Monuments and Sites (ICOMOS), The United Nations Educational, Scientific and Cultural Organization (UNESCO), The International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM), Council of Europe, resulted in deepening awareness of the importance of preserving cultural heritage as well as in the formation of international documents, charters and declarations. The documents verified by these organisations provided important definitions of the term heritage and a set of principles for its preservation, which are still relevant and indispensable starting points for heritage research. Within the framework of documents, declarations and charters important for the study of cultural and natural heritage, the concepts of cultural and natural heritage, principles and guidelines for their protection, presentation and promotion in the contemporary context are defined, aligned with the imperative of preserving their natural and cultural-historical values. Also, globally recognised charters, declarations, conventions, and recommendations represent an attempt to transform the theoretical thought about the importance of cultural heritage preservation into its practical application in the process of cultural heritage restoration in the contemporary context. Accordingly, their study is a prerequisite for dealing with cultural and natural heritage in the contemporary context.

Taking into consideration the subject and problem of this research paper, which refers to the contemporary principles of revitalisation, presentation and promotion of cultural and natural heritage examined in the case study of the Military Kitchen within the Belgrade Fortress, the importance of studying the Landscape Convention from Florence [2], Charter of Cultural Routes from Quebec [3] and Document of Authenticity from Nara is especially emphasised [4]. Within these documents, the concepts of cultural and natural heritage, cultural landscape and cultural routes are more closely defined. Moreover, the potential of viewing cultural and natural heritage through the concept of protection, presentation and promotion of authenticity of cultural and natural heritage, as well as presentation and promotion of landscapes and cultural routes, due to which cultural and natural heritage is perceived as an inseparable part of the environment in which it is located, is displayed. The importance of studying cultural and natural heritage authenticity is especially highlighted by recognising the value of cultural and natural heritage that should be protected, presented and promoted in the contemporary context. According to the Document on Authenticity, authenticity encompasses the subject of trustworthiness of a particular source of information that can be linked to several attributes of the heritage source, from form to substance and other qualities [5]. The term authenticity thus defined indicates the complexity of authenticity as a quality of heritage, but also its significance in the process of preserving heritage, which requires a comprehensive overview of all its values - material and immaterial, but also a dedicated search for the truth that should be preserved, presented and promoted appropriately in the contemporary context. The importance of the Document is particularly emphasised when integrating contemporary architecture into spaces with pronounced natural and cultural-historical values, where the preservation of all existing cultural-historical layers, which built the identity of the cultural heritage over time and influenced its current state, is an imperative in the protection process, presentation and promotion of cultural heritage in the contemporary context [6].

Application and respect of the principles of protection, presentation and promotion of cultural and natural heritage defined in internationally recognised documents, charters and declarations, along with examination of the possibility of their implementation within projects of protection and revitalisation of natural and cultural heritage through contemporary architecture expression, represents a possible way for integration of natural and cultural heritage into contemporary trends, and for seeing them as an integral part of the space in which they are located, which is also sought through the case study of the Military Kitchen within the Belgrade Fortress.

2. DEVELOPMENT OF EDUCATION IN THE FIELD OF CULTURAL HERITAGE PRESERVATION AT THE FACULTY OF ARCHITECTURE IN BELGRADE

Within the University of Belgrade - Faculty of Architecture, special attention is paid to educating young colleagues and future architects about the importance of cultural heritage - its values, authenticity, and integrity, but also its potential in establishing sustainable development and improving the environment. Within the framework of the first-degree studies - Bachelor and Integrated academic studies of architecture, and through teaching in numerous compulsory courses in the field of history and theory of architecture and protection of cultural heritage - students, first of all, learn about the imposing world architectural heritage from different historical periods, from prehistory to the contemporary moment. Furthermore, students acquire basic knowledge about cultural heritage - its meaning and significance in relation to the contemporary context. Through the presentation and analysis of important internationally verified documents in the field of cultural heritage preservation defined by relevant organisations such as UNESCO, ICOMOS, ICCROM and the Council of Europe, students are introduced to the contemporary principles of cultural heritage protection and its adequate integration into the contemporary context. On the other hand, within the framework of the second-degree studies - at the Master's and Integrated academic studies of architecture and through numerous elective courses - students are enabled to expand and practically apply previously acquired theoretical knowledge about architectural heritage in the local context, using examples of cultural heritage in the Republic of Serbia.

It is precisely within the elective course Medieval Fortified Cities in Serbia that students in the first year of the Master's academic studies in architecture and the fourth year of Integrated academic studies in architecture can apply the previously acquired theoretical knowledge in the field of cultural heritage preservation practically, through the development of students' conceptual solutions for protection and revitalisation of the specific example of medieval cultural heritage in the Republic of Serbia. The selection of a case study that will represent a research ground for examining the alternative future of a medieval cultural monument is made in relation to factors:

- availability of relevant sources of information - archival material, literature and other;
- the current state of the cultural monument - the degree of its deterioration;
- accessibility to the cultural monument;

In addition to educating students about the importance of cultural heritage and the adequate application of contemporary principles for its preservation in the contemporary context, the main goal of the research within this elective course includes an examination of the possibility of preserving all the values of the cultural heritage, its authenticity and integrity while perceiving the cultural heritage as an integral part of the contemporary context and way of life. Special attention is devoted to examining the character of new contents and functions that should be incorporated into restoring cultural heritage, with the aim of better integration into the contemporary context and ensuring its survival for future generations. On the other hand, it is necessary to ensure that newly introduced contents and functions do not threaten the survival of inherited values. As a result, an important segment of work within the elective course represents the study of relevant documents and contemporary principles of cultural heritage preservation, which form the necessary theoretical basis for any action on cultural heritage in the practice of its preservation. Therefore, the research methodology within the elective course represents a combination of theoretical and practical research, divided into 5 main research phases:

- Presentation and analysis of relevant international documents, charters, declarations, conventions and contemporary principles of cultural heritage preservation;
- Analysis of successful examples of world architectural practice in the field of cultural heritage preservation in the contemporary context;
- Analysis of selected case studies of medieval cultural heritage in the territory of the Republic of Serbia - analysis of historical development, analysis of the urban, spatial, social, political, cultural and historical context, analysis of architectural and artistic characteristics, analysis of the current state and technical protection measures used so far;
- Development of students' conceptual solutions for the revitalisation of a selected case study of medieval cultural heritage as a representation of its alternative future;
- Valorisation of students' conceptual solutions in relation to the degree of success in simultaneously preserving all inherited values and integrating cultural monuments into contemporary trends;

based on which it can be determined to what extent it is possible to transform the theoretically defined guidelines for the preservation of cultural heritage into their practical dimension, with the simultaneous use of contemporary architectural expression and the introduction of new contents and functions aligned with the contemporary moment.

3. CASE STUDY OF THE MILITARY KITCHEN WITHIN THE BELGRADE FORTRESS

Considering the increasingly pronounced inadequate modern construction in the immediate vicinity of the Belgrade Fortress, recognised as a cultural monument whose values are endangered, the question of its protection, revitalisation, presentation and promotion presents the basis for its further life. Due to its imposing cultural-historical values, continuity of duration through different historical periods, and the availability of relevant sources of information about cultural heritage over time; the Belgrade Fortress was selected as an adequate testing ground for examining the possibility of protection and revitalisation of a cultural monument in the contemporary context.

3.1. THE POSITION AND IMPORTANCE OF THE BELGRADE FORTRESS IN THE CONTEMPORARY CONTEXT

Due to its exceptional geostrategic position and historical circumstances, Belgrade was created and developed over a broad period of almost two millennia. It thus influenced the history of European nations and states [7]. Its origin and development are primarily related to the area of the Belgrade Fortress, and today, it represents a complex and layered monument with more or less preserved material remains from all historical epochs and stages of development [8].

The new period of the Belgrade Fortress is linked to its rapid decline that began after the Second World War. The development paths of the modern city have led to rifts in the ramparts of the old Fortress and, thus, to the integrity of this monument. The new road cut through the Lower Town of the Belgrade Fortress, and the outer elements of the fortification were gradually covered with park areas [9]. Accordingly, the Belgrade Fortress finally lost its defensive significance, which led to the development of a new period in the life of this imposing space and a specific cultural monument adorned by the layering of heritage from all epochs of Belgrade's development. The layered nature of this monument was recognised by the Department for the Protection of Cultural Monuments within the Art Museum, and in 1946, a decision was made declaring the Belgrade Fortress [10] a cultural asset of exceptional importance and thus placed under legal protection. The beginning of systematic archaeological research was facilitated by declaring it a cultural asset of exceptional national and international importance. Starting in 1948, they are continuously carried out to this day, providing extensive data for evaluating and applying technical protection measures over the Belgrade Fortress.

The specificity of the Belgrade Fortress necessitated the application of concrete measures of technical protection and revitalisation on each part of the fortification and historical buildings [8]. The ways of using the Fortress as a whole, and within that, the purpose of individual buildings, were of great importance for solving the way of including this protected area in the urban structure of Belgrade. A crucial role in this was played by the park development that had already started, which spread from the area of Kalemegdan to the western part of Upper Town between the two world wars [11]. This process caused the Fortress with its fortification and park to be combined into an open-air historical park. The basic concept of the revitalisation and arrangement of this cultural monument was aimed at its presentation as a monument of the history of the city of Belgrade and as a city park area with accompanying sports and recreational facilities (Figure 1). The condition in which the remains were found, as well as general conservation principles based on the preservation of the integrity of the monument, dictated general approaches to the protection of the Belgrade Fortress. The problem of lack of space that would contribute to the revitalisation of the Belgrade Fortress by introducing contemporary content was one of the first tasks that the Institute for the Protection of Cultural Monuments of the City of Belgrade faced in the first decade of its work. As for this problem, the Institute has decided that revitalisation should be the primary goal because it greatly influences the conservation approach to the protection of this cultural monument. In other words, it was insisted that in defining the new purposes, the Belgrade Fortress's monumental properties should be considered. In this way, a symbiosis of the historical and contemporary life of the monument should be created.

Following the above-mentioned, the Institute proposed a program of future uses of certain parts of the Fortress, which primarily gravitate towards cultural-educational, catering, and sports-recreational content. A successful example of the revitalisation of the remains of the fortifications of the Belgrade Fortress is undoubtedly represented by the Despot's Tower, which has corresponded with its contemporary purpose as the Ruđer Bošković National Observatory for decades. The success of the revitalisation of the Despot's Tower indicated the well-established conditions in determining a new purpose for the monuments in the area of the Belgrade Fortress, which were foreseen by the Institute in the 1970s of the last century.

However, despite the well-planned contemporary contents of monuments and spaces, contemporary needs have caused some of the contents to exceed the anticipated capacities, which are conditioned by the existing remains, and the courts of the Basketball Club "Crvena Zvezda" and the Zoo are intended for relocation.

Figure 1. Appearance of Belgrade fortress
(Up: Belgrade fortress, link: https://shorturl.at/ekyz4 (10. 2. 2024); Down left: Appearance of the Upper town of Belgrade fortress link: https://shorturl.at/hqC58 (10. 2. 2024); Down right: Appearance of the Lower town of Belgrade fortress, https://shorturl.at/jqyMX (10. 2. 2024))

Among the recent successful works on the revitalisation of monuments within the Belgrade Fortress, the project "Revitalisation, conservation and reuse of the Nebojša Tower in the old part of Belgrade", which was carried out with the participation of the Faculty of Architecture in 2009 [12], certainly stands out. By reactivating Nebojša Tower as a museum space with a Congress centre, the development of potential and new contents within the Lower Town of the Belgrade Fortress was made possible. According to the above-mentioned, the Belgrade Fortress, with its imposing cultural and historical values and constant challenges in preserving and presenting its monumental properties, represents an ideal testing ground for examining the contemporary principles of protection and revitalisation in a contemporary context. Taking into account the contemporary theoretical understanding of cultural heritage as a non-renewable resource and one of the essential factors of sustainable development, we come to the point of view that it is necessary to re-evaluate the Belgrade Fortress with all the changes that are the results of decades of research, protection and revitalisation of discovered material remains from all eras of its development. Through ratified international conventions and charters, new values were established that opened the possibility of checking the existing valorisation based on the original state [8]. This was, first of all, stimulated by the recognition of intangible cultural heritage and a new category of heritage - cultural landscape, which caused a change in the interpretation of values from material to a combination of material and immaterial, i.e. values as the interaction of a man, nature and built space. Contemporary principles of protection and preservation of cultural heritage point out the necessity of redefining the area of the Belgrade Fortress as the city's historical core, which stems from changed and expanded understandings of values. Observing international recommendations and the importance of the Belgrade Fortress for the creation and development of the city, it is feasible to apply contemporary approaches in defining methodological procedures for its protection and revitalisation. Thus, the potential of this cultural monument would be used with the aim of its better integration into the structure and functions of the contemporary city.

3.2. ANALYSIS OF CULTURAL AND HISTORICAL VALUES OF MILITARY KITCHEN

On the ramparts of the Lower Town of the Belgrade Fortress, between the Gate of Carlo VI and the Nebojša Tower, there is a building of the former smelter, the Military Kitchen (Figure 2).

Information about the origin of this building is unknown. However, it was preserved until 1941, and information about its existence within the Lower Town of the Belgrade Fortress can be seen in only a few drawings and photographs. Professor Gligorije Elezović and architect Petar Popović gave the first information about the architectural dimensions and position of this building only in 1937. In their research, they indicated the existence of the Military Kitchen facility in the Lower Town as early as the first half of the 19th century, publishing two Turkish plans of the Belgrade Fortress where its dimensions could be seen. On those plans, this object was marked and called "Military Kitchen" [13]. During the first half of the 19th century, this building was used as a smelter, while in the second half of the century it was used as a kitchen.

Figure 2. The position of Military Kitchen within the Belgrade Fortress (link: https://www.beogradskatvrdjava.co.rs/wp-content/uploads/2014/07/Mapa-Beogradske-tvrdjave-i-Parka-Kalemegdan.jpg (29. 3. 2024))

At the beginning of the 20th century, large chimneys were demolished because modern cauldrons for cooking food were introduced. In place of those chimneys, new lower chimneys were built, which were demolished with the cessation of the kitchen function. In the last years before the Second World War, the Military Kitchen served as a horse barn and a car garage (Figure 3)[8].

The Military Kitchen building, in its original dimensions, remained undamaged during the First World War and until the beginning of the Second World War. On the other hand, other buildings in its vicinity were demolished. The demolition of the Military Kitchen began in 1941 during the occupation of Belgrade. The reason for the demolition was because it "damaged" the appearance of the new park in Lower Town. Of course, this decision could not stand in the way because of the lack of a law protecting historical monuments. However, the building was not completely demolished; it underwent certain changes. First, the multi-pitched roof and annexe of the building were demolished so that only the main body of the building remained, one facade, which is an integral part of the fortification ramparts. There were semicircular arched double doors and windows on the front facade wall, which still represent its architectural specificity today. According to these characteristics, it could be concluded that the Turks built this building after the Austrian occupation because the bricks of the Austrian format were used. Based on the above mentioned, it can be concluded that the Military Kitchen building, from its inception to the present day, has gone through several transformations that reflect changes in military, technological and social circumstances, which caused this building, that is part of the Belgrade Fortress, to be recognised as a cultural monument with exceptional cultural-historical and architectural values.

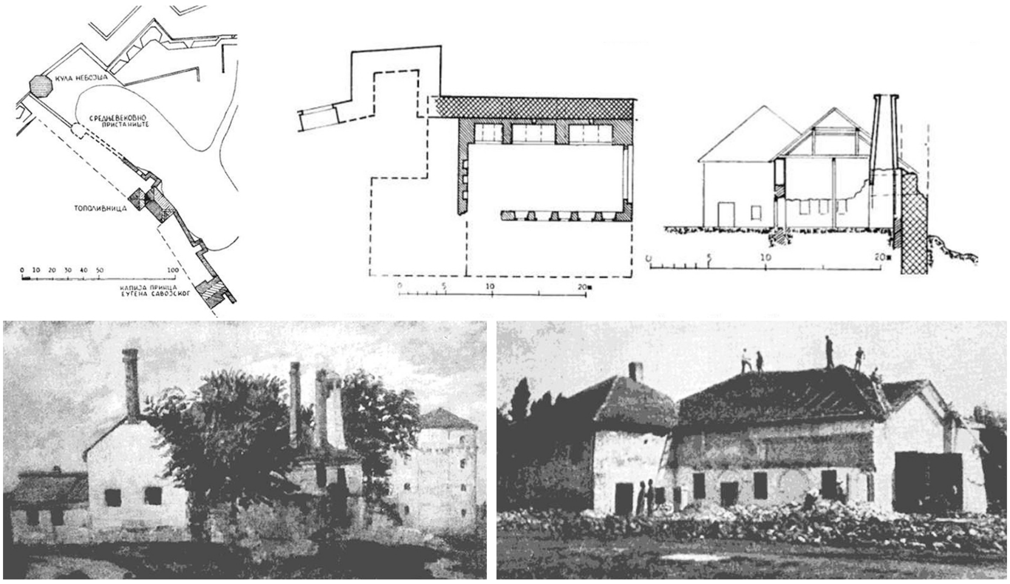

Figure 3. View of Military Kitchen from the first half of the XX Century (Up: Situation, Floor plan and Section, source: D. Jovanović, "Topolivnica Prvog srpskog ustanka", pp. 124 and pp. 128, 1955; Down: Views of Military Kitchen, source: D. Jovanović, "Topolivnica Prvog srpskog ustanka", pp. 123 and pp. 127, 1955)

3.3. ANALYSIS OF APPLIED TECHNICAL PROTECTION MEASURES

Although the Military Kitchen is an integral part of the Belgrade Fortress, it was in very bad condition until 1964, when conservation and restoration work began. The preservation of the Military Kitchen consisted mainly of conservation work with a partial restoration of the missing part of the front facade with openings. The conservation and restoration works on preserving the Military Kitchen took place in three stages. The works on the restoration of this building began in 1962, when the architectural recording started, which followed the analysis and identification of its structural condition. When photographing the building, serious damage was observed to the extensive walls, which were demolished to the ground level in some segments. Based on the data obtained from the architectural survey, a plan was established to implement technical protection measures that would enable the future life of this building. The first plan of preservation included the consolidation of the remains of the Military Kitchen and cleaning the area around the building. The plan first secured the southwest wall, leaning into the field, and therefore was in the most critical condition. In addition to the above-mentioned, according to the plan, conservation and restoration were carried out on the stone facade walls by adding the missing parts with bricks. The roof was made of wooden construction, four-gable covered with tiles [8]. However, although it can be said that the approach and plan for the preservation of this building conveyed an enviable level of respect for the authenticity and integrity of a monument, it must be pointed out that this plan made one mistake, which is reflected in the decision not to return three magnificent chimneys that were a significant and recognisable element of this building.

The last adaptation plan for this cultural monument was drawn up in 1971 and represents the state of the building today. The adaptation plan established hygienic and health conditions that enabled the placement of workspace within this facility to study and preserve archaeological artefacts found on the site. With the adaptation project, ventilation holes were very carefully implemented within the northwestern wall niches, representing the positions of the former chimneys that provided adequate conditions for preserving valuable artefacts. Today, in this building, which was intended for preserving artefacts according to the adaptation plan from 1971, there is a complementary content - the Centre for the Research of the Belgrade Fortress within the Archaeological Institute of SANU [14]. At present, all movable archaeological findings from the Belgrade Fortress, as well as all documentation and photographs of research works, are stored within this building. However, the revitalisation with exclusively scientific and research content has prevented its availability for visits and tours.

Figure 4. Current state of the Military Kitchen
(Up:Floor plan and Section, source: Documentation of The Cultural Heritage Protection Institute of the City of Belgrade (10.2.2024); Middle: Military Kitchen and itssurroundings, link: https://shorturl.at/rwKU7 (10.2.2024); Down left: The main Facade of Military Kitchen, link https://beogradskevesti.info/vojna-kuhinja-beogradska-tvrdjava/ (10.2.2024); Down right: Interior of Military Kitchen, link: https://shorturl.at/GVX59 (10.2.2024))

Based on the above-mentioned, it can be concluded that the Military Kitchen within the Belgrade Fortress is not only an architectural building but also a living monument that bears witness to both urbanism and social changes that influenced the development of a city's identity. Due to comprehensive efforts in protection and revitalisation, this monument is in good condition today (Figure 4). However, its purpose as the Research Centre of the Archaeological Institute prevents the presentation of its potential and historical significance within the Lower Town of the Belgrade Fortress. The proximity of the recently revitalised Nebojša Tower and the Congress Centre, as well as the Gate of Carlo VI, indicates that this object needs to be given a purpose that will activate and connect this space. According to the above-mentioned, it is necessary to revise the current purpose of the building, which, in addition to preserving the cultural heritage, would also enable its integration into the contemporary trends and needs of the users.

3.4. POSSIBILITIES OF PROTECTION AND REVITALISATION OF THE MILITARY KITCHEN - PRESENTATION OF STUDENTS' CONCEPTUAL SOLUTIONS

Through the development of students' conceptual solutions for the protection and revitalisation of the Military Kitchen building and its immediate surroundings, possibilities for an alternative future of an important cultural monument and an integral part of the Belgrade Fortress, which could be implemented in other spatial and programmatic segments of the Fortress, were explored. Special attention is directed towards finding the appropriate contemporary architectural expression and functions that would satisfy the needs of the contemporary way of life of the cultural monument but also preserve and adequately display all the found values of the cultural heritage. As part of the research on the elective course, two students' conceptual solutions particularly stood out, which, to the greatest extent, managed to find a compromise in establishing the relationship between the old and the new in the process of protection and revitalisation of the Military Kitchen. Their detailed presentation is described in the continuation of this paper.

3.4.1. GROUP 1 – MUSEUM OF MEDIEVAL FOOD

The project of students Olivera Pantelić, Milica Vujović, Jovana Stojević and Aleksa Marinski stood out due to their idea of recreating the space of the medieval market that once existed in the area of the Military Kitchen. The backbone of the project is the revitalisation of the Military Kitchen into a Museum of Medieval Food (Figure 5), and the surrounding area is arranged in such a way that it fits completely into the existing park environment. The specificity of the outdoor space design is reflected in the design of pavilion-type buildings, a kind of market stall that symbolically, but also spatially and programmatically - with their position, dimensions and function, recreate the former ambience of the market. On the other hand, these objects take on functions that align with the contemporary moment of their use, such as a souvenir shop, information desk, wine shop, sale of spices, sale of ceramic products and unique spaces for displaying medieval food and music. Moreover, the project envisages recreating the former position of the pier and restoring the pedestrian bridge over the existing remains through the design of the water surface - an artificial lake. Thus, the Lower Town of the Belgrade Fortress would get an additional ambient quality that would attract visitors to use it actively for recreation and walking in a dominantly natural environment.Another important element of the project presents its relationship with the remains of the Belgrade Fortress - ramparts, towers, Nebojša Tower and Gate of Carlo VI. The project envisages the entire stretch from the Gate of Carlo VI to the Nebojša Tower to be connected by the introduction of footbridges that would allow viewing of the remains of cultural heritage, but also an unhindered crossing over the traffic road that currently separates the Nebojša Tower from the rest of the Belgrade Fortress, disrupting the perception of the space as a unique spatial program unit. The students envisioned the conservation of the found remains of ramparts above which the footbridge stretched. In contrast, the remains of towers in the immediate vicinity of the Military Kitchen were restored and revitalised by the project into exhibition spaces with inserted vertical communications - panoramic elevators. Both the towers and the footbridge are designed in a contemporary architectural expression, using steel structures, perforated corten steel and glass (Figure 6). The Military Kitchen building itself was revitalised in such a way as to fully preserve its existing values and characteristics, including the existing dimensions of the building, positions and dimensions of facade openings, stone and brick facade cladding, roof design, positions of structural elements and vaults inside the building. On the other hand, new contents necessary for the functioning of the Museum of Medieval Food have been introduced into the interior of the building, such as an information desk, exhibition spaces, a presentation hall and a restaurant. All the newly introduced contents are designed using wood, steel, and glass as appropriate materials that clearly distinguish between the old and the new in protecting and revitalising cultural heritage. The specificity of the interior of the Military Kitchen presents a centrally placed fishing boat that points to the former purpose of the fish market and invites visitors to learn about the way of life and food in the area of the Belgrade Fortress in the Middle Ages through viewing the exhibition.

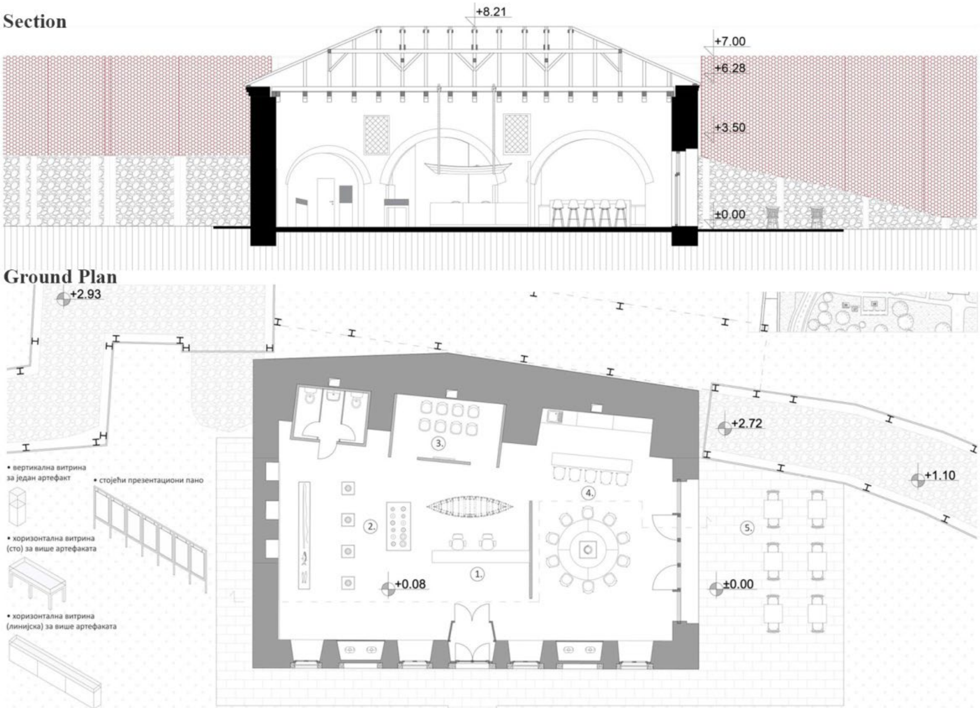

Figure 5. The Students' Proposal – Technical Drawings.
(authors: O. Pantelić, M. Vujović, J. Stojević, A. Marinski, 2024)

Figure 6. The Students' Proposal – Ambiental Views.
(authors: O. Pantelić, M. Vujović, J. Stojević, A. Marinski, 2024)

3.4.2. GROUP 2 – CULTURAL AND EDUCATIVE CENTRE

The project of students Jovana Ćirović, Tanja Radivojević, Marina Selenić and Nikola Ribarić stood out due to its contemporary architectural expression and integration with the existing character of the area of the Lower Town of the Belgrade Fortress. At the urban planning level, the project envisages the connection of different segments of the Belgrade Fortress into a single whole. By introducing a footbridge over the remains of ramparts and towers in the immediate vicinity of the Military Kitchen, the entire stretch from the Gate of Carlo VI to Nebojša Tower is connected to allow visitors to see different cultural and historical layers of the past (Figure 7). Furthermore, the footbridge is intended to solve the existing problem of the road that physically separates the Nebojša Tower from the rest of the Lower Town. In addition to introducing a footbridge processed in a combination of steel constructions and corten steel, new pedestrian paths were formed in the ground floor arrangement, activating the Military Kitchen's surrounding area. In the area of the former dock, the new paths plunge into a specific natural environment surrounded by water surfaces, which becomes a new area for outdoor exhibitions. The project envisages the conservation of the remains of ramparts and towers near the Military Kitchen, over which a footbridge will be formed for their viewing. A panoramic elevator has been placed in the position of the former tower, the height of which recreates the former volume of the tower and enables the vertical connection of the footbridge with the park area. The steel staircase forms another form of vertical communication between the footbridge and the ground floor (Figure 8).

The project's specificity presents the membrane encompassing the Military Kitchen building and places it in a glass volume. Its function is twofold - it protects the Military Kitchen building from atmospheric influences and other negative factors and forms a distinction between the inherited and new elements in the space. The membrane is designed in a combination of glass and steel elements of small dimensions, which forms a transparent effect in relation to the Military Kitchen building, which, together with corten steel walkways, panoramic elevators, and stone remains, becomes an example of the harmony of old and new in a culturally-historically and naturally challenging space (Figure 9). The Military Kitchen building was revitalised in such a way that all its found values were preserved and appropriately presented, including the existing materialisation, the building's volume, the position and dimensions of the facade openings, the roof, structural elements and vaults inside the building. The Military Kitchen became a cultural and educational centre that promoted the values of the Belgrade Fortress and the Military Kitchen in different periods of their development. The revitalisation project foresees the insertion of a gallery level, which increases the spatial capacity of the building. This type of intervention is feasible due to the great height of the Military Kitchen, so it doesn’t disturb its original dimensions. Newly introduced facilities include exhibition spaces of different characters - presentation rooms, audio--video zones, exhibition displays in combination with service areas, information desk and catering facilities - a restaurant in the glass membrane zone gets its extension as a winter garden.

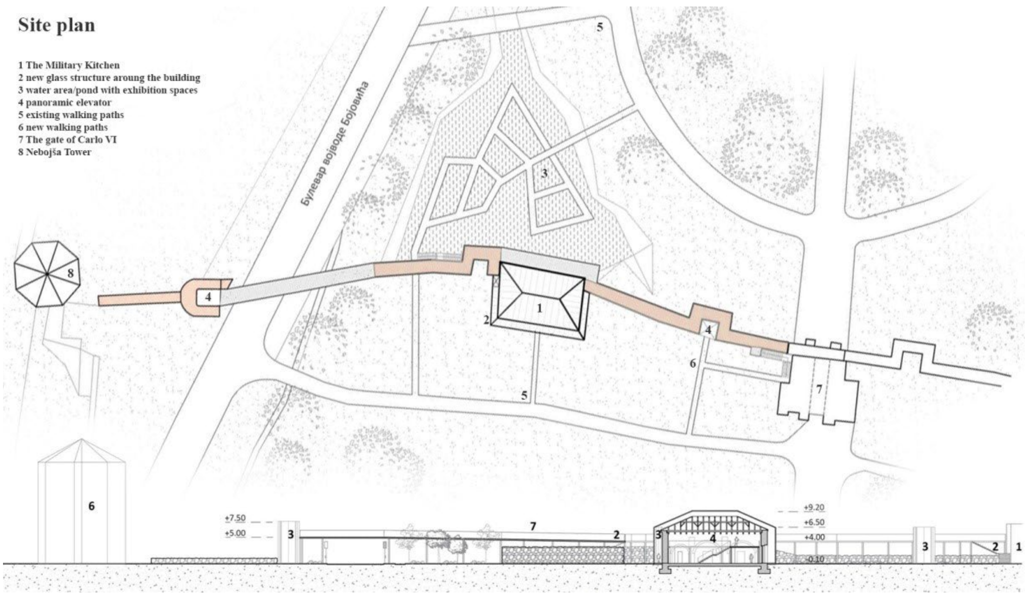

Figure 7. The Students’ Proposal – Site Plan.
(authors: J. Ćirović, T. Radivojević, M. Selenić, N. Ribarić, 2024)

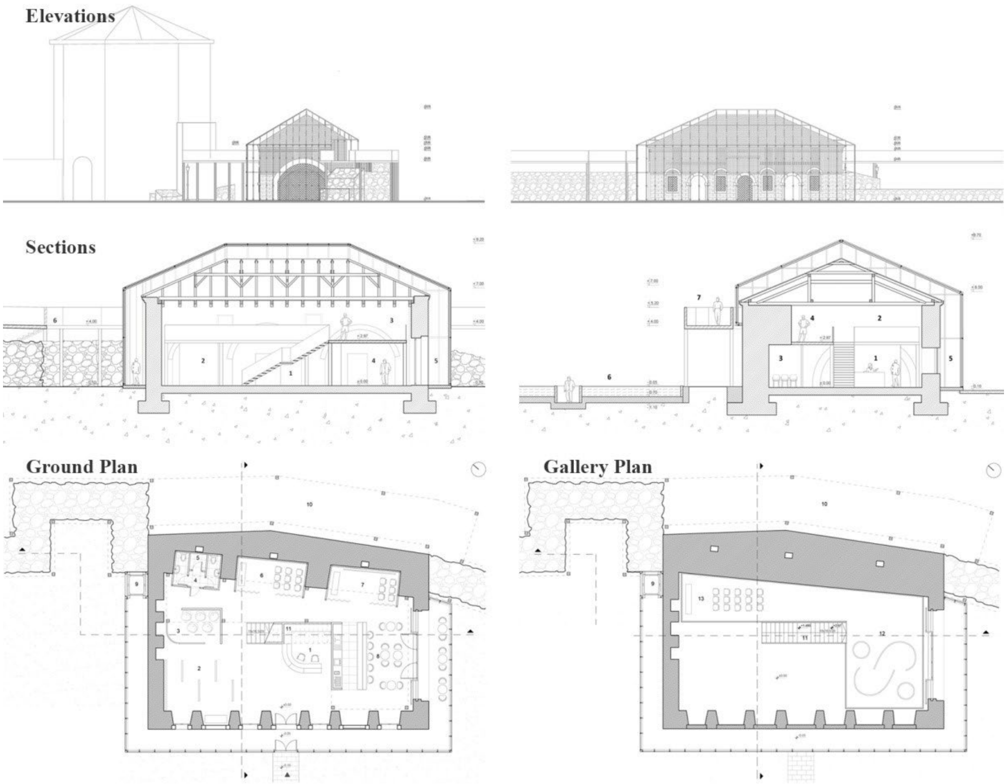

Figure 8. The Students' Proposal – Technical Drawings.
(authors: J. Ćirović, T. Radivojević, M. Selenić, N. Ribarić, 2024)

Figure 9. The Students' Proposal – Ambiental Views.
(authors: J. Ćirović, T. Radivojević, M. Selenić, N. Ribarić, 2024)

4. DISCUSSION

An important aspect of the research within the elective course refers to the critical analysis of projects for the protection and revitalisation of the Military Kitchen and its surroundings. Through the valorisation of students' conceptual solutions, it is possible to see to what extent the contemporary principles of preserving cultural heritage have been respected; the relationship between authentic remains, inherited values and contemporary architecture; the character of the new purposes and their relationship with the previous purpose of the object. Valorisation was carried out concerning a set of criteria. The fulfilment of these criteria within the projects indicates the students' awareness of the importance of applying contemporary principles of preserving cultural heritage and the necessity of introducing new content to integrate cultural monuments into the contemporary context better. The set of criteria includes:

- Preserving the authenticity of spatial organisation - preservation of the original organisation of the space, spatial program zones and communication positions;
- Preserving the authenticity of structural assembly - preservation and reuse of authentic structural elements (pillars, beams, walls, roof structures);
- Preserving the authenticity of stylistic features - preservation of authentic facade elements, dimensions of facade openings, decorative plastic (if any), and facade cladding;
- Preserving the ambience and spirit of the place - preservation of the previous purpose of the object or its presentation, preservation of all material and immaterial values of the object and its surroundings that participate in the formation of the spirit of the place;
- Introducing new purposes - refers to purposes that are complementary to the previous, which ensure the active use and survival of the cultural monument for future generations, and which do not impair the established values of the cultural monument;
- Applied materials and principles of sustainability - compatibility of new materials with authentic materials of cultural monuments, sustainability of applied materials and application of sustainable solutions that improve the quality of the environment;

Based on the valorisation of the students' conceptual solutions, it is observed that both projects fully respect the existing spatial characteristics of the cultural monument. Moreover, they successfully integrate new purposes from the domain of culture and education and connect them with the existing values of the object, its historical development and its way of use over time. When it comes to preserving the ambience and spirit of the place, both projects subtly incorporate contemporary architectural expression, spatially and visually separating the new architectural elements from the authentical. By introducing additional outdoor content, they improve the ambiental characteristics and the quality of the environment. The valorisation of both projects of protection and revitalisation of the Military Kitchen is thoroughly presented in the table below.

PROJECT	CRITERIA 1 *preserving* the authenticity of spatial organisation	CRITERIA 2 *preserving* the authenticity of structural assembly	CRITERIA 3 *preserving* the authenticity of stylistic features	CRITERIA 4 *preserving* the ambience and spirit of the place	CRITERIA 5 *introducing* new purposes	CRITERIA 6 *applied* materials & principles of sustainability
1	• the possitions of authentic walls • the possitions of current program zones • the relationship between outdoor/indoor space • the existing building's height	• protection of authentic constructive elements • reuse of authentic constructive elements • integration with new architectural and constructive elements	• the possitions of facade openings • the dimensions of facade openings • the existing slope roof	• preservation of the existing object's volume and materials • incorporation of the walking paths and elevators to activate the area around the building and connect it to its surroundings • reactivation of the market area	• exhibition areas • educational content (presentation areas) • comercial content (restaurant, gift shops, market stalls) • gathering areas (outdoor park design, water area)	• usage of authentic materials in combination with steel, corten steel, timber, glass • applied materials are reusable • outdoor space activation with water area and greenery improves the environment
2	• the possitions of authentic walls • the possitions of current program zones • the relationship between outdoor/indoor space • the existing building's height with introduction of the gallery plan	• protection of authentic constructive elements • reuse of authentic constructive elements • integration with new architectural and constructive elements	• the possitions of facade openings • the dimensions of facade openings • the existing slope roof • the introduction of new protective glass structure respects the existing stylistic features	• preservation of the existing object's volume and materials • incorporation of the walking paths and elevators to activate the area around the building and connect it to its surroundings • reactivation of the outdoor spaces	• exhibition areas (indoor and outdoor) • educational content (presentation areas) • comercial content (restaurant, gift shop) • gathering areas (outdoor park design, water area)	• usage of authentic materials in combination with corten steel & glass • applied materials are reusable • outdoor space activation with water area and greenery improves the environment

Figure 10. The Valorisation of Students' Proposals.
(authors: E. Takač, M. Nikolić, J. Šćekić, 2024)

5. CONCLUSION

The research methodology presented in this paper indicates the real possibilities for the implementation of theoretical principles and concepts in the practice of sustainable preservation of cultural heritage while at the same time preserving all its values and authenticity but also fitting contemporary architectural expression into spaces with pronounced cultural and historical values. Referring to the principles of international charters and conventions, the main goal of this paper is to spread knowledge about the possibilities of protection, revitalisation, presentation and promotion of the cultural heritage of the Belgrade Fortress with a focus on its integration into contemporary trends. The application and respect of the principles in the field of cultural heritage preservation defined in the framework of internationally recognised documents, charters and declarations, along with examining the possibility of their implementation within the framework of cultural heritage revitalisation projects through contemporary architectural expression, represents a possible way to integrate cultural heritage into contemporary trends, and perceiving them as an integral part of the space in which they are located, which is what is being sought through the case study of the Military Kitchen.

Through work on specific topics related to the research, valorisation, protection and revitalisation of cultural heritage as well as design in protected areas, the teaching process at the University of Belgrade - Faculty of Architecture enabled students of the Master's and Integrated studies of architecture, future architects, to see the problems and challenges in preservation of medieval monuments - their historical and urban context, developmental stages, cultural, urban and architectural values. A particular focus is directed to examining and comparing various possibilities for protecting and revitalising medieval monuments in the contemporary context and by introducing new, complementary contents harmonised with the contemporary use of buildings. The results of the research presented through the case study of the Military Kitchen within the Belgrade Fortress indicated the possibility of integrating contemporary architecture into spaces with pronounced cultural and historical values. The main task was to devise sustainable solutions that, on the one hand, would preserve the cultural and historical values, authenticity and integrity of the Military Kitchen within the Belgrade Fortress and, on the other hand, ensure its revitalisation and high-quality integration into the immediate urban environment, which has, despite the carelessness, preserved a recognisable historical ambience. In conceiving the future approach to the presentation and integration in the contemporary life of the Military Kitchen, the emphasis was placed on comprehensive research of its duration, from the time of its creation to the present time, and the discovery of specific cultural value and character that are the basis of its preservation in the future. According to the above-mentioned, the students, through their conceptual solutions for the revitalisation of the Military Kitchen and the Lower Town of the Belgrade Fortress, filled it with numerous contemporary cultural, educational and artistic contents that are connected with the character and importance of the place, enabling its active life in the future. This case study indicates that, in order to preserve a recognisable and authentic historical environment, it is necessary to incorporate international recommendations to a greater extent into the contemporary practice of protection and revitalisation of cultural heritage, with the aim of its adequate integration into the contemporary context.

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08
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ASSESSMENT OF THE QUALITY OF DESIGN OF POST-PANDEMIC MULTI-RESIDENTIAL BUILDINGS

Abstract

Covid-19 pandemic brought to surface the new requirements for urban life. These requirements do not only strengthen urban resilience but also improve the overall quality of living. By taking the City of Belgrade as an example, this paper aimed to research whether the multi-residential sector took a new post-pandemic developmental course by embedding specific quality-related spatial features into designed buildings. A set of 33 assessment criteria was introduced to evaluate the quality of projects of ten selected multi-residential buildings. Results point out significant differences among studied cases and the aspects of residential space, however there is an overall need to revise ongoing designing practice.

Keywords:urban living, Belgrade, design, criteria, assessment, ranking

ОЦЈЕНА КВАЛИТЕТА ПРОЈЕКАТА ПОСТ-ПАНДЕМИЈСКИХ ЗГРАДА ЗА ВИШЕПОРОДИЧНО СТАНОВАЊЕ

Сажетак

Ковид-19 пандемија изнијела је на површину нове захтјеве живота у граду који не само да јачају урбану отпорност већ и побољшавају укупан квалитет становања. Узимајући за примјер град Београд, овај рад је имао за циљ да истражи да ли је сектор вишепородичног становања заузео нови правац развоја након пандемије, уграђивањем у пројектоване зграде специфичних просторних карактеристика везаних за квалитет. У раду је уведен сет од 33 критеријума и на основу њих извршена оцјена квалитета 10 одабраних пројеката вишепородичних стамбених зграда. Резултати указују на значајне разлике међу проучаваним случајевима и аспектима стамбеног простора, али и на општу потребу за ревизијом текуће пројектантске праксе.

Кључне речи: градско становање, Београд, пројектовање, критетијуми, оцјена, рангирање

1. POST-PANDEMIC DESIGN GUIDELINES FOR MULTI-RESIDENTIAL BUILDINGS

Covid-19 crisis brought many challenges to conventional urban lifestyles and changed the understanding of the quality of urban life. With disease outburst, large proportions of central urban zones and metropolitan areas of cities developed in the late 20th and early 21st centuries demonstrated a lack of capacity to control virus transmission successfully. In the indoor space, especially in public circulation areas like lobbies and corridors, the proper ventilation, daylight, occupancy rate, materialization and hygiene became critical parameters for disease spread [1], [2], [3], [4]. In multi-residential buildings, a residential unit became an isolation healthcare unit, and a long time spent inside impacted the users by means of spatial characteristics [5], [6], [7] and the possibility to adapt to newly emerged needs for privacy, work, entertainment, exercising, socializing, and other [8].The impact of residential space on users' well-being and the quality of life during pandemic so became key topics exploited by numerous studies. Based on results of these studies, different sets of guidelines for the design of residential space that can better respond to potential future epidemics were developed, e.g., [1], [9], [10], [11]. Buildings possessing the pandemic-proof qualities – the co-called post-pandemic buildings – became synonyms of safety and health-related resilience. While many of the emerged guidelines bring multiple benefits, yet some are one-dimensional and exclusive to the prevention of infection spread, e.g., the introduction of specialized sanitary spatial barriers, installation of no-contact elevators, installation of materials that retard or stop pathogen growth [12], multipurpose modular furniture with surfaces that can be easily sanitized, and other. Next to the special descriptive guidelines, the first international model for systemic evaluation of building "immunity" – the Immune Building Standard [13] – was launched in 2021 to allow an organized assessment of pandemic-related building resilience and to enable comparison between different buildings.

Besides strengthening physical and mental resilience of residents' during an epidemic of an infectious disease [14], most Covid-19-related design guidelines for multi-residential buildings in parallel greatly enhance the quality of urban life, primarily in the domains of comfort and well-being. Table 1 features the comprehensive list of design guidelines and their targets to simultaneously enhance building immunity and the quality of everyday life in multi-residential buildings. All listed guidelines are grouped into two categories: I – Residential unit; and II – Common building space, according to the adopted research boundaries that overlap with physical boundaries of a multi-residential building, i.e., with its envelope. Generally, however, the significance of the features of the outdoor space surrounding a multi-residential building should not be underestimated, both in terms of pandemic-related resilience and the improvement of the quality of life [15], [16].

Table 1. Design guidelines and their targets to simultaneously enhance building immunity and the quality of life in multi-residential buildings.

Design guidelines	Impact on resilience strengthening	Impact on the quality-of-life upgrade
CATEGORY I (C.I) – RESIDENTIAL UNIT		
Clearly bordered and well-sized bedrooms	Decreased risk of disease transmission [2]; Enabled privacy during the lockdown periods; Various activities carried out at the same time without mutual disruption	Increase of the level of comfort, and multifunction
Flexible common living zone	Possibility of rapid transformation and adaptation to newly emerged residents' needs (e.g., work, playing, exercising, or studying)	Enriched spatial comfort and the long-lasting suitability to ever-changing users' needs
Clearly bordered entrance zone	Improves hygiene and serves as a sanitary buffer [5]	Improves hygiene and comfort in general
Separate and spacious kitchen	Better comfort when cooking at home is intensified; Kitchen used as one separate room [17]	Increase of spatial and air comfort
Increased number of bathrooms and toilets	Efficient physical distancing and self-isolation, and hygiene improvement [5]	Increase in the levels of comfort and hygiene

Separated work & study space	Undisturbed work and studying in parallel to other home activities [18]	Enhancement of the overall occupants' productivity and the use of on-line means of work and education; Comfort increase
Active use of semi-open private space (balconies) for multiple functions, enabled through adequate size and the dimensional ratio	Provision of direct connection with the outside; Possibility to mimic outdoor activities such as leisure, working, exercising, or dining [5], [19]	Provision of direct connection with the outside; Possibility to mimic outdoor activities such as leisure, working, exercising, or dining; Comfort increase
Semi-open space as an extension of common living area	Enrichment of the scenery of living zone; Psychological stress reduction [20]	Enhancement of spatial and visual comfort in a residential unit; Multifunctionality
Greenery integrated into private semi-open space	Benefits of direct contact with natural elements to psychological health and well-being [21], [22]	Benefits of direct contact with natural elements to good psychological health and well-being
Provision of acoustic insulation	Prevention of negative noise-induced psychological effect during long periods spent indoors	Enhancement of acoustic comfort
Cross ventilation	Improvement of the quality of indoor air by effective natural (passive) ventilation means	Improvement of the quality of indoor air; Improvement of air and thermal comfort
Naturally ventilated kitchen and sanitary rooms	Improvement of the quality of indoor air; Rooms naturally lit [5]	Improvement of the quality of indoor air; Improvement of visual, light and thermal comfort
Orientation of main rooms that allows direct sunlight exposure	Positive impact of direct sunlight on users' health and well-being; Improvement of spatial, visual and thermal comfort	Positive impact on users' health and well-being; Provision of passive heating; Improvement of spatial, visual and thermal comfort
The depth of residential space allows for efficient penetration of natural light	Positive impact of natural light on users' health and well-being; Improvement of spatial and visual comfort	Positive impact on users' health and well-being; Improvement of spatial and visual comfort
Views from windows provide rich visual contact with the outside (and especially with natural elements)	Good visual contact with surroundings strengthens mental resilience, reduces the feeling of isolation, and promotes well-being [23], [24], [25], [26]	Humane and healthy living environment; Improved visual comfort
Storage as a separate room	Provision of space for stocks during lockdown periods	Improvement of hygiene and spatial comfort
CATEGORY II (C.II) – COMMON INDOOR SPACE		
Shared indoor space for work, socialization, relaxation, or exercising	Cut need to mix in larger groups; Opportunity for residents to spend their free time in smaller groups; Provision of experience of social environment within the building system	Depending on needs of residents and the size of residential unit; Benefits to community strengthening
Greenery integrated into common indoor space	Benefits of direct contact with natural elements to psychological health and well-being; Improvement of the quality of indoor air	Benefits to good psychological health and well-being; Air comfort enhancement

Shared open green spaces within the building envelope (green roofs and green atria)	Promotion of good health and well-being by allowing safe direct contact with natural elements [27]	Humane, healthy and sociable living environment; Benefits to community strengthening
Increased size and number of common horizontal and vertical indoor communication elements (corridors, staircases and elevators)	Enabled larger physical distance [5] among building occupants; Crowding prevention; Better quality of the indoor air	Overall increase of building comfort

Covid-19 crisis revived the concept of healthy buildings, highlighted the importance of the topic of urban quality of life and resulted in new and for now informal requirements regarding the design of multi-residential buildings. Although, according to some authors, the effects of Covid-19 crisis on architectural design cannot yet be well perceived because it is too early [28], [29], the research question of this study is whether the incorporation of non-binding guidelines listed in Table 1 into current designing practice has begun, and if so, to what extent?

The work consists of four key parts, one of them being the derived and presented design guidelines (Section 1). Section 2 features the description of case study area (City of Belgrade, Serbia) and of ten selected multi-residential case studies from that area, as well as the explanation of applied methodology to evaluate selected case studies. Here, the list of 33 derived, widely applicable assessment criteria is given together with belonging indicators and the means of their verification. Obtained results were presented and discussed in Section 3. Finally, Section 4 summarizes conclusions and draws limitations as a basis of future research.

2. MATERIAL AND METHODS

2.1. TEN CASE EXAMPLES FROM BELGRADE, SERBIA

Metropolitan Belgrade is currently the largest construction site in Serbia, and multi-residential buildings stand out in the typology of newly constructed buildings. From total number of building permits for multi-residential buildings (with three or more residential units [30]) issued in the territory of the Republic of Serbia in 2023, about 25% refer to the metropolitan area of Belgrade. Likewise, from the total number of construction permits issued in the territory of the metropolitan Belgrade in 2023, about 26.16% refer to multi-residential buildings. 344 construction permits for multi-residential buildings were issues in Belgrade in 2023 [31].

For this research, ten examples of projects of multi-residential buildings whose construction is planned or initiated in Belgrade during 2023 were selected. From each of those ten buildings, one representative residential unit was subsequently chosen. Thus, the analysis encompasses ten residential units and ten multi-residential buildings where those units are placed.

At the time of research data collection, that is from December 2023 until February 2024, all selected projects were available at online portals of investors or the agencies that advertise the sale of residential units. The year 2023 was marked as relevant since the pandemic rate had already decreased at that time; on May 5, 2023, namely, the World Health Organization announced that Covid-19 no longer represents a global threat [32]. The three-year period from Covid-19 disease outbreak until 2023 was sufficient to gain experience, draw conclusions and shift the designing practice. This research aims to reveal whether the Covid-19-related lessons caused the shift in real-life architectural practice.

The requirements for case examples selection were the following:

- Availability of project documentation with details needed to carry out a comprehensive assessment of the quality of design;
- Size of residential units – ranging from 81-100 m^2 with balconies included – meaning larger units with a greater possibility for implementation of guidelines listed in Table 1. Given size range corresponds to national classification of units in multi-residential buildings, and is mainly used in statistical representations;
- Location of multi-residential buildings. To enable comparison, all examples selected are planned to be built in central parts of Belgrade, in densely built areas. Knowing that density

can be brought into connection with increased risk for an infectious disease transmission, the need to implement resilience- and quality of life-related design guidelines in central urban areas is generally valid. Intricate conditions in dense central zones and unsuitable ratio between design limitations and potentials require intelligent design responses and this study, to that end, aims to reveal and discuss the solutions found.

Having considered that all selected examples are currently available in the real estate market, their identification data such as exact location, design plans, or the name of the project will not be shown in the paper. That way, the authors secure objectivity and prevent any potential conflict of interest. Nevertheless, the complete research material is available in the authors' database.

The list of general characteristics of selected case examples of residential units, relevant for further research steps, is given in Table 2.

Table 2. Characteristics of ten selected case examples of residential units whose construction is planned or initiated in 2023 in central zones of Belgrade, Serbia

Designation	Position in the building layout	Floor in the building	Units per floor	Structure (Nº of bedrooms)	Size (m^2)	Estimated finalization	Price (EUR per m^2 without taxes)
CS1	Corner	2/9	7	2	86	2025	3.500
CS2	Central	12/21	6	3	84	2026	3.000
CS3	Corner	3/6	2	2	83	2025	4.000
CS4	Corner	10/20	16	2	87	2027	4.800
CS5	Corner	1/8	6	3	83	2025	3.000
CS6	Corner	1/5	5	3	87	2025	2.800
CS7	Central	2/10	10	3	97	2027	4.100
CS8	Corner	2/8	6	2	90	2027	3.300
CS9	Corner	4/7	4	2	97	2025	4.300
CS10	Corner	2/7	3	3	83	2025	2.700

2.2. ASSESSMENT METHODOLOGY

The methodology to evaluate application of guidelines for the design of multi-residential buildings is based on the definition of a list of criteria and associated indicators. All introduced criteria are derived from general guidelines shown in Table 1. For every assessment criterion, at least one measurable qualitative or quantitative indicator is offered (Table 3). Important to note, none of the derived and listed criteria currently stands in national regulations. Moreover, the criteria derived are stricter than national regulations and, in that sense, the list presented in Table 3 can be understood as a precursor of design rules to be established in future. Finally, the list of offered criteria can be understood as a newly proposed assessment system, a new design aid tool, or an auxiliary tool that buyers can use while making decisions as regards the purchase of their new residential space.

Table 3. Set of criteria to assess the application of design guidelines that simultaneously enhance resilience and improve the quality of urban life.

No	Criteria and indicators	Means of verification
C.I.1	Every bedroom is clearly separated from other parts of a residential unit by walls and a door. Where a bathroom is added to a bedroom, and both form one single zone that is clearly separated from other unit parts, the criterion will be considered fulfilled.	Yes/No
C.I.2	The size of bedrooms is at least 5% larger than the national minimum standard: • *2-person bedroom – min 11,00 m^2,* • *1-person bedroom – min 7,00 m^2.* Number of bedrooms whose size is larger at least 5% than minimally required (A) compared against total number of bedrooms (B) in a unit.	A/B x 100 %

C.I.3	The width of bedrooms is larger than given by the national minimum standard: • *210 cm for 1-person room,* • *240 cm for 2-person room,* • *At least one 2-person bedroom with 280 cm width.* Number of bedrooms whose width is at least 5 % larger than minimally required (A) compared against total number of bedrooms (B)in a unit.	A/B x 100 %
C.I.4	The common living zone of a residential unit features an open-plan space that can easily be reorganized and separated into subzones.	Yes/No
C.I.5	The entrance zone is clearly separated from other parts of a residential unit by walls and doors.	Yes/No
C.I.6	The kitchen is clearly separated from other parts of a residential unit by walls and door(s).	Yes/No
C.I.7	The size of kitchen space is larger than given by the national minimum standard (that is larger than *4,00 m^2*), and it amounts to at least 7 m^2.	Yes/No
C.I.8	The number of bathrooms equals the number of bedrooms.	Yes/No
C.I.9	There is at least one bathroom in the bedroom zone.	Yes/No
C.I.10	There is at least one toilet room in the common living zone of a residential unit.	Yes/No
C.I.11	There is a separate work & study room within the residential unit.	Yes/No
C.I.12	Residential unit has at least one balcony with the depth of not less than 1,50 meters to allow active space use.	Yes/No
C.I.13	The area of the unit's largest balcony is at least 7,00 m^2, which equals the size of a 1-person room as given by the national minimum standard.	Yes/No
C.I.14	There is a balcony that represents a physical and functional extension of the common living area of a residential unit with direct connection.	Yes/No
C.I.15	The balcony from criterion C.I.14 is the largest semi-open space within a residential unit.	Yes/No
C.I.16	Greenery is embedded into unit's semi-open spaces by design.	Yes/No
C.I.17	A residential unit is acoustically insulated from other units and the common indoor space.	Yes/No
C.I.18	The rooms within one residential unit are acoustically insulated from each other.	Yes/No
C.I.19	A residential unit has cross ventilation potential as its space leans on two opposite façade walls.	Yes/No
C.I.20	Kitchen space is ventilated naturally.	Yes/No
C.I.21	Number of naturally lit bathrooms and toilet rooms (A) compared against their total number (B).	A/B x 100 %
C.I.22	Living zone with dining space is oriented towards east, south-east, south, or south-west.	Yes/No
C.I.23	Number of bedrooms oriented towards east, south-east, south, or south-west (A) compared against their total number (B).	A/B x 100 %
C.I.24	There are no dark floor areas in the living zone. The distance from window openings to the farthest point of the floor does not exceed 6 meters in any direction.	Yes/No
C.I.25	Windows in main rooms provide far-reaching views to a street and/or common open space (Number of rooms with the far-reaching view to a street or open space (A) / total number of main rooms (B)).	A/B x 100 %
C.I.26	Windows in main rooms provide views to natural landscapes (Number of rooms with the view to a park / other open green areas / tree alleys / water bodies / other natural element (A) // total number of main rooms (B)).	A/B x 100 %
C.I.27	The residential unit has a separate storage room.	Yes/No
C.II.1	The plan of a multi-residential building features shared indoor space for at least one of the following functions: work, socialization, relaxation, or exercising.	Yes/No
C.II.2	Greenery is embedded into common indoor space by design.	Yes/No

C.II.3	The plan of a multi-residential building features open shared green space within the envelope (green roofs and/or atria).	Yes/No
C.II.4	There is more than one elevator per building entrance.	Yes/No
C.II.5	The width of staircase is at least 10% larger than minimally required by the national regulations *(120 cm)*.	Yes/No
C.II.6	The width of corridors is at least 10% larger than minimally required by the national regulations *(140 cm)*.	Yes/No

3. RESULTS AND DISCUSSION

The methodology presented in the previous section, together with the list of criteria for the assessment of the quality of design of post-pandemic multi-residential buildings, was applied to ten selected newly designed cases in Belgrade (CS1-CS10). The results of the analysis are given in Table 4.

Table 4. Assessed quality of design of ten new multi-residential buildings in Belgrade.

	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9	CS10
C.I.1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
C.I.2	50%	100%	100%	100%	100%	66,7%	100%	100%	100%	100%
C.I.3	50%	66,7%	50%	100%	66,7%	100%	33,3%	100%	100%	33,3%
C.I.4	No	No	Yes	Yes	No	No	No	Yes	No	No
C.I.5	No	No	Yes	No	No	No	No	No	No	No
C.I.6	No	No	No	No	No	No	No	No	No	No
C.I.7	No	Yes	Yes	N/A	N/A	No	N/A	Yes	Yes	N/A
C.I.8	No	No	No	Yes	No	No	No	Yes	No	No
C.I.9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
C.I.10	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
C.I.11	No	No	No	No	No	No	No	No	No	No
C.I.12	No	No	Yes	Yes	No	No	No	Yes	No	No
C.I.13	No	No	No	Yes	No	No	Yes	Yes	No	No
C.I.14	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
C.I.15	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
C.I.16	Yes	No	No	Yes	No	No	No	No	Yes	No
C.I.17	Yes	N/A	N/A	N/A	N/A	Yes	N/A	N/A	Yes	N/A
C.I.18	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C.I.19	No	No	No	No	No	No	Yes	No	No	Yes
C.I.20	Yes	Yes	Yes	No	No	No	No	No	No	No
C.I.21	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
C.I.22	Yes	No	Yes	Yes	No	No	No	Yes	Yes	No
C.I.23	100%	0%	100%	100%	33,3%	100%	66,7%	100%	100%	66,7%
C.I.24	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes
C.I.25	100%	100%	100%	100%	50%	25%	50%	33,3%	100%	100%
C.I.26	0%	0%	0%	100%	25%	100%	0%	100%	0%	50%
C.I.27	No	No	No	No	No	No	No	No	No	No
C.II.1	No	No	No	No	No	No	No	No	No	No
C.II.2	No	No	No	No	No	No	No	No	No	No
C.II.3	No	No	No	No	No	No	No	No	No	No
CII.4	Yes	Yes	No	Yes	No	No	N/A	Yes	No	No
C.II.5	No	Yes	No	No	No	No	N/A	No	No	No
C.II.6	No	No	Yes	No	No	No	N/A	Yes	Yes	No
N/A: Not applicable										

3.1. CATEGORY C.I – RESIDENTIAL UNIT

In every examined residential unit, all bedrooms are clearly separated from each other and from other unit parts by walls and a door. This finding, however, is not necessarily connected with the implementation of post Covid-19 design guidelines; it rather represents a reflection of regular architectural practice on a national level aimed at securing spatial comfort.

At least one bedroom in all examined cases is larger in size (m^2) for minimally 5% compared to prescribed national threshold, and in eight cases the size of all bedrooms is larger for at least 5% than minimally required. On the other hand, the width of bedrooms does not always comply with the size increase, which points to elongated bedroom plans and a more challenging organization of bedroom space. Even though at least one bedroom per residential unit has a width which is at least 5% larger than nationally required, only four analyzed units have the increased width of all bedrooms. There is a discrepancy between bedroom area and its width, and in two cases it is very pronounced. Looking at the cost of analyzed residential units, it can be concluded that the weakness detected occurs independently from the price of residential space.

While all ten studied residential units feature an open-plan concept of the common living zone, in only three units this zone could easily be reorganized and separated into subzones. The major constraint as regards identified spatial inflexibility is the lack of window openings in bordering walls, often in combination with the excessively elongated plans, which further prevents sufficient supply of natural light and the ventilation.

There are several examples of residential units where the entrance area is functionally well positioned and separated from key unit sections, yet in only one studied example the entrance zone physically indeed is separated by walls and doors. Other several examples feature a significant weakness: entrance zone here amalgamates with the kitchen and dining space, i.e., the bedroom area, most probably because of the design goal to reach as efficient size of communication area within a unit as possible. Another identified weakness in this respect refers to the large distance from the entrance to the first sanitary room, i.e. the bathroom. In none examined cases, worth to mention, the entrance zone has direct natural light and the ventilation.

Next to that, in none of the designed residential units the kitchen is clearly separated from other parts of a residential unit by walls and door(s). Even more, at a web portal where one of the studied units is being advertised for sale, the open plan of the kitchen is highlighted as a key positive feature. In several analyzed examples, though, the kitchen space has a potential (in terms of spatial position and the sufficient size) for future separation, however the lack of window openings to allow direct natural light and the ventilation would represent a limitation factor in such an adaptation-related action.

Having considered that in none of the studied residential units the kitchen space was found to be physically separated from the rest of a unit, the criterion C.I.7 could not be fully implemented. Only in those cases where kitchen represents a clear functional unit, its area could be accurately expressed. In other cases, kitchen space is integrated into living zone and the necessary surfaces are overlapping, most probably for the reason of designing a size-efficient layout. Therefore, the not applicable (N/A) mark in Table 4 refers to spatial weakness within this domain.

In only two studied cases the number of bathrooms equals the number of bedrooms. On the other hand, there is in all cases at least one bathroom per bedroom zone. Worth mentioning, in three cases the bedroom zone was dispersed because of which the access to bathroom from a distanced room was intersected by the day living area. Toilets in the common living zone of a residential unit exist in nine of ten cases in total. In some cases, these are the bathrooms, in fact.

Examined plans of residential units do not foresee the organization of work & study space as a separate physical whole. Instead, the workstation (desk and the chair) is mostly nested into a bedroom corner. Likely, this is the result of standard national designing practice and of existing norms where workspace is not given a lot of attention. Anyhow, the bedrooms can easily be converted into an autonomous work & study room if that suits the users' needs and the size of household.

All residential units have at least one balcony. However, in just three cases of newly designed residential units there is a balcony whose depth is larger than 1,50 meters to allow active space use. Most often, these semi-open spaces feature narrow and elongated plans. Likewise, the size of semi-open space of at least 7 m^2 is found in only three cases. In two out of ten studied residential units the balconies are larger than 7 m^2 and wider than 1,5 meters, which means that only two examples provide the possibility for active use of semi-open space.

In all cases, there exists a balcony that is adjacent to the common living area, although in some examples it is positioned laterally and not frontally. A balcony attached to the living zone is the largest semi-open space of the unit in all cases, but its size and width in eight out of ten cases are not sufficient to allow for active space use, as stated above.

Most 3-dimensional representations of studied multi-residential buildings feature greenery on facades, however in only three cases the greenery indeed is integrated into semi-open space of residential units by design. This integration refers to the vegetation pots built into the solid fence of a balcony.

While there are three units whose space is insulated acoustically from other adjacent units, there is just one residential unit whose space is acoustically insulated both from the outside and between encompassed rooms. In most cases, however, the data as regards applied acoustic insulation measures are not available in used web sources, and the subject criteria cannot be considered fully exploited, to that end.

Cross ventilation is generally known to impact the quality of indoor air significantly and positively, however in this study the potential for cross ventilation was found in only two units whose space leans on two opposite facade walls.

The kitchen space is naturally lit and ventilated in only three examples.

Neither one bathroom nor a toilet room from studied units is naturally lit and ventilated.

In 60% of studied examples, the living zone with dining space is oriented towards east, south-east, south, or south-west. In one case, neither the bedrooms nor the living zone have favorable orientation; in three cases the orientation of at least one bedroom is satisfying, while good orientation of all bedrooms is achieved in six cases (60%). In general, the orientation seem to be the consequence of existing conditions at the location, and it varies among the units within one same multi-residential building.

30% of residential units analyzed do not receive enough natural light in the living zone as distance from windows to the farthest floor point exceeds 6 meters.

The quality of window views significantly varies among examined residential units. While all units provide views to the materialized open urban space from at least one main room, there are 50% of units that do not offer views to natural landscapes. In one studied example only, the quality of views is rated high (100%) both in terms of materialized urban space and the natural landscape.

A separate storage room was not found in any of the studied residential units. In a few examples, however, the storage has been planned next to the garage space, or within the building entrance zone.

3.2. CATEGORY C.II – COMMON INDOOR SPACE

As regards the quality of common indoor space of multi-residential buildings where ten selected units are nested, the analysis resulted in scarce positive findings from all listed criteria.

Shared indoor space that would host at least one of the following residents' activities: work, socialization, relaxation, or exercising, was not found in any of the studied multi-residential buildings. On the other hand, more than half of studied buildings have the designed commercial space in the ground floor level. Though these premises may also be used by the residents of a building, they still do account for a public content and hence do not fulfil the criterion C.II.1. The exact purpose of the ground floor commercial content is not defined in the design stage. In one studied example, a common space for relaxation and exercising has been identified, however outside the building envelope which was marked as research boundary. Finally, in one example, the ground floor features the heritage remains and the corresponding activity program (education, arts and culture), yet this space is open to the public and not reserved for building users only.

The greenery is not integrated into flat roofs, atria, nor the common indoor space. Even more, the common indoor (communication) space lacks natural ventilation and light in most cases.

The installation of more than one elevator for in-building vertical communications was found in four out of ten examples. However, the width of staircase is larger than minimally required in only one case example, while the width of corridors is enlarged in comparison with minimal standard in three out of ten cases in total. Overall, there is an obvious lack of direct proportion between the number of residential units per building floor (i.e. the number of users per floor), and the width of staircase and corridors.

3.3. RANKINGS AND HIGHLIGHTS

Results presented in Table 4 allow to subsequently determine the percentage of fulfillment for every individual assessment criterion (Figure 1). Seven criteria were not met in any of the analyzed cases, and their percentage score hence equals 0%. On the opposite side, four out of 33 criteria in total were met in all cases (100% fulfillment). From the total number of 33 criteria, only ten were fulfilled in more than 50% of cases. Overall, it can be concluded that there exist more weaknesses than strengths when it comes to the quality of design of examined post-covid residential buildings as the number of criteria fulfilled in more than half of studied examples is lower than the number of criteria fulfilled in less than 50% of cases. It further means that there is an urgent need to advocate a more noticeable shift in design practice as regards multi-residential buildings.

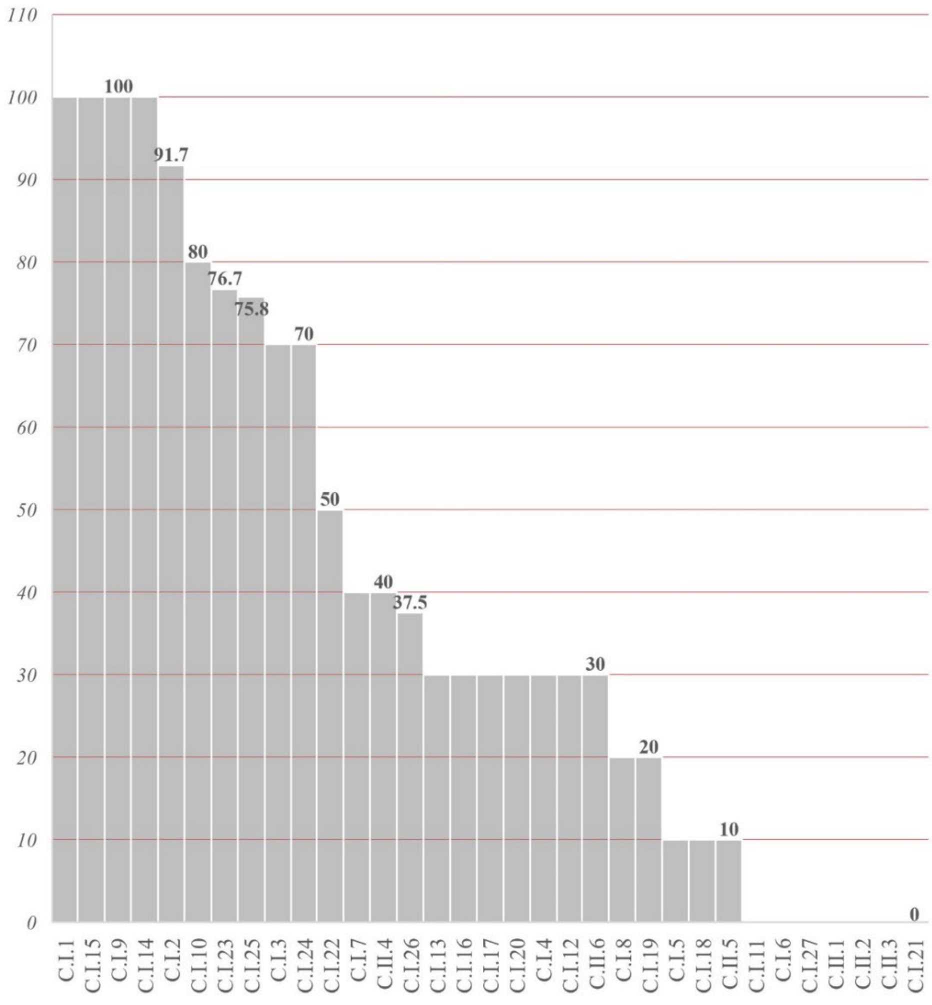

Figure 1. The percentage of assessment criteria fulfillment.

3.3.2. WEAKNESSES AND STRENGTHS

The results of evaluation in relation to the quality of design of ten selected residential units, and the buildings where those units are nested, point at seven most critical issues (Figure 1, 2). Furthermore, three assessment criteria were fulfilled in only one out of ten cases in total, hence the aspects encompassed by these criteria also represent significant weaknesses in the current design of multi-residential buildings. Finally, as two criteria were fulfilled in only two cases, they also account for major shortcomings in present-day design practice.

On the other hand, the analysis showed that studied multi-residential spaces nevertheless possess certain qualities. In that sense, clearly separated bedrooms (C.I.1), existence of at least one bathroom in bedroom zone (C.I.9) as well as the existence of a (largest-in-a-unit) balcony that represents a physical and functional extension of the common living area (C.I.14 and C.I.15) were found in all examined cases. Next to that, the increased size of bedrooms in comparison with national minimum standard was also commonly found (91,7%), followed by the existence of a toilet room in the common living area (80%), proper orientation of bedrooms (76.7%), provision of far-reaching window views (75.8%), increased bedroom width (70%), and sufficiently lit living zones (70% fulfillment).

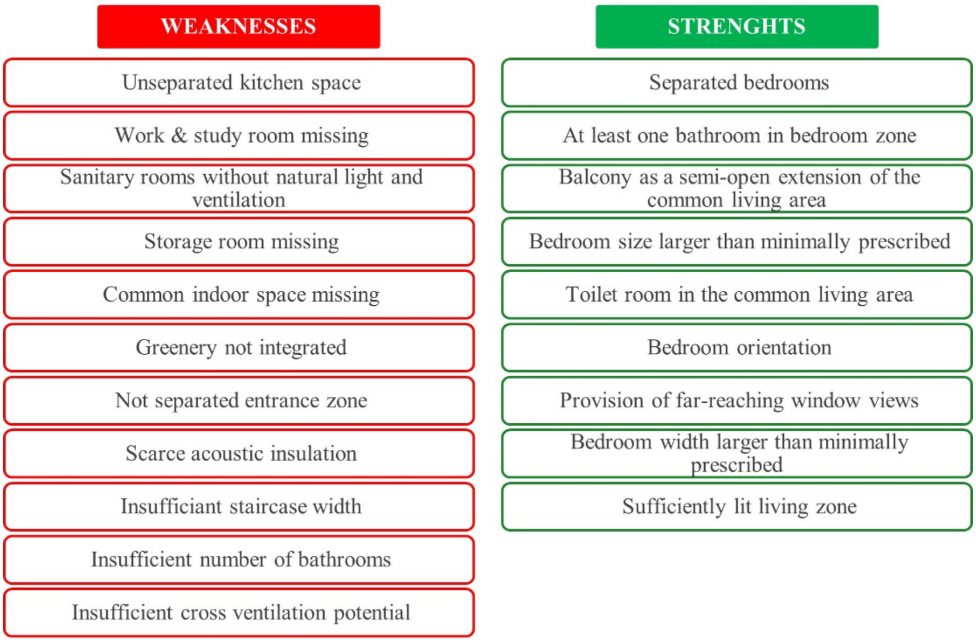

Figure 2. Most significant weaknesses and strengths of examined case studies.

3.3.3. COMPARISON OF CASE STUDIES

When mutually compared based on the percentage of criteria fulfillment, examined case studies show rather significant differences (Figure 3). The best ranked case example has a score of 55.55%, while the case with the least quality has a score of 26.52% criteria fulfillment. In only three examined examples, the score of criteria attainment is 50% or higher.

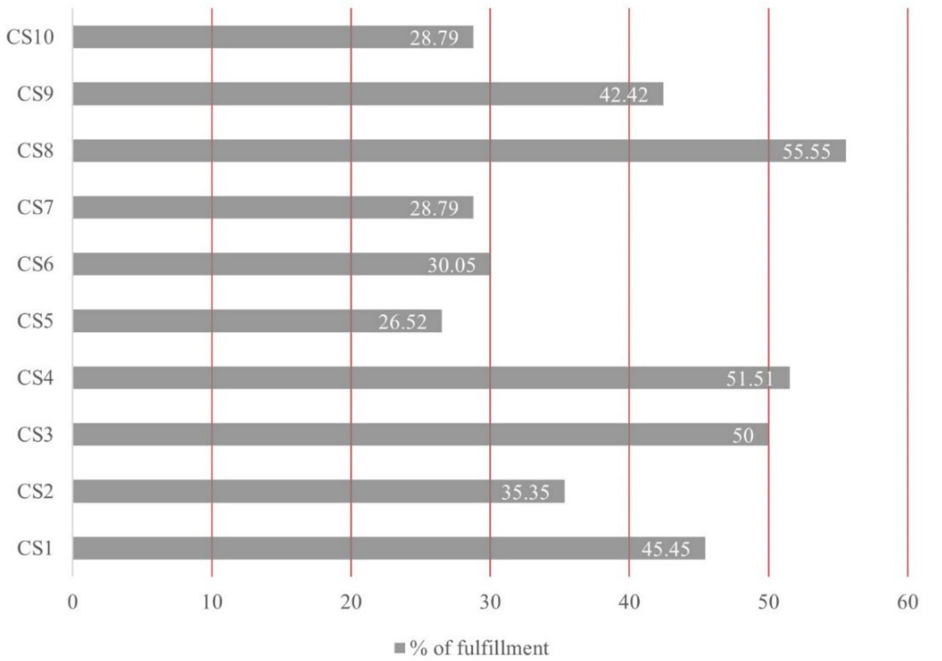

Figure 3. Comparison of the quality of design of examined case studies based on the percentage of criteria fulfillment.

Although this study did not introduce any threshold values, it may be concluded that the overall quality of design of examined post-covid multi-residential buildings in Belgrade is insufficient. The average percentage of criteria accomplishment amounts to 39.4%.

3.3.4. QUALITY VS. ECONOMIC VALUE

The final step in the analysis of selected case examples of residential units, and the buildings where these are nested, refers to the comparison between obtained quality and economic price (Figure 4). In 50% of cases, the economic and quality-related values are mutually balanced. In one studied case, the economic value significantly exceeds the quality of design, while in one other case the quality significantly exceeds the price. In three cases, the quality exceeds the price moderately. Overall, the ratio between the quality and price is favorable, however it should be noted that the study did not include calculation of economic value of applied criteria and has, instead, considered available market prices per square meter of a residential unit as given in Table 2.

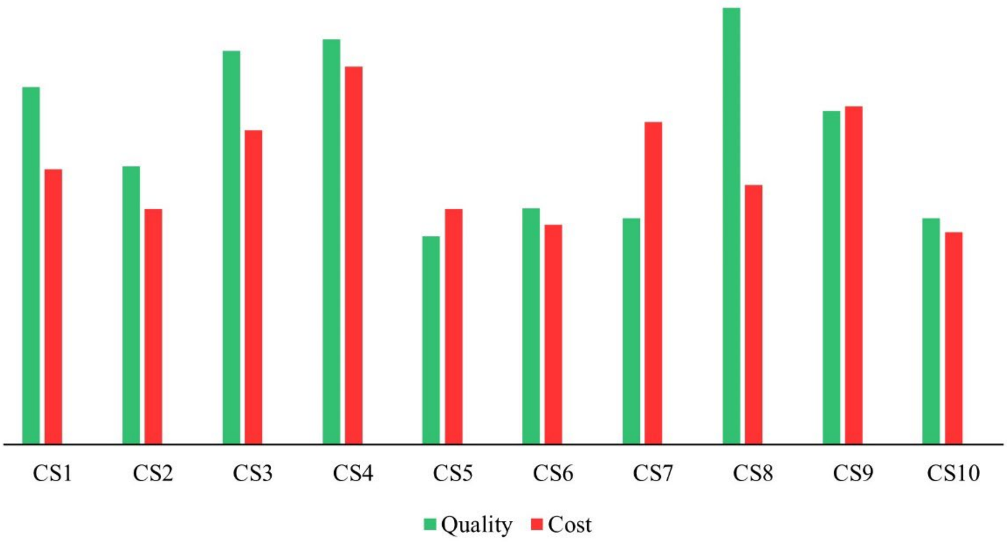

Figure 4. Comparison between quality and economic value of case studies.

4. CONCLUSIONS

On the example of the City of Belgrade, Serbia, this work pointed out the trends in current practice of multi-residential building design, and revealed the most significant strengths and weaknesses from quality-related perspective. The research developed a unique yet universally applicable methodology for assessing the quality of newly designed multi-residential buildings with 33 criteria, and brought a plentitude of relevant specific results. To improve existing characteristics of an urban residential space, the general conclusion is that a change in designing practice is necessary. With an increased number of fulfilled assessment criteria, the quality of everyday living and the well-being of residents will improve.

The study carried out, on the other hand, has several limitations that should be dealt with in further work. For example, as the boundary of research overlaps with building envelope, the assessment of external surrounding environment – which also is very important for achieving good quality – was not considered. Furthermore, it will be necessary to introduce into future studies a threshold of quality, thus, to determine which case units are not acceptable, and to calculate the weight of every individual criterion. Since in this study the assessment of quality refers only to projects and not to completed multi-residential buildings, it is necessary to further consider the implementation of a two-phase assessment, i.e. to include into research the quality of built space as well. Finally, considering that some specific data were not available, meaning that the criteria to which those data refer could not be applied, several results could actually be more positive than presented.

The most significant limitation concerning application of offered methodology, that is of criteria for quality assessment, concerns observed direct proportionality between the extent of fulfilled criteria and the size of living units in multi-residential buildings. In other words, more fulfilled criteria mean a larger size of a residential unit, and this correlation will inevitably affect the increase of economic price, too. In economies that are not sufficiently developed, a higher price is a limiting factor for the overall improvement of the quality of urban housing, i.e., a barrier to promoting social cohesion and establishing the market available to different categories of urban dwellers. To change current designing practice and achieve better quality of urban living space, therefore, it will be necessary to involve into an organized action not only designers but as well other local and state actors who influence the multi-residential sector.

In current Serbian housing policies, the quality of urban residential space is seldomly discussed, and its impact on users' wellbeing is not considered at all. Current regulations are limited to standards and requirements for minimal dimensioning of residential units [30], i.e. to the aspects of management, use and maintenance of multi-residential buildings [33]. National Law on Housing and the Maintenance of Buildings [33], however, adheres to the principle of sustainable housing development, recognizing a need to continuously enhance housing conditions and the value of housing fund. On urban design level, the Strategy Belgrade 2030 in its section "Urban Comfort and Mobility" acknowledges a change in perspective of urban dwellers following Covid-19 crisis, and proposes as a response to growing demand for a larger, greener and quieter living space the polycentric development of the city [34]. As partially recognized in the Draft of the National Housing Strategy [35], there is a necessity to further deepen the quality component of urban housing by developing precise and functional national and local policies and politics, and the capacities to enable their implementation.

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09
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BETWEEN URBAN RESISTANCE AND PARTICIPATION: THE CASE OF A CIVIL INITIATIVE FOR THE PRESERVATION OF OPEN PUBLIC SPACE IN BANJALUKA

Abstract

This paper deals with the role of urban activism and civil initiatives in the process of urban transformation of post-socialist cities. The aim of the paper is to underline the transformative potential of civil initiatives and the importance of activism as an informal tool for involving citizens in the decision-making process in urban planning. The case of a civil initiative for the preservation of open public space in a residential area in the center of the city of Banja Luka is presented. The case indicates the importance of informal and formal forms of organizing citizens to preserve the interests of the community. Finally, the paper indicates the presence of the conflicting participatory planning model and the need for the development of new planning tools with the aim of achieving more effective participation of citizens and social goals of the sustainable development of Banjaluka.

Keywords: urban activism, civil initiatives, participation, urban transformation, Banjaluka

ИЗМЕЂУ УРБАНОГ ОТПОРА И ПАРТИЦИПАЦИЈЕ: СЛУЧАЈ ЦИВИЛНЕ ИНИЦИЈАТИВЕ ЗА ОЧУВАЊЕ ОТВОРЕНОГ ЈАВНОГ ПРОСТОРА У БАЊОЈ ЛУЦИ

Сажетак

Рад се бави улогом урбаног активизма и цивилних иницијатива у процесу урбане трансформације постсоцијалистичких градова. Циљ рада је да нагласи трансформативни потенцијал цивилних иницијатива и значај активизма као неформалног алата укључивања грађана у процес одлучивања у урбаном планирању. У раду је приказан случај цивилне иницијативе за очување отвореног јавног простора у стамбеном насељу у центру града Бањалука. Примјер указује на значај неформалних и формалних облика организовања грађана за очување интереса заједнице. Коначно, рад указује на заступљеност конфликтног партиципативног планског модела, те на потребу за развојем нових планских алата с циљем постизања ефикасније партиципације грађана и друштвених циљева одрживог развоја Бање Луке.

Кључне ријечи: урбани активизам, цивилне иницијативе, партиципација, урбана трансформација, Бањалука

1. INTRODUCTION

The neoliberal competitive forms of urban growth and development consist primarily of attempts of cities to enhance their locality in the international competition for investors, advanced services, and megaprojects [1]. In literature, neoliberal urban development is qualified as a “growth-oriented by means of liberalization, deregulation and privatization of public goods and space and the outsourcing of public services” [2, p. 97]. Furthermore, neoliberal urban politics reduces public governance and participatory options of the civil society, raises serious questions about democratic legitimacy, and usually increases social polarization [2, p. 97].

In such conditions, different actors with diverse interests and level of social and political power shape and direct the planning of urban development. Seeking for competitive business environment cities worldwide fail to menage urban development effectively and preserve social justice and sustainability. In such uneven balance of power, needs of citizens are not recognized or are completely ignored, even in urban planning systems of democratically more developed societies. On the other hand, active participation of the public in decision-making process is of greatest importance for creating public values, achieving socially sustainable solutions and better quality of life in cities, and avoiding the failure of top-down urban planning approach. Many researchers agree that meaningful participation and community engagement, which foster a positive relationship between a government and a public in decision-making process are the imperatives of contemporary democratic society [3], and solution for key global problems [4]. When local authorities fail to manage urban development through the active participation of citizens, the phenomenon of urban activism and movements emerges to challenge neoliberal urban policies and their consequences [5]. Urban movements are considered institutionalized and permanent form of urban grassroots activism and are defined as “diverse network of organizations and social groups involved in the process of spatial planning and urban policy making, often outside the formal institutional framework” [6, p. 188]. In developed civil societies urban movements are important actor in urban planning process. Urban civil society, which includes the private sector, community-based organizations, associations and non-governmental organizations, is willing to participate in urban planning and make interests of the *weak* and *strong* public more balanced.

The alignment of interests, stakeholder collaboration and efficacy of public participation are particularly challenging in urban planning system of post-socialist non-EU countries with less developed civil society. In these countries democratic principles are more slowly adopted and the transition to a democratized open-market society is still ongoing due to war in 1990's and isolation on the global scene. Post-socialist urban planning has been influenced by a slow transition from protected and highly directed economies to systems based on competition, international trade, and free markets [7]. Also, local governments have acquired wider administrative responsibilities and a new political importance due to decentralization, what has reinforced the political power of new political elites and business interests [7, p. 2]. The reduced role of the state in the economic system, the established capitalist principles of private ownership and market-lead economy have significantly influenced changes in the management of urban development, which is mainly driven by short-term goals and private interests. The main development directions are defined by partial area plans, which are “easily modified without extensive legal wrangling to suit the aspirations of any private developer” [8, p. 76]. The emerging practice of developers is based on strict profit principles that are usually opposed to proclaimed public interests and “usually do not take care of social justice requirements, subject to which all citizens are entitled to have an access to basic urban services and resources and to enjoy a good quality urban environment“ [9, p. 49]. In these conditions, top-down approach to citizens’ participation, regulated by law, is applied in urban planning. This approach lacks mechanisms that provide greater citizens engagement and give equal chances to all citizens. Besides, decision-makers are neither motivated to accept participation as method for better governance nor skilled enough to implement it [4]. Involved citizens are just mere passive participants without being able to affect any planning decision. This often results in the emergence of urban activism and urban movements against imposed planning solutions. In post-socialist context urban movements are not developed as mass scale actions engaged in protests or mobilized around political or social issues, but small-scale actions that tend to directly influence changes in urban development and improve the quality of the urban environment. Also, informal forms of activism are the most common in implementation of policies of urban development. However, over the years of social, political and economic transition various forms of movements emerged such as: organizations from former socialist regime, non-governmental organizations, local grassroots activism and mobilization through the social network [10]. Some actions initiated as local neighborhood activities over the time develop into a formal organization dealing with local problems. Majority of actions are developed as reactive, but this trend has changed in last decade and urban movements are becoming more proactive gaining important role in formal urban planning.

Despite many different forms of urban activism emerging in post-socialist cities, the phenomena of civil society, urban activism and movements have not been significantly researched in literature, and especially in one that refers to non-EU cities. The focus of previous research is on social, political and cultural aspect of urban activism and its role in dynamics of civil society [1], [5], while the role of in(formal) activism in dynamics of urban development and transformation remains neglected. This paper deals with the transformative potential of civil initiatives in the process of urban planning and transformation of post-socialist cities. The aim of the paper is to provide new understanding of the role of civil initiatives in urban development projects based on their attributes and effectiveness of their actions.

The paper is structured as follows. First, theoretical framework for studying civil society, urban activism and movements and participation in urban planning process is presented. Then, based on these theories new theoretical model of understanding the phenomenon of civil initiative and its role in urban planning process is developed. Further, contemporary trends and tendencies in urban planning of Banjaluka are analyzed, including formalized practices of participation and emerging urban resistance movements. This is followed by the case study of civil initiative for preservation and transformation of open public space in Banjaluka. The qualitative analysis was backed by the collection of data on activities of civil initiative and proposed visions of development. This includes data from the civil initiative websites, social media posts and blogs, articles in local newspapers in addition to data obtained directly from members of social movements during the meetings. This initiative is an example of successful self-organization of citizens which has transformative potential in the process of urban development and thus becomes new informal partner of city authorities in urban planning of Banjaluka.

2. URBAN ACTIVISM IN POST-SOCIALIST URBAN DEVELOPMENT

Much research advocates the idea that urban activism has played an important role in the development of civil society in post-socialist cities of Central and Eastern Europe. The rise of urban activism in post-socialist cities has been related to the restructuring of civil society and empowerment of citizens in process of transition towards democracy. Various formal and informal groups, urban movements and organizations are organized to preform collective actions to promote quality of urban environment and sustainable urban development in neoliberal economy.

Dealing with the role of urban activism in shaping urban governance Bitušíková [11] focuses on relations among different local civil society actors, such as urban activist and local non-profit organizations that act as important catalyst of citizen engagement in the cities. The same author concludes that urban activism and urban movements in Central and Eastern Europe have been undergoing development with diversity of forms of actions and improved interaction and collaboration among actors, which results in increased citizen interest and participation in urban initiatives contributing to the changes of urban governance [11, p. 220].

Theoretical approaches in contemporary debate about post-socialist civil society refer to either the new opportunities of the post-socialist present or the remaining effects of the communist past on the transition towards democracy. Much research mainly focuses on formal and non-governmental organizations rather than informal activism and grassroots organizations. However, civil society is defined as weak, meaning that it lacks power to promote and improve citizen engagement and mobilization in public affair as well as at the grassroots level [11]. Similarly, Howard [12] argues that post-communist civil society is distinctively weak, characterized by low level of organizational membership and participation by ordinary citizens. Making research on collective pattern of (non)participation in voluntary organizations throughout post-communist Europe, Howard infers that variations in weakness among countries are relatively small. The same author discusses three main causal factors which back his main assumption about weakness of civil society in post-communist countries. The first one refers to mistrust of citizens in organizations even when participation is voluntary. Second, many people find private and informal networks, that developed under communism and persist today in new institutional environment, discouraging to join formal organizations. Finally, the disappointment of post-communist citizens with the new political and economic system, which has not lived up to their hopes and ideals, caused them to withdraw from public activities. All three factors involve experiential reinterpretations of people's past experiences within newly constituted institutions and have a negative effect on membership and participation in voluntary organizations [12, p. 10]. Besides, a state and economic system are the main elements of communist experience and its lasting effects. The main hypothesis is that a strong, active, and supportive state encourages the development of civil society. Considering many political turmoil and widespread corruption in branches of government in post-communist context, it is evident that state has not provided the necessary resources and support for civil society. Another prerequisite of strong civil society is a stable and functioning economic system, which enhances the material well-being of citizens. It implies that economic uncertainty and chaos, that have even increased since the collapse of communism, influence the weakness of civil society of post-communist countries [12].

On the other hand, the weakness of civil society has been challenged by other researchers arguing that organizational membership is not the only aspect of citizen engagement in post socialist cities [13]. Petrowa and Tarrow [13] indicate the significance of the level and frequency of citizen participation and the type of engagement in public politics. Besides, Císař [14] clarifies the main rationale behind the phenomenon of low level of civic participation asserting that collective actions remained associated with communist system since previous regime relied strongly on political mobilization. Also, political freedom, as the main paradigm of post-communist society, is not understood as an opportunity to express social needs and participate in politics, but as an idea of freedom from politics [14].

Besides participatory activism that might be qualified as weak, other types of activism are present in post-socialist context literature: transactional activism (advocacy-based activism focused on inter-organizational networking), radicalism (extra-institutional activism) and civic self-organization (organization- independent and episodic) [15, p. 199]. Similarly, Bitušíková recognizes two main categories of urban activism: “a) formal organizations and movement, or organized or semi-organized groups, organizations and movements with proactive strategies aimed at strengthening social capital by supporting citizen participation in various areas of urban development; and b) informal and ad hoc movements and initiatives, or protests and pressure groups and initiatives that mobilize citizens in the city’s public spaces against neoliberal politics, mainly through opposition to new construction and development projects with the aim of protecting urban heritage” [11, p. 226]. Arguing that with the emergence of urban activism a stronger civil society is developed, Císař [16] notes that civic self-organization, as a way of citizen mobilization without formal organizations, is considered the most common type of activism in post-socialist cities of Central and Eastern Europe. The informal and spontaneous self-organized urban grassroots activism arises in response to urban policy measures and manifests itself in proactive or reactive community initiatives, protest and petitions to protect public spaces, green areas or heritage sites [11, p. 222]. Collective mobilizations around the resistance activities and movement are organized by dedicated individuals. Mobilizations tend to be numerous and small with protests and non-violent demonstrations as main actions. These informal movements challenge the city authorities’ non- transparent decision making in the sale of public property to private investors and aim to stop new development that would jeopardize public space and interests.

3. THE WEAKNESS OF PARTICIPATION IN POST-SOCIALIST URBAN PLANNING

Meaningful and efficient participation and civil engagement in decision-making process which protect public interests are important imperatives of contemporary democratic society [17] Participation is considered a cornerstone of democracy and a fundamental way to empower citizens. Public participation in urban planning refers to the direct involvement of citizens in compiling plans and shaping urban environment that might affect them [3, p. 3]. Very similar term mentioned in literature is community participation described as a means for creating opportunities that unable people in a community to influence and shape development processes [18].

The participation of the public in urban planning is mainly rooted in the concept of constructive dialogue and consensus building [19]. Due to the involvement of many actors with diverse interests, such as citizens, profit and non-profit organizations, planners, public administrators and private entities, the conflict is inevitable part of the urban planning process [20] [21]. On the other side, participatory planning approach makes use of its stakeholders’ knowledge, resources, and commitment [4]. The most common mechanisms and tools of participation in planning are different activities such as civil debate and communication, consultations, activities division, partnership, esc.

The level of citizen participation in urban planning and extent of citizens’ power in determining the plan have been thoroughly explained by Arnstein’s [22] concept of eight-rung ladder which distinguishes gradations of citizen participation. At the nonparticipation level (manipulation and therapy rungs), people have no influence in decision-making process and are "cured" and "educated" by powerholders. The medium level of participation refers to the informing and consultation in which people are allowed to hear and to be heard, but again without any possibility of intervening, and placation in which members of the public are allowed to advice, but the powerholders retain the continued right to decide. At the highest level of participation citizens are awarded different degrees of power which is distributed through the collaboration between public and powerholders. Citizens can either enter a partnership with powerholders that enable them to negotiate or obtain the most of or full managerial power. Similarly, Anokye [23] defines different participative approaches to planning such as: a) transformative approach in which bottom-up strategies for information flow are used and public is allowed to be significantly and powerfully involved; b) instrumental approach which advocates for the top-down communication with no effort for consensus building; and c) mix of the two previous approaches. However, which approach is to be applied in planning system depends on socio-cultural, economic, situational, and developmental factors [23], whereby socio-cultural factors are considered the most important in affecting an individual's willingness to participate.

The theory and practice of participation in urban planning of post-socialist countries have gained attention mainly in the framework of EU accession process and urban planning requirements imposed by the EU funds. The great legacy of post-socialist countries is the lack of participation and top-down planning approach. Besides, some authors claim that weak participation or non-participation is positively corelated with economic development which is lower in post-socialist countries [24]. Given this, the question of participation becomes more challenging in non-EU countries with less developed democracy and economies. The position of citizens is weak in triangle of business, authorities and politicians, and citizens [25]. Citizens are formally involved in planning process but are essentially passive participants who only provide data and information and have no influence on decision-making. The reason for this tokenism level of participation lies in strong legacy of socialism in which social equality, collectivism and economic prosperity were main paradigm of development, while political freedom was not advocated. Unfamiliarity with democracy is the socio-cultural factor that mostly affects the civil engagement and participation in development projects. Nevertheless, results of the studies conducted in post-socialist countries indicate that the extend of the weak participation has started to change gradually and that more interest groups have been represented in planning process [25, p. 716]. In Arnstein's terminology this is understood as climbing the ladders. Participation is present at the level of non-government organizations and civil initiative activities [26]. According to Maier, the process of strengthening the participatory planning is two-dimensional. The first dimension refers to gaining recognition of "weaker" participants, while the other refers to the changing of the power relations. The same author concludes that the effective participatory approach is learning prosses for all interest groups, and it implies combination of bottom-up and top-down initiative [25, p. 716]. In situations when weaker participants are not recognized as important urban actors, urban movements as form of resistance against imposed plans are emerging.

4. THE ROLE OF THE CIVIL INITIATIVES IN URBAN PLANNING AND TRANSFORMATION

Based on the theoretical framework of urban activism and participation in post-socialist urban planning and development the new theoretical model of understanding the phenomenon of civil initiative and its role in urban planning is developed. The model is based on defined attributes of civil initiative that could affect goals of its actions and results of urban planning process. The initiatives with more success have transformative potential, while the ones with less success may have partial or zero potential. Relating the attributes of the initiative with its results gives the possibility of identifying the key attributes which contribute to its transformative potential. The attributes of civil initiatives are explained in the text that follows.

Structure of actors and their collaboration. There is a great diversity of actors which makes the organization of civil initiative complex. Actors can be individuals, citizens, communities, non-governmental organizations, educational organizations, private sector organizations, etc., and are guided by some rules of internal coordination in formal and informal structures. For the initiative to be effective, members should be consistent and cohesive, and share the same aims and support each other in the group. Fixed organizational structure provides clear communication channels and reduces fears of losing independence and transparency. However, the challenge that initiatives often face is constant changing of active members over time because of the long-time dimension of initiatives and not receiving financial benefit for the engagement. Besides, very often none of the members is expert in urban planning and management field which makes it difficult to manage the activities of the initiative.

Structure of organization. The way citizens are mobilized affects the structure of organization of civil initiative. Self-organization, as a way of citizen mobilization, is considered the most common type of activism in post-socialist cities in which local actors, confronted with local government decisions, make a collective action against imposed planning solutions. The autonomy of self-organized initiative is based on the free self-rule of the society. That is the reason why self-organized initiatives attract more members and have a lower risk of co-optation by decision makers. The other way of citizen mobilization is implemented through formal organizations and movements or organized or semi-organized groups. Eventually, as it grows over time self-organized initiative might develop into a formal form of action.

Number of actors. Number of actors involved in an initiative depends on the level of contested place and aims of the initiative. Due to the weakness of civil society in post-socialist cities urban activism is characterized by small-scale civil initiatives. Unfamiliarity with democracy is the socio-cultural factor that mostly affects the low civil engagement in development projects. Larg-scale civil initiatives appear when self-organized groups are supported by formal organizations so that their demands and proposals could be heard more loudly or when the aims of the initiatives are for the benefit of all city residents.

Scope and aims of actions. Accurate, clear, and not too broad goals of the civil initiative actions addressed to the authorities and decision makers are a prerequisite for their achievement and overall success. While some civil society organizations may ask for basic conditions that are no longer met by improving the quality of neighbourhoods, others may aim at more broad goals such as changing unsustainable political, social, ecological, economic, and cultural patterns. In post-socialist cities the most common goal of civil society initiatives is to promote social justice and quality of urban environment. They strive to ensure that “the right to the city” of each individual is respected. With that goal and through collective efforts civil initiatives advocate for policies change, postponement of the plan's implementation, etc. On the other hand, they work on fostering collaboration with city authorities, building self-capacity and empowering communities.

Scale of actions: The scale of civil initiative actions directly depends on the aims and scope of the initiative. In post-socialist cities civil initiatives are not developed as mass scale actions mobilized around border political or social issues, but small-scale actions that are aimed at changes in urban development and improvement of the quality of the urban environment. In order to achieve broader social and political issues, several organizations join together in common activities and address common requests to the authorities. On the other hand, the neighbourhood-scale initiatives are more effective in preforming common actions because of the pre-existing social ties within community and mutual trust between members of the initiative.

Types of actions. Civil society is powerful actor in the conception and implementation of urban planning and management. There is a range of actions through which actors involved in civil initiative impact urban planning and outcome of that process. The type of activities depends on the main goal of the initiative, values that are contested (use value, land value, real estate, heritage value, economic value, etc.) and the phase of urban planning process. Regarding this, some actions might be part of formal participatory process such as drafting demands and making proposals for development, filing objections to the plan proposals, etc., while others are performed anytime as part of informal participatory process such as: protests, petitions, group meetings for exchange of information, site visits, place making activities, art festivals, cultural events, etc. Some initiatives are even able to conceive, develop and implement their own alternative solutions and plans. Therefore, all these actions, either proactive or reactive, might be central to a potentially new co-design planning culture.

Strategies and modes of action. Two models of strategies of urban activism are present in post-socialist cities. The dominant model is reactive strategy of civil initiatives that mobilize citizens against neoliberal urban politics, mainly through opposition to new construction, development projects and plan implementation, with the aim of protecting city’s public spaces. The other model, proactive strategy aims at strengthening social capital by supporting citizen participation in various areas of urban development. Dynamic civil society initiatives which ought to open the planning process and initiate the urban development projects rarely take place in post-socialist civil societies.

Continuity. Persistence and frequency of the activities are two crucial elements of continuity of initiatives and accomplishments of goals. The disappointment of post-socialist citizens with values of collectively which have not persisted, causes them to withdraw from public activities. Therefore, short-term mobilization of citizens is the most common form of civil society practice in post-socialist cities. Nevertheless, long-term mobilization of citizens gains more credibility in negotiations with city officials. At the same time, it is challenged by the ability of members to develop "political culture" in terms of horizontal self-management practice.

Inception of actions. Civil initiatives can take part in different phases of urban planning process, from initiation to plan implementation and monitoring. Accordingly, different formal and informal participatory tools are used, and actions performed. They range from institutional tactics and official participative schemes (public insight and hearing) of negotiating with the city authorities to very diverse non-institutional "direct actions". Performing diverse actions within the same civil initiative gives a greater possibility of achieving better results. The time when official activities of civil initiatives begin within the planning process is of great importance for their success. Civil initiatives which open the planning process and commence improvements in urban environment are more likely to have more significant position in negotiation with decision makers and city officials. Timeliness of the actions is especially important if they are undertaken as a part of institutionalized (formal) participation in urban planning. Missing the deadline for filing objections to the proposed plan may result in loosing opportunity to make changes.

Collaboration with city authorities. Actors involved in civil initiative develop antagonistic attitude towards institutions due to their distrust in post-socialist institutions, whose activities are considered non-transparent. On the other hand, institutions see urban initiatives as a threat to their programmes. The examples are showing that the lack of communication and prejudice are the main obstacle of effective collaboration between these two parties. Cooperation is even hampered by low level of formal participation (tokenism level) in urban planning which increases the risk of developing the conflicts between the weak and the strong. Therefore, establishing communication channels, constructive dialog and finally partnership between civil initiative actors and institutions come across as the most promising cooperation. Eventually, taking great part in institutionalized channels of participation might be challenging for civil initiative organizations. In some cases, the more the city authorities are efficient in providing effective participatory channels the bigger is the risk of co-optation for civil initiatives.

5. URBAN RESISTANCE MOVEMENTS IN POST-SOCIALIST BANJALUKA

Banjaluka is the second largest city in Bosnia and Herzegovina and political, financial, administrative, university and cultural center of one of the entities of the country- Republic of Srpska. As many other post-socialist cities Banjaluka is the place of dynamic socio-economic and spatial transition and transformation. In socialism, Banjaluka had a well-earned international reputation of the Yugoslav industrial and green city with a vast range of open spaces. Today, Banjaluka is a city of different administrative and political shifts that influence its urban development [27] . The increased role of local administration, capital principles of private ownership and marked-lead local economy have brought urban changes for the benefit of private capital or investors urbanism. The role of the private sector, seeking for the profit, becomes dominant in management of urban development, which is the reason why places of public interest are shrinking. This phenomenon is the cause of the increasing dissatisfaction of citizens of Banjaluka whose needs are neglected, and voices rarely heard. To better understanding the role of the citizens in formal planning process and the weakness of their position in relation to strong private capital, current trends and tendencies in public participation in Banjaluka are re-examined in the following text. The most important questions are in which phase of a planning or policy process stakeholders are invited, which role they are assigned, and what degree of participation is to be achieved [28].

Due to the lack of strategic planning document Urban plan of Banjaluka, urban development and transformation are commonly based on the preparation and implementation of spatial planning documents (preparing physical and urban planning documents as regulatory plans, urban planning and design and parceling out plans). The main legal act that regulates participation in formal urban planning in Republic of Srpska is Law on Spatial Planning and Construction [29] which implies that the public is informed through the public enquiry prior to preliminary draft preparation. The public has 15 days to express its attitude towards exposed documents. The exposed documents include a decision of the City Assembly with text that provides an explanation of initiative, an excerpt of strategic planning document and drawing of a pre-existing state. After the closing date of the informing the public without effective collaboration, the process of initial program setting is completed, and planners start with preparing the preliminary draft. During public insight into the draft plan, the public is allowed to make objections to the plan proposal within the 30 days. After public insight is closed, the public is invited to a discussion about objections filed to the proposed plan. Planning practice dealing with implementing planning documents indicates that plan proposal prepared in accordance with initial program, shall not be substantially transformed in the final stage of the planning process regardless of public opinion. This means that the urban planning process in Banjaluka applies extremely top-down method of participation with the superior position of the local government. In addition, only two formal forms of public participation are public insight and public discussion on draft plan. To be even worse, alternative tools for motivating all stakeholders to get involved in compiling plans do not exist.

One more obstacle to meaningful participation is urban planners themselves and their “disinterest, mistrust, skepticism, animosity, arrogance and fear to connect with citizens and include their opinion, knowledge and wishes in plan making” [3, p. 9]. On the other hand, there is a lack of theoretical and methodological knowledge about formal and informal tools and techniques for involvement of citizens in urban planning process. In these circumstances, there is a great distrust in institutions and citizens perceive the process as non-transparent and often are not willing to participate.

Given the above, it can be argued that citizen participation in urban planning practice in Banjaluka is not efficient and meaningful. As a response to top-down planning approach various local civil initiatives with different aims and requests have emerged in last fifteen years. Civil initiatives, as a specific kind of civic engagement and activism, are common urban phenomenon in developing countries, due to weak state and governance structures, corruption, and scarce (financial) resources [28, p. 1690]. They arise from dissatisfaction of citizens with governmental politics and actions, or from “nonaction” of authorities due to the budget cuts. The growing consciousness of the residents of Banjaluka, that resulted in urban resistance movements and civil initiative, gradually changes the balance of power between all stakeholders. Local actors (society, stakeholder groups or NGOs), confronted with local government decisions, are self-organizing to make a collective action against imposed planning solutions. This bottom-up approach is gaining an extreme form of participation-organized, voluntary and independent. The most prominent civil initiatives in Banjaluka are i.e., “Park is ours!”, “Građiš belongs to us!”, “Recreational zone Banja Luka”, “Civil society initiative BORIK”, etc. One of the most successful self-organized initiatives in terms of achieved goals and improved position of the public in urban planning process was Civil initiative “Građiš”.

6. THE CASE OF A CIVIL INITIATIVE FOR PRESERVATION OF OPEN PUBLIC SPACE IN BANJALUKA

Open public space located on the roof of the underground bomb shelter in Sime Šolaje Street in centre of Banjaluka was an improvised children's playground for decades. This place, popularly named “Građiš” or “Građa”, was paved with concrete with no greenery and equipment, but still was the only playground that kids from this residential neighborhood had (figure1).

The story about civil initiative for preservation of this public space started in 2011 when children's playground should have been converted into a parking with 74 parking spots, which was in accordance with the valid Regulation plan Centre adopted in 2007. In September 2011 everything was ready for the plan implementation and the excavators were already on the site. A group of children, who wanted to preserve and improve their playground, were seating in front of excavators during the day, shouting "We don't give up on Građiš!", and scattering building material at night. Soon after children received the support of their parents and other tenants, who joined them in a peaceful and almost everyday protests. Besides, they signed many petitions against these interventions and addressed them to the city authorities. With the help of some media that reported daily on the events on the playground and the Ombudsman for Children's Rights of the Republic of Srpska who met with city officials, this civil resistance paid off after a few months and the City Administration initially abandoned the idea of building a parking lot. At the same time, citizens were promised that the amendment of Regulation plan would be initiated, and new children's playground would be planed and built. This decision marked the beginning of more significant operation of the civil initiative actors.

Figure 1. “Građiš” as the roof of the underground bomb shelter.

Given that the promise was not kept the citizens did not give up their struggle. In the following years citizens organized many events and activities, with the support of formal civil society organizations from Banjaluka. In September 2015 an international public event PARKing Day was celebrated at Građiš place with music, poetry, frisbee throwing, drawing and playing social games. This is the action, organized by Centre for Environment, in which citizens, artists and activists together temporarily transform a public parking lot into a public space accessible to all citizens. The aim of celebrating PARKing Day at this site was to point out the growing need for open public spaces and to initiate a public discussion about how public spaces are created. The organizer wanted to show what Građiš place would look like if there was a park on it. Next year in December, Centre for the Environment in collaboration with a few more organizations coordinated a public forum "Citizens build the Building" aiming to present the results of the survey on the development and design proposal for this public space that civil initiative actors conducted themselves. The forum was also attended by representatives of the City Administration who (once more) came to hear the needs of the citizens of this neighborhood. During the seven-day survey 165 citizens were questioned, and the results have shown that only 6.1% of citizens are in favor of building a parking lot at this location, over 77.6% of them are in favor of a children's playground, and a large number also suggest occasional activities that might be held at Građiš, such as creative workshops, a flea market, clothing exchange, humanitarian actions and an organic food market. In Jully 2017 the same civil society organization invited all citizens to take part in transformation of this site into children's playground and a space for young people through art and floor paintings. This action named “Građani grade građevinu” (“Citizens are building the building”) was organized within the framework of civil initiative "Naš prostor" (“Our space”) which goal was to promote a greater citizen participation in the process of drafting and adopting spatial planning documents. Similarly, In Jully 2020 one-day Graffiti Jam event was organized by several organizations from Banjaluka seeking to raise awareness of the importance of preserving green areas and children's playgrounds. However, long after 2011 Građiš has not been reconstructed and converted into playground and green area. Very often it serves as an informal parking lot, which compels citizens to report it to the municipal inspection using citizen patrol application.

After almost 10 years of struggle and continued pressure on the administration, the Mayor of Banjaluka announced that the green roof with children's playground would be built in 2019. This roof should have been the largest green roof in BiH, but since the city was not able to finance the project, this proposal failed again. At the beginning of 2020 city officials and architects presented new design for park and playground which included 10 parking spots and was characterized as “compromised design”. The citizens were explicit in refusing the parking and rejected the new design proposal. Since then, the new design hasn’t been completed.

In accordance with new development needs but also the interests of private capital, new Regulation plan of part of the central area of Banjaluka was adopted in 2018. The playground on the Građiš site is finally planned by this implementation planning document, which was the main goal of community-based initiative. However, the plan also envisages the construction of a large high-rise residential complex on the neighboring plot, which, in the opinion of this community representatives would additionally impair the quality of life in this neighborhood. Due to the formal irregularities in the adoption of this plan and based on the initiative of the residents, the Constitutional Court of the Republic of Srpska declared the Decision on the adoption of the plan unconstitutional. This means that the Regulation Plan from 2007 is still in force.

Eventually, the story about Građiš gets an epilogue in Jully 2022 when the roof of underground bomb shelter was designed and painted as the color park "Citrus Park" (figure 2). Inspired by vibrant colors and citrus fruits, the park is divided into three functional zones: sport zone, the children's zone and the free zone. Meanwhile, the city reached an agreement with a private investor and offered him alternative plot for high-rise residential complex. Waiting for new plan to be adopted, authorities decided to build a temporary park on the plot previously planned as residential. The work on project design is still in process, and the park has not been built yet.

Figure 2. "Građiš" as "Citrus Park".

Considering all the above, the case of Građiš is example of persistent community-based initiative which had power to preserve open public place and prevent it from becoming parking. Although the primary requirements of the community were not met in terms of creating a green oasis with an equipped playground, this compromised design was approved by the residents. This is the reason why this case is a symbol of the success of the activism initiated by children.

7. CONCLUSION

The aim of this research is to provide a better understanding of the role of civil initiatives as co-creators in the process of urban development of post-socialist cities. Regarding this, new theoretical model of understanding of the phenomenon of civil initiative and its role in urban planning process is developed, based on the theoretical framework of urban activism and participation in post-socialist urban planning. The model is backed by ten identified attributes of civil initiative that could affect the achievement of its goals and results of urban planning process. In relation to achieved results and the role in urban planning, the initiatives might be characterized as those with transformative, partial and zero potential. The new model is applied as analytical tool for identification of attributes of civil initiatives that mostly influence their effectiveness in urban planning and development. In other words, application of the model and results of the analysis can improve transformative potential of civil society in urban development projects and social sustainability of transformation of post-socialist cities.

The case of the civil initiative “Građiš” for preservation of open public place in center of Banjaluka is presented in the paper. Initiative was raised in 2011 and finally got epilogue in 2022. This case is a symbol of persistent activism and urban resistance of informal group of people who over the time got a great support from formal city organizations. Members of the initiative were consistent, shared the same aims and supported each other in the group. Strong organizational capacity made communication channels with city authorities clear and transparent. This is the initiative in which citizens' self-organizational capacity improved over time and was gradually built through small-scale and place-making activities, which is the reason why this community was given more credibility in negotiations with city officials. Moreover, actors of initiative were skilled enough to make an alternative design proposal for contested place which indicated a transformation of the initiative's approach from reactive to proactive. Eventually, this case showed that pre-existing social ties within community were beneficial for common actions because there was already mutual trust between members of initiative. All these identified attributes contributed to the transformative potential of initiative in neighborhood development project. However, to prove the general link of transformative potential of the initiative with its attributes more case studies in Banjaluka need to be conducted.

The results of this research show that in the face of limited participation and deficiencies of the urban planning approach civil initiatives are alternative way to challenge development processes in post-socialist cities. Urban activism plays an important role in strengthening the civil society, changing urban planning approach and implementation of politics of urban development. Civil initiatives are becoming more important actors of urban change because they identify problems, challenge the decisions of the authorities, and become new informal partners in the urban planning process. It is recognized that citizen activism and urban movements have powerful transformative force in strengthening the bottom-up planning approach. The greatest ability of civil initiatives is their social capital such as: commitment to the project, local ties, networks, relationships, and particularly strong local knowledge. Regarding this, the improvement of the actual urban planning methodology in Republic of Srpska, regulated by the strict regulatory framework, is needed. Improvements are based on the making use of the social capital of the civil initiatives. Mixing local knowledge of civil society with technical knowledge of planners, decision makers and authorities may lead to the improvement of planning processes. To benefit from local knowledge, it is necessary to introduce new formal (besides public insight and hearing) and informal participatory tools in urban planning. The co-design in public realm based on the mixture of expert-driven and user-driven ideas is learning process for all interest groups which implies effective participatory approach and provides promising development pathways.

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STEPGRAD
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DETERMINING THE THERMAL TRANSMITTANCE COEFFICIENT OF THE OPAQUE FAÇADE WALL ELEMENT USING NON-INVASIVE METHOD

Abstract

Prior to building retrofitting, thermal performance assessment of the building is essential. An adequate assessment can provide useful insights to heat-losses and envelope anomalies i.e. thermal bridges, mold, air infiltration etc. The most important physical quantity that needs to be defined is the thermal transmittance (U-value) which is the key factor in determining the transmission heat loss coefficient HT, as well as in determining the building's energy efficiency. In the absence of documentation, experimental methods are the only solution to identifying such parameter. This paper makes overview of experimental methods; and presents an example of non-destructive method by using Quantitative Infra-Red Thermography (QIRT) in service of calculating U-value of the opaque façade wall element.

Keywords: U-value, Quantitative Infra-Red Thermography (QIRT), building energy efficiency

ОДРЕЂИВАЊЕ КОЕФИЦИЈЕНТА ПРОЛАЗА ТОПЛОТЕ НЕПРОЗИРНОГ ЕЛЕМЕНТА ФАСАДНОГ ЗИДА НЕИНВАЗИВНОМ МЕТОДОМ

Сажетак

У процесу обнове зграде, од суштинског значаја је процјена топлотних перформанси омотача. Адекватна процјена може пружити увид у топлотне губитке и аномалије омотача нпр. топлотни мостови, појава влаге, инфилтрација ваздуха итд. Најважнији физички параметар који треба одредити је коефицијент пролаза топлоте (U-коефицијент) постојећег зида, који је кључни фактор за одређивање коефицијента трансмисионих губитака топлоте H_T као и енергетске ефикасности зграде. У недостатку документације, експерименталне методе су једино решење за одређивање U-коефицијента. У овом раду је дат преглед експерименталних метода; и приказан примјер примјене недеструктивне методе коришћењем квантитативне инфрацрвене термовизије у циљу одређивања U-коефицијента непрозирног елемента фасадног зида.

Кључне ријечи: U-коефицијент, квантитативна инфрацрвена термовизија, енергетска ефикасност зграде

1. INTRODUCTION

In order to conduct an energy audit and analyse the thermal properties of the envelope, it is necessary to determine the thermal transmittance of the transparent and opaque elements of the building envelope. In practice, the documentation is often not available, or is insufficiently clear to accurately determine the composition of the walls, and therefore their energy characteristics. The thermal transmittance coefficient (U – value, W/m^{2}K) is defined by the ISO 7345:2018 standard as the heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on each side of a system [1]. The U-value of the wall is an important physical quantity that indicates the thermal performance of the building envelope. If it is overestimated, the result will be insufficient thickness of thermal insulation on the wall, and vice versa, if underestimated resulting in inadequate interventions that will not lead to adequate results in building's energy efficiency and can often cause unnecessary financial costs. The U-value represents the starting point for the calculation of the required energy for heating and cooling.

Taking into account all mechanisms of heat transfer, which are conduction, convection, and radiation, the thermal transmittance can be determined as follows:

$$U = \frac{\mathrm{q}}{t_{int} - t_{out}} \tag{1}$$

That is, the U-value can be obtained by measuring the heat flux density (q) and the temperature difference between the indoor (t_{int}) and outdoor (t_{out}) air during stationary heat transfer.

In order to determine the U-coefficient of the existing wall, several methods have been defined, which are divided into theoretical, destructive, and non-destructive methods. Although there are different methods of on-site measurement in practice, not all of them are accepted as sufficiently precise to be applicable, while the decision on the most favorable method depends on many factors, which will be discussed in the following text. According to ISO 9869-1:2014 [2], equipment for determining the heat transmittance consists of a heat flux sensor and temperature sensor (indoor and outdoor temperature probe), which are usually placed on a north wall in order to avoid direct solar radiation. The reliability of the obtained results is affected by conditions such as sun, rain, wind, and temperature. However, non-invasive and non-destructive methods like thermography are advised to be performed prior to precise measurements since different structural abnormalities can be found in the wall, making it easier to choose the exact wall and spot where to install the measuring units.

2. OVERVIEW OF THEORETICAL AND EXPERIMENTAL METHODS TO DETERMINE THE U-VALUE OF THE OPAQUE FAÇADE WALL ELEMENT

In practice several methods are present, and theirs benefits and downsides range from being non-destructive to the ones which are leaving marks on the walls; secondly, some are easier to conduct since they require easy to use and install equipment and do not require repetitive measuring process, while others require 72 hours sequential measurements; thirdly, not all require entrance to the interior space leaving tenants unbothered. General spectrum is as following:

Theoretical method (ISO 6946:2017) [3] [4] explained theoretical approach to calculation of the thermal transmittance - U-value, which is described using the following equation:

$$U = \frac{1}{\mathrm{Rtot}} = \frac{1}{1\mathrm{Rs,i} + \sum_i^n R_i + \mathrm{Rs,e}}, \tag{2}$$

where Rtot is the thermal resistance of the wall, and $R_{s,e}$ and $R_{s,i}$ (m^2 K)/W are the thermal resistances of the outer and inner surfaces [5]. ISO 6946:2017 [3] defines this method as a way to calculate the thermal resistance and thermal transmittance of building components and elements, excluding doors, windows, glazed units, curtain walling, components transferring heat to the ground, and those designed for air permeation. The calculation relies on the designated thermal conductivities and ticknesses of the building element layers (resistances of the material layers). This approach applies to components and elements composed of thermally consistent layers, which may incorporate air layers.

Heat-flow meter method (HFM) (ISO 9869-1:2014) [5] - The ISO standard details the utilization of heat flow meters for evaluating the thermal transmission properties of flat building components. These components, primarily composed of opaque layers perpendicular to heat flow, are assessed for their thermal resistance (R), thermal conductivity (λ), overall thermal resistance (R_t), and transmittance (U) between defined environments. The thermal transmittance of a wall is determined by measuring the heat flux through the wall and the temperatures of the environment on either side of it. [2] This method is highly accurate and non-destructive, however, its downside is the lack of possibility for thermal bridge analysis due to the very local measuring zone, the requirement to access the building, limitations where probes often make marks and small damages on the wall, and the difficulty of ensuring a thermal gradient of > 10 °C while performing measurements. This method is commonly used when temperature differences are greater, i.e., in the winter, when internal space is heated, or in the summer, when it is cooled, etc. According to ISO 9869-1:2014 [2], there are three criteria that need to be met:

- The measurement period should last at least 72 hours, with a specific range of sampling and logging intervals.
- The R_c value (conductive thermal resistance (m^2KW^{-1})) obtained from the last two measurement days should not differ by more than 5%.
- The difference between R_c values obtained from the first and last certain number of days is within 5% [5] [6].

Infrared method/ Quantitative infra-red thermography (QIRT) [6] **-** This is non-contact, non-destructive and rapid method which utilizes the amount of irradiance of the regions in contact with outside air from the surface temperature, total heat transfer coefficient and environmental temperature. The indoor surface temperature distribution is measured using an Infra-Red (IR) camera, the indoor environmental temperature is measured by installing Environmental Temperature (ET) sensor on the surface of the building component, and the indoor total heat transfer coefficient of the surface of the building component is measured using a heat transfer coefficient sensor [6]. Additionally, some researchers suggest the use of a hot-wire anemometer to monitor variations in wind speed near the wall [7]. In conclusion, the IR method calculates heat transmittance by knowing the emissivity of the material, measuring reflection temperature, surface temperature, and temperature of the internal and external environments [8]. Besides being used in determining the U-value, this method opens possibilities for detecting thermal anomalies such as thermal bridge occurrence, air infiltration, the presence of moisture or leakage in the wall, etc. Furthermore, it is useful to measure barely reachable areas.

The simple hot-box flow meter method (SHB-HFM) combines the Guard Hot Box (GHB) and Calibrated Hot Box (CHB) methods [9] - Hot box methods are laboratory tests characterized by controlled temperature of the environment, and are thus not limited by climate conditions, and have low measurement errors [10]. However, usual HB-HFM methods are rarely useful for in-situ measurements so recent studies have focused on developing in-situ hot box methods. Temperature-Control-Box (TCB-HFM) is one of such and it consists of a hot box mounted to the inner surface, which heats or cools air (depending on the season) to ensure optimal thermal gradient of > 10 °C while performing measurements. The items required to perform this methodology are: (1) a simple hot box; (2) three heat flux plates; (3) a temperature probes; (4) surface temperature probes; and (5) a data logger [11] [12].

Thermometric method (THM) [4], also called the air-surface temperature ratio method, is a non-destructive method that determines thermal transmittance by measuring the internal surface temperature of the wall and the temperatures of the environments divided by the wall [4]. Considering this technique, its main advantage is the absence of heat flow sensors, which only involves temperature sensors that are tightly mounted on the wall. This method can be combined with infra-red thermography to ensure that the probes are placed tightly and in the correct position [13].

3. USING QUANTITATIVE INFRA-RED THERMOGRAPHY (QIRT) TO DETERMINE THE U-VALUE OF AN OPAQUE FAÇADE WALL ELEMENT

All objects with a temperature higher than absolute zero emit infra-red radiation as a function of their temperature. Thermal imaging is a non-invasive method that enables non-contact measurement of surface temperature based on the emitted electromagnetic radiation in the long-infra-red range.

According to Stefan Boltzmann's law, the net radiated power per unit area (q) is proportional to the fourth power of the absolute temperature (T) and also depends on the emissivity (ε) of the body:

$$q = \varepsilon\sigma T^4 \tag{3}$$

Where $\sigma = 5.67 \cdot 10^{-8} \frac{W}{m^2K^4}$ is Stefan Boltzmann's constant. The emissivity coefficient is defined as the ratio of the energy emitted by a certain material to the energy emitted by an absolute black body of the same temperature. According to the definition, it can have values in the range 0-1.0. Emissivity depends on the wavelength, material finish, and temperature of the surface.

Based on the amount of infra-red energy that is emitted, transmitted, and reflected from the surface, a thermal image in which the different temperatures are represented by different colors is obtained. This imaging method can be applied for non-destructive testing, quality inspection in materials, civil engineering, and building sciences [14]. Inhomogeneities in the material near the surface of the structural elements will result in a different temperature and color; this is especially important in the case of moisture. In the building analysis, active and passive methods of infra-red thermography are implemented, with the active method being further distinguished into pulsed thermography (PT) and lock-in thermography (LT) [15]. Pulsed thermography (PT) presents an active thermographic method that involves the use of a heat source to stimulate an object with a heat pulse. An infra-red camera then records a video of the object to measure the cooling process on the object's surface [16]. Lock-in thermography (LT), whose principle is based on the application of the periodic input energy wave to the surface of the object being examined and analyzing the resulting local temperatures on the surface of the object [17].

IRT building diagnostics includes the determination of thermal characteristics of the envelope, detection of thermal bridges and areas of increased heat loss, air leakage, thermal insulation damage, and the presence of moisture [15].

An example presented in this paper is the usage of an IC camera on the wall of a residential building from the period 1970 – 1980, whose envelope condition is in need of renovation. Thus, this method can provide insights into the current condition of the envelope and approximately determine the U-value as the main input parameter for the further process of designing envelope refurbishment. Measurements on the envelope are performed in accordance with the standard ISO 6781-1:2023 [18] (previously used as ISO 6781-1983) and EN 13187:1998 [19]. Thermal inspection was made with the thermal image camera FLIR b60. Table 1. shows thermal image camera specifications.

Table 1. Properties of IR Camera used for the U-value measurement [20]

Parameter	Value
Field of View	25° × 25°
Thermal Sensitivity	< 0.1°C (0.25°C) / 100m
Image frequency	9 Hz
Detector type	Uncooled microbolometer
Spectral range	7.5–13 μm
IR resolution	180 x 180
Object temperature range	-20°C to +120°C
Accuracy	±2°C or ±2% of reading
Emissivity table	0.1 to 1.0 adjustable or selected from list of materials
Operation temperature range	-15°C to +50°C
Storage temperature range	-40°C to +70°C
Humidity (operating and storage) range	24h 95% relative humidity

In the case of thermal transmittance coefficient value assessment by IRT application, there is no prescribed normative. However, in some papers, suggestions were given in order to determine the thermal transmittance coefficient value (U-value) using non-contact and non-invasive methods. According to Albatici and Tonelli [7] as well as Nardi et al. [21], the U-value can be determined through IRT by measuring the surface temperature of the element T_w, the indoor environment temperature T_{int}, the outdoor environment temperature T_{out}, the wind velocity v, and the emissivity of the material ε_{tot}:

$$U = \frac{5{,}67 \cdot \varepsilon_{tot}\left[\left(\frac{T_w}{100}\right)^4 - \left(\frac{T_{out}}{100}\right)^4\right] + 3{,}8054v(T_w - T_{out})}{(T_{int} - T_{out})} \tag{4}$$

Furthermore, some of the authors have suggested a new methodology based on measuring inside and outside air temperatures and the inner wall surface temperature in order to avoid the influence of external climatic conditions [22].

4. IMPLEMENTING QIRT TO THE CASE STUDY OF AN OPAQUE NORTH-ORIENTED FAÇADE WALL ELEMENT

For experimental purposes, existing residential building, from the period 1970-1980, is taken into consideration (Figure 1). The building is a representative sample of the mentioned period and has a skeleton structural system of precast prestressed columns and floors with walls of prefabricated sandwich panels and thermal blocks plastered on both sides with cement mortar.

The average wind speed measured around this sample does not exceed 1 m/s, i.e., the west-northwest, which is the most frequent, is 0.3 m/s, followed by two more dominant directions: north-northwest (0.4 m/s) and north-northeast (0.6 m/s), and they do not additionally affect the calculation of the thermal resistance and thermal transmittance coefficient values of the building, which are not already provided for by the standard [3]. Since the orientation of the wall where QIRT measurements are made is north – northeast, wind velocity of 0.6 m/s is used for further calculations. Based on these values, thermal resistance of the outer surface is R_{se} = 0.040 m^2K/W.

Figure 1. Layout of building and position in Borik neighbourhood, Banja Luka

The thermal transmittance coefficient value (U-value) for a representative part of the façade was evaluated using the theoretical method. The values for the wall components are given in Table 2: density, thickness, thermal conductivity coefficient, and estimated U-value. The physical properties of the materials are taken according to mean values of such types of materials and according to material properties present at the time of construction. The calculated U-value using a theoretical model based on the composition and thermal properties of the sampled wall is 1.37 W/m^2K (table 2). This U-value is in line with the average U-value for buildings from this period, as stated in the Typology of the Residential Buildings in Bosnia and Herzegovina [23]. According to the Rulebook on minimum requirements for the building energy characteristics currently used in the Republic of Srpska [24], the prescribed U-value for the opaque façade elements is U = 0.30 W/m^2K. The calculated U-value is too high and does not meet the prescribed requirement.

Table 2. The composition and thermal properties of the sampled wall

Wall	Layers of the element				
Sample north oriented opaque façade wall	Material	Density ρ (kg/m^3)	Layer thickness d (m)	Thermal conductivity coefficient λ (W/mK)	Thermal resistance R (m^{2}K/W)
	Cement mortar	1900	0.015	0.70	0.021
	Thermal block	1400	0.30	0.58	0.517
	Cement mortar	1900	0.02	0.70	0.029
	Thermal resistance of the inner surface			Rsi	0.125
	Thermal resistance of the outer surface			Rse	0.040
	Heat transfer coefficient (U-value)			U (W/m^{2}K)	1.37

The theoretical method is followed by the qualitative method using the infrared camera FLIR b60. A thermal image of the sample is shown in Figure 2 where the following parameters can be seen: wall temperature (- 0.1°C), material emissivity (ε = 0.97), and temperature range (-7°C to 21°C).

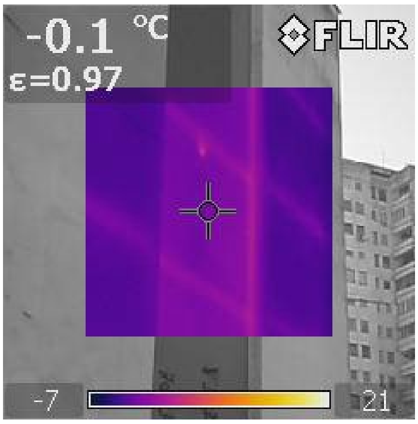

Figure 2. Thermal image of the north-oriented façade wall

After the theoretical value has been estimated and the sample wall screened using a thermal imaging camera, there are all the parameters necessary to calculate the U-value using the previously shown equation 4. Table 3. shows an overview of in-situ measured parameters used for further evaluation of the U-value.

Table 3. Parameters that are necessary for the calculation of the U-value.

Parameter/ unit		Measured	T (K)
t_{int} (℃)	indoor environment temperature	21.8	294.95
t_{out} (℃)	outdoor environment temperature	-5.4	267.75
t_w (℃)	surface temperature of element	-0.1	273.05
ε	emissivity of the material	0.97	-
v (m/s)	wind velocity	0.6	-
U (W/m^{2}K)– value			1.29

The calculated U-value, based on the characteristics of the sampled wall, is 1.37 W/m^{2}K, while the U-value obtained by applying the QIRT method is 1.29 W/m^{2}K. By comparing the results of the theoretical method and the QIRT measurement method, it can be concluded that the U-value matches adequately, with a difference of around 5%. Still, it is possible to obtain more precise results by repeating the measurement at multiple points on the wall and obtaining an average U-value.

5. CONCLUSION

This paper provides an overview of potential methods to determine the U-value, beginning with theoretical and moving through a range of experimental methods. The significance of thermal imaging is well known in the detection of anomalies. However, studies are showing that its use can be useful to determine the thermal transmittance coefficient value of the wall without causing damage to the element. With the wide range of methodologies currently being used to experimentally determine the thermal transmittance this method showed as easy to conduct while providing the immediate results. In comparison to other methods, it does not require 72 hour measurement range, and can be used from outside without compromising the privacy of the tenants. By applying the QIRT methodology, this paper showed promising results in terms of reliability in determining the U-value of the opaque façade element, with an accuracy of 5% compared to the U-value obtained by the theoretical method. This is of great importance, taking into account the ease of use and the measuring process, which is not as complex compared to other experimental methods. Future research should be made by comparing measuring outcomes from several points on the wall, hence the sampling results could be statistically approved. Furthermore, the results obtained with the QIRT method can be compared with those obtained with the HFM method to determine compatibility and relevance in architectural practice.

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11
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DIVERSITY OF RESIDENTIAL BLOCKS OF NIŠ PERIPHERY – CONTRIBUTION TO THE GUIDELINES OF FUTURE URBAN-POLICY

Abstract

The area of Niš, the third Serbian most populated city, has a dynamic topography. Located in a valley crossed by several rivers, surrounded by hills and plains, the rural settlements around the city, that were administratively integrated into it, are extremely diverse. The consequences of such variety are many, reflecting on residential block concepts and increasing everyday challenges in urban planning. In this paper, we analyzed the three villages for which urban plans were done for the first time in 2023. These settlements are located within a radius of about 10 km from the city center. This paper is a scientific elaboration of the urban plans that were presented as single exhibit at the annual international Salon of Urbanism, held in the Republic of Serbia, and was awarded by the Association of Urban Planners of Serbia in 2023.

Keywords: classification of settlement, urban planning, peri-urban area, rural development, block

РАЗНОВРСНОСТ СТАМБЕНИХ БЛОКОВА НА ПЕРИФЕРИЈИ ГРАДА НИША – ДОПРИНОС СМЈЕРНИЦАМА БУДУЋЕ УРБАНЕ ПОЛИТИКЕ

Сажетак

Подручје Ниша, трећег по величини града у Србији, карактерише динамична топографија. Обзиром да је град лоциран у котлини коју пресијеца више ријека, окружен брдима и заравнима, сеоска насеља око града, а која су административно интегрисана у градско подручје, изузетно су разноврсна. Посљедице такве разноврсности су бројне, и рефлектују се на концепт стамбених блокова и додатне свакодневне изазове у урбаном планирању. У овом раду, анализирали смо три села за која су, по први пут, израђени урбанистички планови током 2023. године. Ова насеља, налазе се у полупречнику од око 10km од центра града. Овај рад је научна разрада урбанистичких планова који су представљани као јединствен рад на годишњем међународном Салону урбанизма који се одржава у Републици Србији, награђен од стране Удружења урбаниста Србије на Салону урбанизма 2023.г.

Кључне речи: класификација насеља, урбанистичко планирање, периурбано поручје, рурални развој, блок

1. INTRODUCTION

The Balkan Peninsula has a rich topographic diversity and the area of Nish reflects that very well. Compared to flat Vojvodina or fully hilly Western Serbia, the area of Nish includes both hills and valleys - “a bit of all” types of terrains. The microclimate is milder than in most parts of the country. There are short, but snowy winters, early spring, and draughts in the summer, prevented by waters from springs and rivers – numerous but not particularly rich in water. Such circumstances create permanent challenge for urban planners and also have a strong effect on the overall development of the area.

Numerous migrations [1] and topographic diversity caused a great variety of living conditions and approaches between relatively near villages. The history of urban planning in Niš started approximately 150 years ago, however rural development received insufficient attention from the local authorities until a decade ago. It changed with the enlarging the administrative area of the city to 596,73km^2, incorporating numerous villages, and adopting the Spatial plan for the administrative area of Niš 2021 [2]. Global changes put peri-urban and rural development into new perspective.

Urban plans have been arranged in 2022-2023 for three former villages for the first time: Kapetanove pojate (KP), Lalinske pojate (LP), and Radikina Bara (RB). They are situated within a radius of 10km from the city centre (fig.1). Although rather near to each other, their residential blocks significantly differ.

The planning was based on recognizing original patterns and identifying order in existing urban morphology, learning from it, and plan changes which will provide long-term benefits for the settlements. Those three urban plans were exhibited together and awarded at the International Salon of Urbanism in 2023 by Serbian Association of Urban Planners.

This paper is scientific elaboration of that exhibit. It is expected that the conclusions contribute future urban polices for Serbian territories.

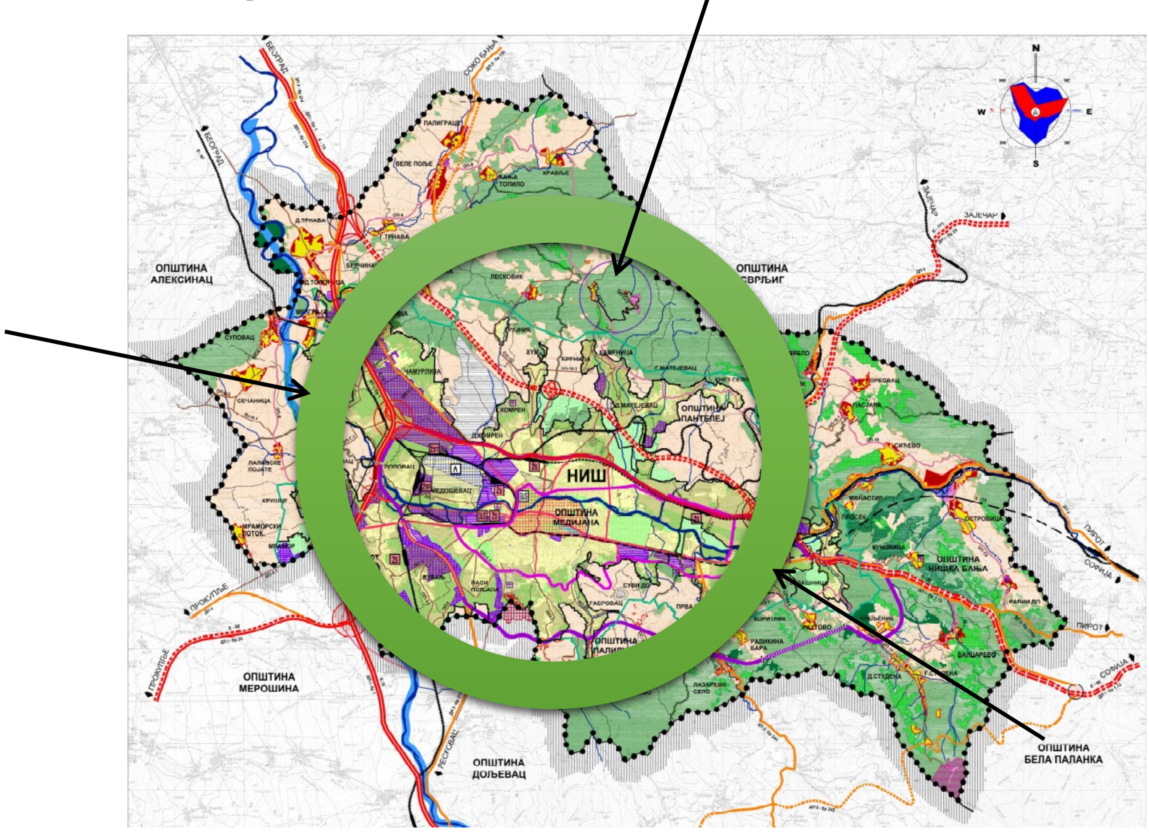


Figure 1. Location of Kapetove Pojate, Lalinske Pojate, and Radikina Bara from Nish centre - the green ring marks 10km distance

2. MATERIALS AND METHODOLOGY

2.1. MATERIALS

Kapetanove pojate (19 ha), toponym also known as Paprat, is in the centre of Niš tourist area B, situated near city's favourite picnic area, Kamenicki vis (in Serbian: Каменички вис), along the road connecting Cerjanska cave, opened for tourists, and historical site Cegar (in Serbian: Чегар). Currently, a dozen of weekend houses is scattered on both sides of the road near known water spring, and surrounded by the woods. The purpose of the urban plan (fig. 2) is to enable it to become a permanent settlement, with functions that provide basic self-sufficiency of the settlement. The area is also rich in wood.

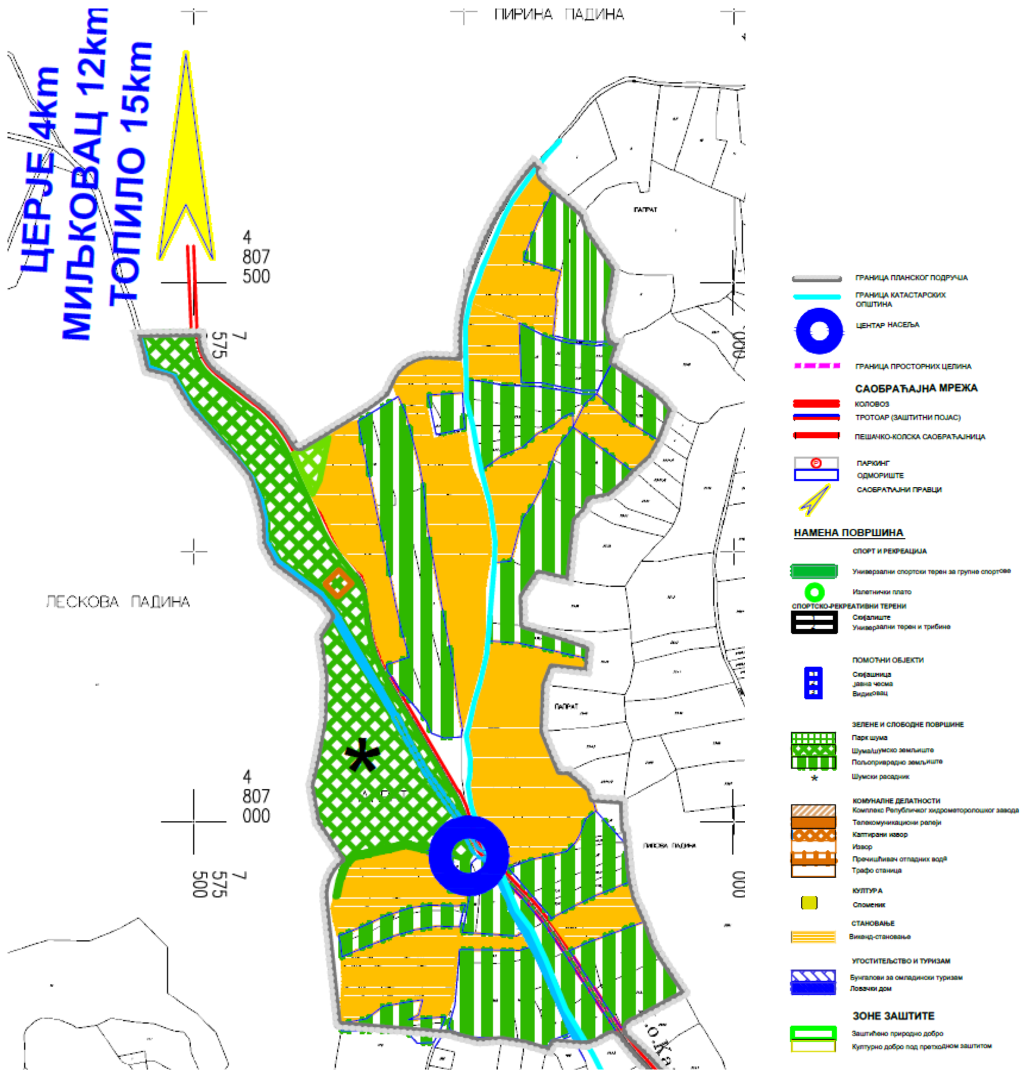


Figure 2. Excerption for the urban plan for detailed arrangements for Kapetanove Pojate

The urban intervention was mostly directed towards finding regularity in formerly forest roads, and defining for the first time the planned urban morphology - the core of future urbanity.

Lalinske pojate (46 ha) was originally a dislocated agglomeration of premises for agricultural purposes, separated from the village of origin by the river South Morava. The word "pojate" means premises for agricultural tools, hay, and even animals, and, ethimologically, the place where animals drink water. Its meaning is related but different from, also frequent, toponym "katun", a Vlachos-Albanian word for temporary, typically summer shelter for shepherds. The extension of village Lalinac developed in the 20th century, but some premises existed much longer. The settlement is predominantly surrounded by wheat fields and it conspicuously lacks trees, public services and amenities. Common public places for children and the entire community were at the top of the list of requests by residents, regarding the expectations from an urban plan.

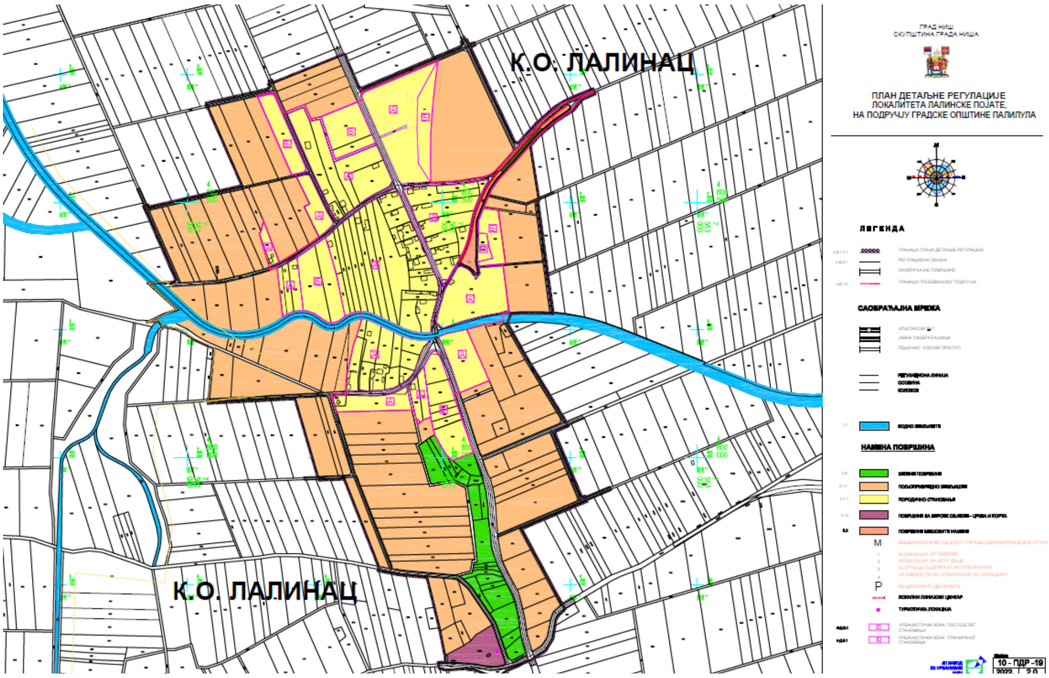


Figure 3. The excerpt from the urban plan for detailed arrangements for Lalinske pojate [3]

The local community-initiated land consolidation, which happened several decades ago. Consequently, the sizes of the blocks are bigger than expected. The plot in the centre of the village was segregated in that process because it forms a natural terrace, a few meters high, with a nice view to the otherwise flat area, including view to the river South Morava. It is narrow, distinctively long and steep, and as such unsuitable for agriculture. Therefore, it was chosen for the new linear centre of the village. The residential blocks were designed to meet needs of rural households, with un-detached houses and many auxiliary facilities on large construction plots, with area of over 1000m^2 in average (fig. 3).

Radikina Bara (107 ha) was an almost abandoned village two decades ago, however investment in water supply infrastructure, in addition to the natural beauty of the landscape, and rare suitability of the top of the hill for paragliding - enabled revival. The authorities of the nearby spa, centre of the tourist area A - Niška Banja, (which is one of the city municipalities, currently going through development crisis due to lack of land for development), recognize this village as suitable for extension of its own tourist area (New Niška Banja). The advantages of this location are several: it's only three kilometres away, having access to the same praised water springs, it is located close to the crest between two valleys, having an exceptional view, furthermore, it is south orientated, with many sunny hours per year. The vernacularly formed streets of the village turned out to be unusable to high extant for the desired purpose. Existing roads are both narrow and steep, and that is why:

- from the existing vernacular transportation network, only the part which follows the isohypses (approximately 4km or 50% of the existing streets) was preserved, and reconstructed using natural, ecological materials, with high water absorption capacity, and
- in total, 80% of preserved existing routes are kept as pedestrian, or dominantly pedestrian,
- while providing new, fast access by the outer ring, along which many public parking lots are situated, to motivate users not to use cars inside the ring, unless absolutely necessary;
- finally, the terrain is dominantly steep with an inclination between 15-40%, meaning that it is suitable almost exclusively for terraced houses (fig. 4). That implies that significant changes are required for reaching expected land-use efficiency. The intervention includes locations for solar power plants, tourist areas for investors of diverse capacities, and new main and auxiliary sports facilities for paragliding. Terraced houses are not common in the South of Serbia, and it was necessary to adopt strategy, tools and instrument which would favour such development.

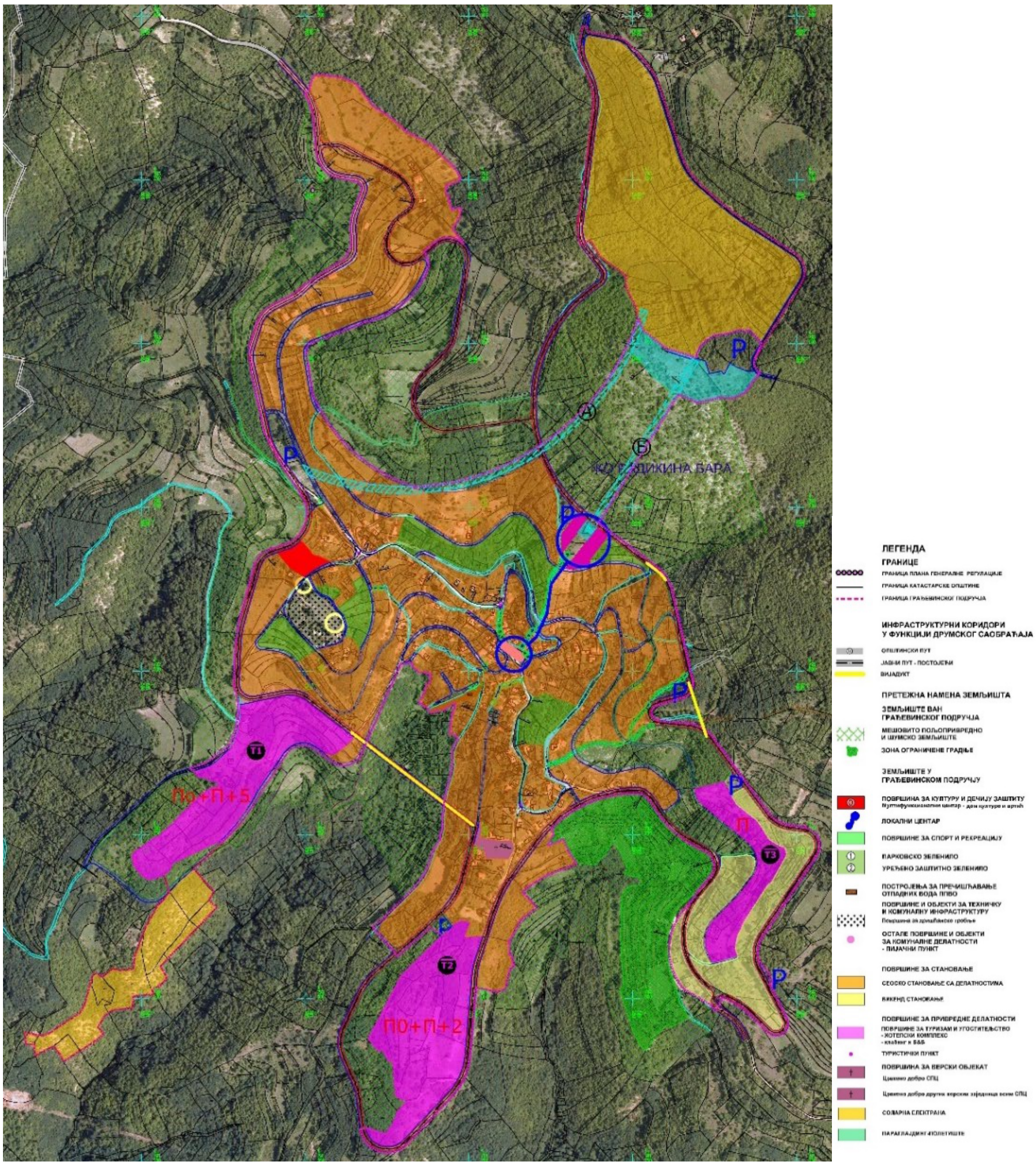


Figure 4. The excerpt from the urban plan for detailed arrangements for Radikina Bara [4]

The residential blocks in these three villages vary in:

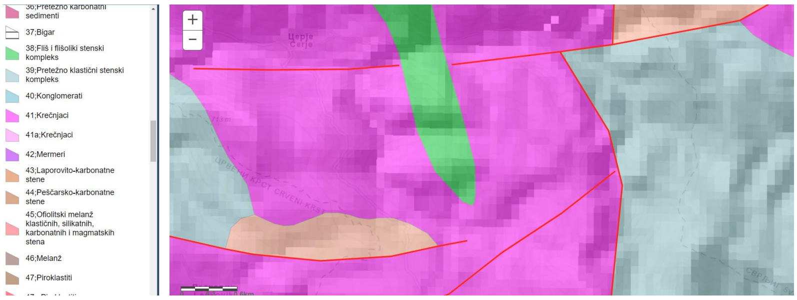
- Size, including the size of the average land plot in the range from 250m^2 to over 1500 m^2,
- Prevailing purpose (urban living/rural living/tourism),
- Inclination of terrain,
- Characteristics of the natural environment (infield/forest). (Figure 5)

In all three cases, around 10% of the area is reserved for transportation, and around 50% of the respective area is designated for construction, keeping the capacity to balance climate change and locally-generated carbon emission and pollution. The building coverage ratio is under 0.5 in residential blocks in the all three villages. Reaching “maximum 10% for the transportation “was particularly challenging in the case of Radikina Bara, where it was achieved through a radical custom-made concept. Numerical outcome, was better than expected – under 12% for transportation, including public parking areas which cover all needs respectively. Providing that literally all streets are fully walkable (with longitudinal inclination under 2%), was particularly important because of dominantly tourist future purpose of the area, and demanding, at the same time, considering that the difference in altitude between the lowest and the highest point is 335m (Table 1.)

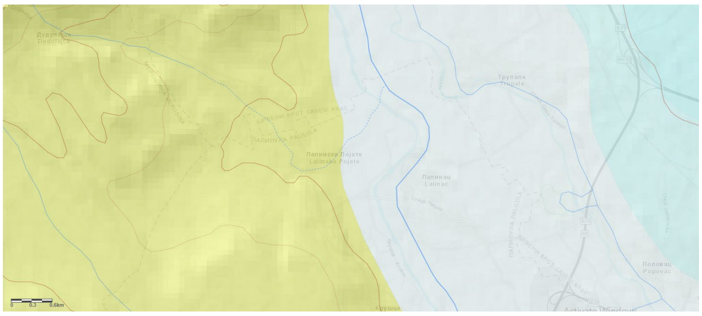
Figure 5. *Types of the residential blocks in A. Kapetanove Pojate B. Lalinske pojate (excerption from the exhibition poster from Salon of Urbanism 2023, [5])*

Table 1. Overview of data for Kapetanove Pojate (KP), Lalinske Pojate (LP), and Radikina Bara (RB)

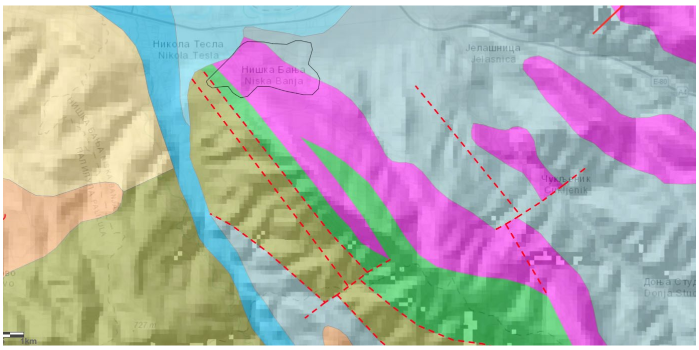
	Site	Area	Altitude scope (m)	Range of block sizes (ha)	Transportation Area (%)	Prevailing type of houses	Number of storeys (P-ground floor)	GBA (ha) (Gross building area)
1	KP	19.6	623-649	0.25-1.9	4.9	Un-detached house	P+2	2.5
2	LP	60.8	179-190	0.1-5.0	4.3	Un-detached house	P+2	12
3	RB	103.5	285-620	0.25-3.4	10.6	Terraced houses	P+1	42



Kapetanove Pojate



Lalinske Pojate



Radikina Bara

Figure 6. Geological characteristics of terrain [6]

3.1.16. ОПШТА ПРАВИЛА ГРАЂЕЊА ЗА ТЕРАСАСТЕ ОБЈЕКТЕ

Терен није погодан за градњу уколико је нагиб већи од 45%.

Уколико је нагиб терена 20% до 45%, за објекте веће од 50м^2 бруто површине основе, и више од 70м2 развијене бруто површине, обавезна је изградња терасастих објеката. На терену нагиба 15-20%, није обавезна изградња терасасатих објеката али се иста препоручује.

За терасасте објекте важе специфична **општа правила грађења** која се односе на:

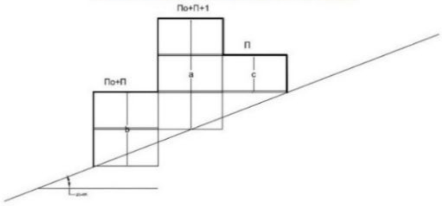
- **висину објекта,**
- **спратност,**
- **удаљење од суседних објеката и**
- **максимални дозвољени индекс заузетости,** као што је објашњено у наставку.

За терасасти објекат потребно је утврдити „**највећу референтну висину објекта**". Највећа референтна висина објекта утврђује се упоређивањем висине објекта од тла до врха у карактеристичним пресецима сваке ламеле терасастог објекта; највећа упоредна вредност висине кроз ламелу узима се као „**највећа референтна висина објекта**" која се користи уместо укупне „**висине објекта**" за одређивање испуњености задатих урбанистичких услова.

За терасасти објекат потребно је утврдити „**референтну спратност објекта**" која се одређује тако што се упореди спратност у карактеристичним пресецима од тла до врха сваке ламеле терасастог објекта и највећа од њих се узима за референтну спратност објекта, а која се даље користи уместо укупне „**спратности објекта**" за проверу испуњености услова о дозвољеној спратности.

Минимално удаљења од суседног објекта код терасастих објеката се утврђује у односу на "**референтну висину објекта**" уместо у односу на укупну „висину објекта".

Ограничења у погледу **максималног допуштеног индекса заузетости се не примењују** за терасасте објекте.



a > b > c Максимална висина објекта је "a" a≤ максималне дозвољене висине објекта

Максимална спратност објекта је По+П+1 (пример са слике)

По+П+1 ≤ максималне дозвољене спратности објекта

Терасасти објекти на подручју овог Плана по правилу имају **приступ** на две или више улица, а нулта тачка мора бити одређена као средња вредност нивелете уличног фронта једне од њих.

Повезивање на јавну инфраструктуру може бити остварена везом са неком од приступних улица или више њих.

Figure 7. Original excerpt from urban plan for Radikina Bara – Rules of Construction [7] for Terraced Houses (in English: 3.1.16. GENERAL CONSTRUCTION RULES FOR TERRACE BUILDINGS The terrain is not suitable for construction if the slope is greater than 45%. If the slope of the terrain is 20% - 45%, for buildings larger than 50m2 of gross building area, and more than 70m2 of gross floor area, the construction of terraced buildings is mandatory. On terrain with a slope of 15-20%, the construction of terraced buildings is not mandatory, but it is recommended. Specific general building rules apply to terraced buildings, which refer to:- the height of the object, - number of storeys, - distance from neighboring buildings and - the maximum allowable floor area ratio, as explained below. For a terraced building, it is necessary to determine the "highest allowable reference height of the building". The highest reference height of the building is determined by comparing the height of the building from the ground to the top in the characteristic sections of each lamella of the terraced building; the highest comparative value of the height through the lamella is taken as the "highest reference height of the object" which is used instead of the total "height of the object" to determine the fulfilment of the given urban requirements regarding the highest allowable height. For the terraced building, it is necessary to determine the "reference building storey" which is determined by arranging the spatiality in the characteristic sections from the ground to the top of each lamella of the terraced building, the object of the occupied object in the object that relates to the objects that relate to the objects. It is further used instead of the total "storey building" to check the fulfilment of the conditions on the permissible dexterity. The minimum distance from the neighboring building in the case of terraced buildings is determined in relation to the "reference height of the building" instead of in relation to the total "height of the building". Restrictions regarding the maximum allowed floor area do not apply to terraced buildings. a >b>c. The reference height of the object is "a", a a≤ the maximum allowed height of the object. The maximum number of floors of the building is Basement+Ground Floor+1 (example from the picture). Basement + ground floor + 1 ≤ maximum allowed floor of the building. Terraced buildings in the area of this Plan, as a rule, have access to two or more streets, and the zero point must be determined as the mean value of the level of the street front of one of them. The connection to the public infrastructure can be achieved via one of the access streets or several of them.)

2.2. METHODOLOGY

Following our intention to scientifically elaborate the abovementioned urban plans, we applied observation method and content analyses.

Among numerous issues addressed in these urban plans, as land abandonment, structural adjustment, adopt land use pattern, resilience to climate change, and, rural revitalization, whose research would exceed the scope of this paper, we focused on what came first - problem of settlement classification, and we discussed it in relation with territorial disparity and climate change resilience.

This research is step towards bridging the gap between practice and theory, which in case of good theory shouldn't exists.

3. SETTLEMENT CLASSIFICATION

The classification of settlements is one of the frequent problems in a scientific research of this kind. A problem, which seems formal and typically gets superficial attention in professional practice, is an important question in scientific terms, however, with non-univocal answer. Traditional urban-rural dichotomy is not adequate for defining territorial disparity nowadays, and there are many approaches which have been used for identification of urban, rural and peri-urban areas. The most widely used methods are those based on demographic and socio-economic variables [8]. Statistical offices, national authorities and scholars contributed taxonomy over the years (ib), resulting in tens of different classification methods, which focus, with different variations, on demographic dynamics, economic and social indictors, settlement structure, distance, or the combination of the previous.

Table 2. The five clusters of urban–rural methods and the variables they use to distinguish between territories [8]

Methods	The variables used for their definition
• **Demographic dynamics**	• Population density or other demographic indicators
• **Economic and social indicators**	• Economic structure, sector specialisation, occupation
• **Settlement structure**	• Size of clusters of dwellings and settlements
• **Distance**	• Distance in kilometres from the main and closest economic/ social centre
• **Hybrid**	• Use of multiple variables

Application of the first one results in unprecise or even wrong dichotomy, while the fourth – distance, defines the areas as urban fringes but has no relevance in the comparison, leaving at stake the middle two or their combinations (Table 2). Economic and social indictors are also of limited help, because economic activity is unmeasurable in practice. Based on specialization, LP can be characterized as rural, with small statistical advantage compared to other occupations, while the other two settlements do not have any specialization. However, the urban plans imply certain economic specializations in the future, in which KP and RB should dominantly specialize in tourism. For social indicators, data as "population changes, access to services, broadband internet connectivity, house prices, tourism and land-use/cover flows" are frequently used [9]. In current state, population increases in the all three, however very slowly, and due to migration in 2 of 3 cases, which happens because of equally-low house prices. Only LP shows some vitality and houses for sale are not available there. Availability of public services may be often a useful indicator [10]. however, in our case, values are similar in all three cases (under 3km of distance for LP and RB, slightly less convenient for KP).

If we add local specificness we come to the following. "In Serbia, the classification of cities and urban areas is based on administrative divisions as defined by law. Serbia's Local Self-Government units (LSGs) are categorized as a 'city' or a 'municipality,' based on the Law on Territorial Organization"… LSGs are further sub-divided into either urban or rural settlements. Typically, each LSG has a central urban settlement and a network of rural settlements surrounding it… Therefore, the territory and population of a "city" or "municipality" combines both urban and rural areas… The city classifications used attempt reflect the Serbian and ECA context while also aligning with global literature. The classification of cities as secondary is based on UN-HABITAT's definition of cities falling between 100,000 and 500,000…" [11]. In our case, the legal categorization may not be applicable, because KP, LP and RB are not any more independent settlements, but urban areas within administrative area of the city, i.e. rural (or not) areas within the city. Among them, only RB has relevant history as an independent rural settlement, while LP and KP are more dependable and more recent.

World Bank Serbia applied the following division:
• "Urban centre (city): The urban centre consists of contiguous grid cells with a density of at least 1,500 inhabitants per km² and a population of at least 50,000.
• Urban cluster (towns and suburbs): The urban cluster consists of contiguous grid cells with a density of at least 300 inhabitants per km2 and has a population of at least 5,000 in the cluster. An urban cluster can be a town or a suburban area.
• Rural grid cell: Rural clusters are villages that do not belong to an urban centre or urban cluster, most these will have a density below 300 inhabitants per km2. "[11]
This classification was established because they have recognized that "demographic data defined by administrative boundaries do not accurately capture the extent of urbanization in many countries across the world" (ib), and that administrative data may not be "reflecting a precise picture of Serbia's urban system", either. According to it, KP, LP and RB should belong to the urban cluster, regarding disposition but not regarding density which is much below limit.
Considering that urban plans imply change, at this point we can identify link between theory and practice – because the plans aimed to increase density to over 300 inhabitants per km^2.
The classification used by the Italian Government in 2014-2020 considered the three different areas in terms of altitude (mountain, plain, and hill) with the four categories of territories obtainable by applying the OECD methodology: urban poles with more than 150 inhabitants/km^2, predominantly urban with population of rural municipalities <15% of total population, significantly rural with population of rural municipalities >15% and 50% of total population etc. Eventually, they identified urban poles, rural areas specializing in intensive agriculture, intermediate rural areas and rural areas with development problems [12].
Structure of the settlements, described as "size of clusters of dwellings and settlements" (table 2) appears crucial in our case, and for it, different variables may be adopted. Spatial characteristics have been taken in account as relevant, indicatively, in countries with significant territorial disparities as Italy [12] [13]In our case, block size and characteristics, which are result of characteristics of terrain (geological, inclination, altitude etc.) are the only variables which significantly differ, leading to very different approach in planning of each area.

4. DISCUSSION AND CONCLUDING REMARKS

Urban fringes develop faster than core areas (Cattivelli, Methods for the identification of urban, rural and peri-urban areas in Europe: An overview, 2021). In 2020, 75% of Europeans have inhabited urban areas: 42% in the cities and the remaining in towns and suburbs. In Serbia, 60% of the population live in cities, contributing to 74% of all jobs and 75% of the national gross value added (GVA) (World Bank Serbia, 2023). This higher economic contribution of cities than expected according to size may be explained by economic advantages or "agglomeration economies" (ib), or significant presence of creative industries (e.g. software industry, gaming) for which vicinity reportedly matters [14]. In any case, urban areas economically matter, and urban fringes are places where they spread [15]
Urban fringes are relevant for food supply chain, and, therefore in Serbia, conversion of agricultural land is forbidden by law. Therefore, areas for living and work must remain where they have always been with some adaptations. Former villages or weekend-settlements, which remain suitable for such purpose, are rarely attached to the city, but more often create appearance of leapfrog development. Nevertheless, they generate a sort of territorial continuum with the urban core due to inherited both urban habits and transportation network, as well as with the rural areas in the vicinity. That is because those areas are not new, but inhabited (not necessarily continuously) for hundreds of years (unlike many cities e.g. in Asia). As such they are already well-adapted to the natural environment, with substantial resilience built in operandum vivendi, and they have already gained its place in the transportation network. Although, they may not have precise morphological identity at the time, often being in the process of urban transformation, they contribute to the economy, quality of living, and sustainability of the city or have potential to do so. They are resilient to speculative construction, and favourable for children and older population. Many obstacles and disadvantages of such areas, have reasonable solutions. For example, the entire water infrastructure in KP can be fully local, which is often neglected despite it being very practical, efficient and as such chosen as prevailing solution in many parts of the world. It is a paradox that Nish had one of the biggest productions of integrated units for water treatment for residential areas until early 21st c, but they were almost never applied locally. This is merely an illustration that technical solutions which were not taken in the account nevertheless exist, and could increase standard of living at

reasonable price without increasing ecological footprint – solving localized problem by localized, custom-made solution.

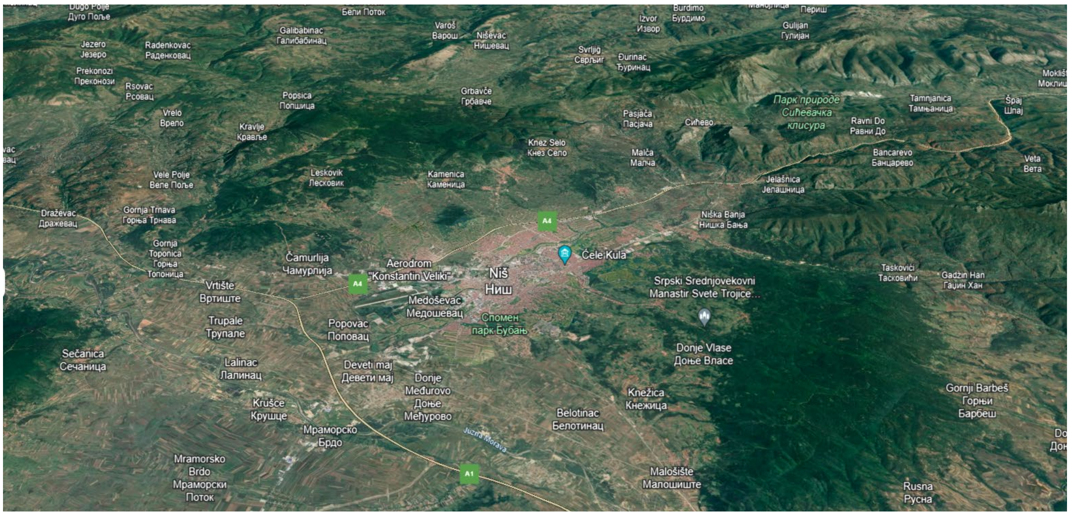


Figure 8. Arial view of Niš administrative area with topography [16]

Peri-urban and rural areas in relation to green transformation are sometimes discussed with positive and sometimes with negative connotation, however they are considered relevant. World Bank Serbia severely criticized such settlements as impossible to govern in sustainable terms, regarding in particular infrastructural network and resilience to climate change [11]. Although it may be true in some cases, and even frequently so in some countries, in case of Nish, based on the abovementioned areas, it is not so, which easily may be extended to Southern Serbian cities or even entire Serbia. The main reason for wrong conclusion is improper classification of such urban areas. The aspect which was neglected, besides from humanistic values of such settlements, is overall existence and relevance of heritage - transferred adoptability for populating certain area among generations, which is by definition long-term sustainable despite oscillations.

The classification of settlements is closely related to territorial disparity, and they are often discussed together due to inter-dependence. Lack of proper classification, the one which does not reflect true territorial disparity misleads both scientists and professionals. For example, in Germany this issue was addressed early – villages in German countries was almost obsessively researched since the late 19^{th} c, and generalization for the country as a whole was created based on numerous studies of small districts and comparative studies of historical and physical factors relevant for development and regional variations [17]. This early inductive research probably contributed that Germany nowadays has equally developed territory, with cases of higher economic contribution to GVA from rural areas (due to some international corporation situated literary in a small, wider-unknown village) than from some big urban areas (e.g. Berlin).

For example, data shows that 1km of street with the following infrastructure in Nish on average costs four times more than in Novi Sad [18]. That means, to achieve the same economic results, the comparative advantages of the location must be used four times more efficiently than in the area of Novi Sad, being used merely as a reference. That implies that the strategy of development must be more carefully planned and that the entire process is essentially different in the south than in the north of Serbia, but furthermore, in Serbia, it is fundamentally different among a few urban areas barely 15km away. Having such great diversity (fig. 6), additional attention must be paid to the strategy of planning areas in hilly terrains, because they represent at the same time both disadvantages and outstanding advantages for the economy, tourism, and quality of living. That further means that we may follow e.g. example of Italian classification, adopting additional variables for the classification, which are tailored for local environment. We intend to test different models in the future research papers.

Finally, it was not originally our intention to devote this paper entirely to the problem of classification od settlement, but to research many other aspects which the three urban plans addressed, and the classification was only the first step. Originally, we wanted to focus on urban morphology and characteristics of blocks, which were atypical, yet well-chosen and adequately implemented, and which gained the biggest attention among professionals. To our surprise, our starting point, the identification of type of the settlements in scientific terms, turned out to be much more complex than we originally expected. Therefore, the further elements of the intended scientific elaboration of our exhibit will be considered in our future research.

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12

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EFFICIENCY OF SOLAR THERMAL COLLECTORS ON STUDENT DORMITORY BUILDING IN THE UNIVERSITY CITY IN BANJA LUKA

Abstract

To achieve sustainable urban development goals, facilities must promote improved living conditions, reduce energy consumption, and preserve the environment. The Nikola Tesla student dormitory in Banja Luka's University City, a public landscape architecture area, meets these standards with its simple design, rational use of space, and moderate architectural expression. This study analyzes energy consumption in the 4th pavilion of the Nikola Tesla student dormitory in Banja Luka from 2018-2023. Solar thermal energy accounted for 4.63% of the total delivered energy. The paper highlights the importance of monitoring energy consumption over time.

Keywords: architectural design, student housing, STC (solar thermal collectors), DHW (domestic hot water)

ЕФИКАСНОСТ СОЛАРНИХ ТОПЛОТНИХ КОЛЕКТОРА НА ПРИМЈЕРУ ЗГРАДЕ СТУДЕНТСКОГ ДОМА У УНИВЕРЗИТЕТСКОМ ГРАДУ У БАЊАЛУЦИ

Сажетак

Да би се постигли циљеви одрживог урбаног развоја, објекти морају промовисати побољшане услове живота, смањити потрошњу енергије и сачувати животну средину. Студентски дом Никола Тесла у бањалучком Универзитетском граду, јавном простору пејзажне архитектуре, задовољава ове стандарде једноставним дизајном, рационалном употребом простора и умјереним архитектонским изразом. Ова студија анализира потрошњу енергије у 4. павиљону студентског дома Никола Тесла у Бањој Луци од 2018-2023. Соларна топлотна енергија је према прорачуну за посматрани период чинила 4,63% од укупно испоручене енергије. У раду се истиче важност праћења потрошње енергије током времена.

Кључне ријечи: архитектонско пројектовање, студентски смештај, соларни топлотни колектори, припрема топле воде

1. INTRODUCTION

The rapid growth of cities and the evolution of technologies and production methods had a huge impact on the development of the urban world. Cities develop in very complex patterns, with spatial, cultural, ecological and socio-economic characteristics. The growing popularity of the dispersive city model in the 20th century not only contrasted greatly with the earlier, more compact cities of the 19th century but also created negative consequences for infrastructure and resources. In response, solutions were sought for growth with less impact on the environment. Green urbanism is defined as the practice of creating communities beneficial to both people and the environment, where ecologically integrated and sustainable city planning can provide and enhance environmental benefits at local, national and international levels [1].

The city of Banja Luka adopted the Action Plan for a green city with a clear vision: "The city aims to be an example of innovative, smart and sustainable communal and traffic infrastructure, supported by an efficient land use system and increased resistance to climate change and other natural disasters." With a healthy and dynamic built environment, a network of green and blue infrastructure will protect and improve water resources, soil quality and biodiversity, maintain Banja Luka's reputation as a "green city" and define the task by which the City of Banja Luka should "establish an efficient system of energy use and reduce harmful impact on the environment to the minimum possible extent, improve comfort conditions and productivity in utility service systems" [2].

Nature in the University City is the most important park in Banja Luka and was placed under the protection of the Republic of Srpska by the Decision of the Ministry of Spatial Planning, Construction and Ecology in 2012, and in 2016 by the Decision of the Banja Luka City Assembly, a protected area with sustainable use of natural resources was declared a Monument of park architecture "University City" [3]. The park consists of rich horticulture from different periods, 1,500 trees, and rows of plane trees, some of which are several hundred years old, stand out. Along with the rich vegetation, 48 species of birds live here, some of which are legally protected, and the Vrbas River flows through one part of the border. The University City of Banja Luka is located in the complex of the former barracks of the JNA "Vrbas" and from the point of view of architecture, this area represents a heterogeneous group of buildings with very different purposes, time of construction, architectural form and material realization. The construction of an object in such a specific area implies the establishment of new qualities, ways of behaviour and the establishment of order, all by the spatial context dominated by the existing natural environment [4].

2. ENVIRONMENTALLY AND ENERGY EFFICIENT ARCHITECTURE

In the urban-architectural approach, the building of the Dormitory of Students and its author's concept followed certain principles of construction. The building of the student dormitory forms part of the street facade of the western approach to the Campus from the direction of the city centre. The extensive program of the House and the unambiguous design directions resulted in the longitudinal volume of the residential building, the dimensions of which are comparable to the neighboring residential district of Borik, an urban residential area typical of the socialist period and built in the spirit of the international style, which is characterized by an urban style of clean and bare forms, as well as a new dimension functionalism. The design of the Student Dormitory building was preceded by the harmonization of its purpose with the proportions of neighbouring buildings and the visual landscape from the Campus where it appears. The basis of the proposed concept is the functional differentiation of the building's contents into common (public) areas and private spaces (premises) so that a large closed structure of the building with a transparent front facade opens in the central part, which vertically connects the common contents.

The break that was made in the formation of the sequence of student rooms is filled by the remaining public facilities of the building - entrance hall, communications, common dining area and common living room. These zones are surrounded by glass walls that allow the view to the outside, but also indicate the internal dynamics of the use of the building to the views from the outside. The ground floor and the basement are part of the public content of the building, which serves as an administrative office, student clinic, classrooms and services. The proposed solution provides a capacity of 280 beds. The rooms are oriented to the east and west, and have natural lighting and ventilation. Long corridors are equally organized on all floors and are rhythmically moved by striking entrances to accommodation units. Each room is designed to accommodate two students and is equipped with a kitchenette in the hall and a bathroom. The authors have used color, thus giving vividness to the interior space of the building, and different floor colors are used to create the visual identity of each individual floor. The view of the outside space in the premises is defined by the existence of a transition zone, loggia. Movable metal shades on the facade give the user the option of choosing the amount of light or shadow that enters the room. Protection from the sun is realized through the form of dynamic design elements on the facade, which is executed in accordance with the layout of the front facade. In addition, the authors created freedom in the architectural expression of the very rational volume of the building by using colour on the facade. A playful set of panels of various colors and dimensions is a direct association with the young tenants of this building.

The goal of the Student House building project is to improve living conditions, reduce energy consumption and preserve the environment through a clear definition of the basic elements of functional organization and architectural materialization of the space. Design principles and ways of realization influenced the expected level of energy optimization and all elements of comfort for people's stay and work in this specific space. One of the goals of the authors of this architecture was to enable a satisfactory level of comfort in the space with minimal energy consumption in a rational way. In terms of achieving optimal conditions of spatial comfort and energy optimization:

• influential factors of comfort were examined /on-site conditions, microclimate, daylight, air pollutants, noise, etc./,

• established limits of desirable or acceptable comfort conditions in the space /temperature, lighting, air quality and acceptable noise levels/,

• controlled variable parameters / heat, air, light and sound / with the help of passive means / characteristics of the object / as far as possible and feasible,

• reduced energy consumption only for the control and maintenance of active means for providing comfort /heating, cooling, ventilation, lighting, noise protection, etc./.

In this paper, the five-year results of the savings obtained by the introduction of 100 roof solar thermal collectors (STC) on about 60 percent of the total area of the flat roof are analyzed in detail. The goal of their installation was to enable the domestic hot water (DHW) in a facility that has 150 bathrooms and is the main consumer of that water with energy from renewable sources.

Figure 1. Student Dormitory 4TH Pavilion, Campus, Banja Luka

3. ENERGY USED FROM RENEWABLE SOURCES

The fourth pavilion of the Nikola Tesla Student Dormitory has a heated gross volume Ve=23030 m3 with a conditioned area Au=7114 m^2 and a building form factor f_0=0.237 m^{-1}. The share of transparent elements in the total area of the building envelope is z=32.0 %. To reduce heat losses in transmission and categorize energy-efficient buildings, the building was designed with a U-value of the outer wall of 0.225 W/m^2K with a thermal insulation thickness of 15 cm. Transparent elements are double-glazed windows with multi-chamber aluminium frames. Flat roof elements are designed with a thermal insulation thickness of 15 cm and a U-value of 0.248 W/m^2K. In addition to the defined geometry, materials and climate parameters, the assessment of energy performance, according to its energy characteristics and the annual energy required for heating the building of the student dormitory, belongs to the *C* energy class [4][5].

The building sector offers many opportunities to enhance energy efficiency by integrating distributed renewable energy sources. The solar water heating systems are an effective technology for utilizing renewable energy, leading to savings on fossil fuels and a reduction in CO2 emissions [6]. Deploying electric water heating technologies is a key instrument for achieving these targets by enabling fuel switching, increasing efficiency, and supporting more renewables in the grid [7]. Solar thermal collectors (STC) are installed on the roof of the student dormitory building to produce energy for the preparation of DHW, visible in Figure 2.

Figure 2. Solar thermal collectors (STC) on the roof of Student Dormitory

One hundred polycrystalline STC with a total effective area of 235 m^2 were placed on a flat roof, oriented to the south and placed at an angle of θ=300. To estimate the energy generated by STC annually, data on the monthly global radiation received on a surface titled at an angle of 30^0 degrees for the coordinates (latitude = 44.77^0, longitude = 17.21^0) were obtained based on satellite observations. The actual efficiency was estimated in 2017 based on the characteristics of the STC and external influences (estimated difference between the inlet temperature of the collector fluid and the ambient temperature, received global solar radiation and shading) [8]. Average monthly efficiency of solar cells is highest in February (η=19.8%) and lowest in July (η=13.9%). The preparation of domestic hot water (DHW) is achieved by using solar energy, through STC, thermal energy from the district heating system and electricity. A system with 100 plates, arranged in 10 fields of 10 plates, was designed for the daily needs of approx. 9m3 of sanitary water. The minimum volume of energy accumulators is 6,000 liters and one sanitary water intermediate accumulator with a volume of 1,000 liters is planned. For the 2-hour consumption of 8700 litres, and the available capacity of the electric boiler 50kW, 4 tanks of sanitary water are provided, each with a volume of 1000 litres, filled via the exchange group Vitotrans 222 with regulation Vitotronic 200HK1B. The solar system is managed by the Vitosolic regulation - Viessmann Vitosol 100-G, absorber 2.3 m^2. The energy generated from STC is obtained using the equation:

$$Q_{sol}=\eta \cdot H_t \cdot A \qquad (1)$$

Where Ht represents the mean sum of solar radiation on the south-facing surface, and A is the total effective surface of the roof STC. The energy generated by STC at the level of one year is 78.2 MWh and represents a part of the total energy that is consumed for the preparation of DHW.

Figure 3. Boiler rooms at the Student Dormitory

The water in the recirculation system is heated by three boilers of 1000 litres to the temperature θw,del=50^{0}C. The temperature of the supply water during the year oscillates from θw,0=8^{0}C in winter to θw,0=14^{0}C in summer. Energy consumption for DHW is estimated based on the following equation:

$$Q_w = \rho_w c_w V_w (\theta_{w,del} - \theta_{w,0}) \quad \text{.....................................} (2)$$

Where ρw is the density of water and cw is the specific heat capacity of water (ρw.cw=1.16 kWh/m^{3}K) [9]. In this way, the annual energy consumption for the preparation of DHW was estimated for each year of the observed period. The total water consumption in the facility by year, 2018, 2019, 2020, 2021, 2022 and 2023 is shown in Figure 4.

The gross final energy consumption of the building during the year can be divided into supplied thermal energy, energy used for the preparation of DHW and electricity used for everything except the preparation of DHW. The values read from the bill for the consumed thermal energy for heating and the total consumed electricity were used to obtain the total annual delivered energy for the observed period. The total electricity used is the sum of the values read from the account by year and the energy obtained from the STC. These values are shown in Figures 3 and 4, while the share of energy obtained from renewable sources in the annual delivered energy, as well as its share in the total consumed electrical energy, i.e. in the energy for DHW, during 2018, 2019, and 2020, 2021, 2022 and 2023 are shown in Figures 4 and 6, and indicators of the value and structure of consumed energy in Table 1.

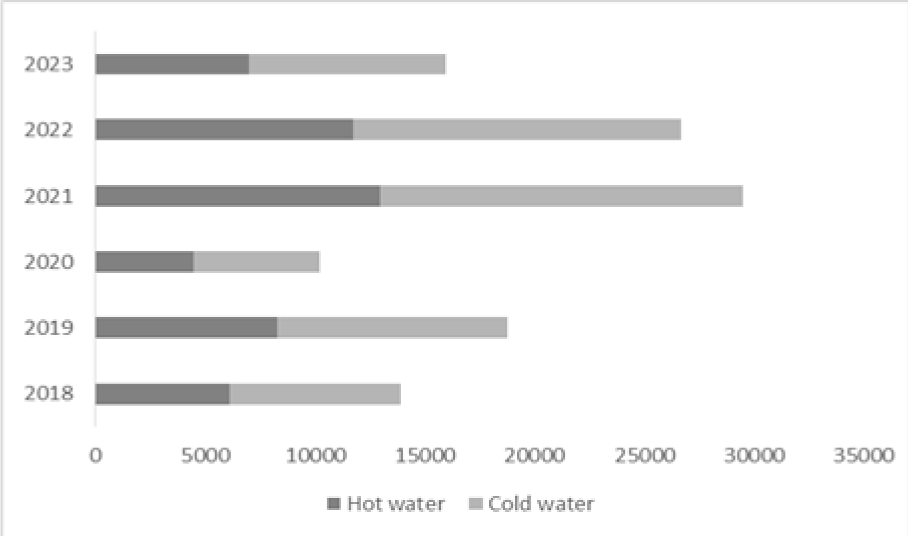

Figure 4. Water consumption in m^3 based on bills

Table 1. Indicators of the value and structure of consumed energy

	2018	2019	2020	2021	2022	2023	TOTAL
annual delivered energy of the building [MWh]	2,345.12	1,498.84	1,696.96	1,905.74	1,876.60	811.54	10,134.80
total electricity used [MWh]	708.84	953.74	915.36	1,040.24	1,172.80	492.70	5,283.68
total energy for DHW [MWh]	276.51	373.85	202.94	587.41	530.96	317.55	2,289.22
energy for DHW obtained from STC [MWh]	78.20	78.20	78.20	78.20	78.20	78.20	469.20
share of energy from STC in the delivered energy [%]	3.33	5.22	4.61	4.10	4.17	9.64	**4.63**
share of energy from STC in the total consumed electricity. [%]	11.03	8.20	8.54	7.52	6.67	15.87	**8.88**
participation of energy from STC in energy for DHW [%]	28.28	20.92	38.53	13.31	14.73	24.63	**20.50**

The annual amount of energy delivered was at its highest in 2018 and at its lowest in 2023. This was in proportion to the consumption of thermal energy for heating, which was highest in 2018 and five times higher than in 2023. According to the previously described calculation of solar energy that can be obtained and the energy data bills obtained, in 2023, the proportion of energy derived from renewable sources was at its highest for the period studied (9.64%), while in 2018, it was at its lowest (3.33%). The total amount of electrical energy used was highest in 2022 and lowest in 2023. The extreme values were recorded in 2018 when the lowest electricity consumption was recorded, and the highest annual amount of delivered energy. The total amount of electricity calculated for DHW has been highest in 2021 and lowest in 2020. This was in proportion to the consumption of DHW, resulting in 13.31% for 2021 and 38.53% for 2020.

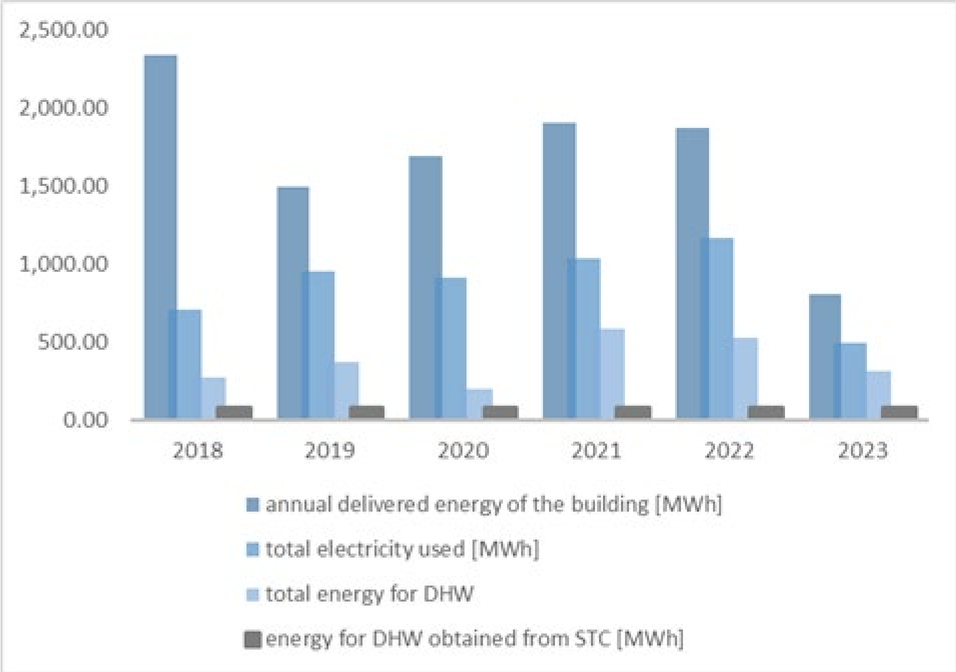

Figure 5. Value and structure of consumed energy

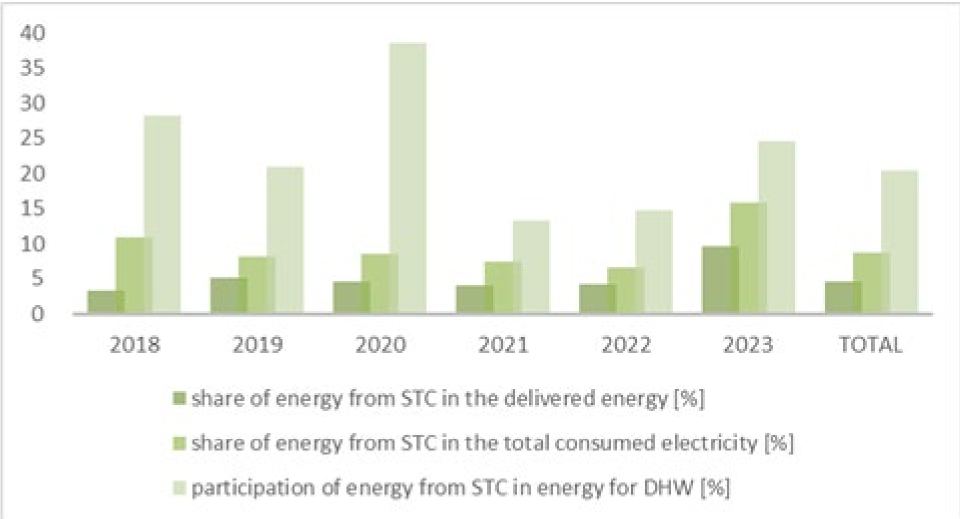

Figure 6. Participation (%) of energy from STC in energy consumption

4. CONCLUSION

The construction of the fourth pavilion of the Nikola Tesla student dormitory in Banja Luka sets an example of energy and environmental responsibility. The building takes into account the specific spatial needs, market and social characteristics of the local environment, along with the energy issue. It uses energy obtained from renewable sources for preparing DHW.

This paper presents the results of a simplified analysis of energy consumption from 2018 to 2023. The study examined the share of energy obtained from STC not only for the preparation of DHW but also for the total energy used by the building. The analysis was based on monthly bills for delivered thermal energy for heating, DHW, and electricity, as well as the calculated energy needed for the preparation of DHW and the energy obtained from one hundred polycrystalline STC on the roof of the building. The losses of the heating system and the system for the preparation of DHW were not included in the analysis.

The paper aims to demonstrate the values and changes in the structure of energy consumption on a yearly basis. The paper also highlights the importance of observing the period for an accurate assessment of energy consumption.

The results showed that the share of solar energy from renewable sources in the total delivered energy was 4.63% over the six years. The mean value of the share of energy from STC in the total electricity used during the same period was 8.88%, while the energy obtained from renewable sources contributed 20.50% to the total energy used for the preparation of DHW.

The share of produced DHW from the total amount of water used for DHW was not quantified, but it was used for research purposes from the values provided by the project. The manufacturer's data was used for the value of thermal energy obtained from the STC since the regulations on the energy certification of buildings in RS and FBiH do not contain a methodology for determining the STC contribution of DHW collectors during the year.

The extreme variability of the value of this participation, viewed individually by year, is due to the variability in the total consumption of energy and water, and other factors.

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13

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GENESIS OF SUBURBAN FORMS FROM THE SECOND PART OF THE 20TH CENTURY: ARCHITECTURE AND URBAN PLANNING IN CORRELATION WITH CULTURAL ASPECTS

Abstract

The dominant spatial transformation which was indirectly supported by the social revolutions of the last century is the suburbis or the suburbs such as are widely spread today. This phenomenon, which has been studied since the mid last century, has been analyzed through different contexts and geographic areas often referred to by different terminologies, depending on local conditions which shaped specific regional types and ways of functioning. The research aims to identify the regional occurrences of this phenomenon and to investigate the conditions that contributed to their formation. Also, it investigates the connection with cultural aspects that have impact on the genesis of settlements, as well as the ways in which the settlements themselves change under the influence of spatial factors.

Keywords: suburbis, genesis, cultural aspects, regional types.

ГЕНЕЗА СУБУРБАНИХ ФОРМИ ОД ДРУГЕ ПОЛОВИНЕ 20. ВИЈЕКА: АРХИТЕКТУРА И УРБАНИЗАМ У КОРЕЛАЦИЈИ СА КУЛТУРОЛОШКИМ АСПЕКТИМА

Сажетак

Доминантна просторна трансформација, која је индиректно подржана друштвеним револуцијама прошлог вијека, представља субурбис или предграђе, какво је данас широко распрострањено. Овај феномен, који се изучава већ од средине прошлог вијека, анализиран је кроз различите контексте и поднебља, често називан различитим терминологијама, у зависности од локалних услова који су обликовали специфичне регионалне облике и начине функционисања. Истраживање има за циљ да идентификује регионалне појаве овог феномена и да истражи услове који су допринијели њиховом формирању. Такође, истражује се веза са културолошким аспектима који имају утицај на генезу насеља, као и начине на које се сама насеља мијењају под утицајем просторних фактора.

Кључне ријечи: субурбис, генеза, културолошки аспекти, реглионални облици.

1. INTRODUCTION

The rural settlement arises as a spontaneous form of coexistence of its inhabitants with nature. It is subject to continuous processes of change, organically conceived, through the application of unwritten rules of construction with distinctly mixed functions of dwelling, agriculture and social life of the villagers [1]. It forms on the edges of fertile land and microclimatic conditions conducive to maximizing sustainability and independence of the settlement for smooth unfolding of everyday life. At the intersections of important routes, a village of greater commercial significance, through changes in its mode of production, assumes predispositions for the emergence of a city as a public good and social phenomenon. Such settlements characterize the presence of central urban functions, a network of social events, organization with clear rules, regulations, building mechanisms and behavioral patterns. Unlike the village, the city does not organize in relation to the territory; instead, it gradually organizes the territory according to its determinants [2]. According to Aristotle, a city is formed in such a way as to provide its inhabitants with a sense of security and happiness [3]. In his text "What is a City?" Luis Mumford states that the city is a special framework that directs the creation of various favorable opportunities for ordinary life with the importance of collective dramas. This essential difference distinguishes the city from the suburb, where the drama is absent. The city is a geographical complex, an economic organization. [4]. The phenomenon of the city forms through the art of living together, and Jean-Luc Nancy says that the city has been invented for the sake of community. It is a community that converges in a system of communication and coordination. Encounters require communication and communication is inherently dynamic. The city is a dynamic process [5].

Léon Krier argues that the basic spatial organization of the city is in the form of urban quarters, each of which contains all necessary central functions for urban life within a pedestrian-friendly territory. An urban quarter characterizes a precisely defined territory and functions within it. Given that certain urban functions are lacking in the suburb, rural use of land often appears, it remains unclear how the suburb should be treated and what it should provide to its residents, as well as how it relates to new changes and challenges. Once a clearly defined difference and basis upon which rural and urban centers have developed through historical changes, now becomes markedly incoherent. Significant changes in social and economic values between the two environments arise with the industrial revolution, marking the beginning of rapidly acting processes from which new spatial patterns emerge. Geographically speaking, the territory between these two patterns, which historically represented a clear boundary with distinct natural values, becomes the destination of transformation processes.

Cultural aspects among the inhabitants of a particular settlement define the way of perceiving, using and acting within space, as well as the existence of a value system, primarily determined by the mentality of the citizens. S.Vujović presents the definition of citizen mentality as "noble urban behavior of educated people whose basic virtues are dialogue, tolerance, and empathy." [6], while D. Simonović states that "the city represents to some extent a projection of the state of mind of its citizens, or their mentalities." [7]. Therefore, the structure of the population and their mentality are significant factors in shaping the space and identity of a settlement, as well as of its final experience.

2. THE GENESIS OF SUBURBIA

The complexity of the relationship between rural and urban areas and the processes arising from them (urbanization and ruralization) often come with mutual negative effects. The direction and monitoring of these processes should result in the sublimation of positive values of both rural and urban areas [8]. Urbanization, as a process of increasing the population of urban areas and the expansion of settlements, which includes the encroachment on rural territory and natural landscapes, illustrates Figure 1. The illustration is based on a typical city for easier visualization and tracking of the process dynamics. The basis for the development of the illustration is an imaginary valley where a medium-sized city is located with its surroundings, which was transformed through the aforementioned process.

Figure 1. Illustration of an imaginary valley.

The process is understood through two interdependent parameters: the space where it occurs and which it transforms and the time over which this change occurs. Time intervals, at which the intersections of the city and its territory are measured, represent significant historical, social, economic and political turning points, such as medieval cities, industrialization, automation, reconstruction after two World Wars and globalization. In fact, the time interval decreases with each intersection, while the space it affects significantly increases creating large oscillations, that is reflecting the accelerating pace of urbanization processes and their accompanying phenomena. Consequently, there are drastic forecasts about expansion of urban areas in the near future, especially in third-world countries. The identified and previously explained process of urbanization occurs in all directions inconsistently forming irregular suburban agglomerations interspersed with „greenfield" neglected green spaces. The acceleration of the urbanization process through continuous explosions and implosions of urban tissue pushes the known boundaries of human settlements so far.

Some time ago, physical and functional distinction between urban and non-urban areas was clear, but it is increasingly fading. The moment when a means of overcoming greater distances through mechanization is found, it will lead to the growth of cities beyond the previously established frameworks. The clear transition between urban quarters and rural surroundings disappears with the influx of new population and the opening of new industrial facilities. The period of economic prosperity and the discovery of new modes of production has long passed, but the process of transformation in urban and suburban structures initiated back then still continues, penetrating deeper into the provinces and leaving behind many unresolved structural and social issues. Particularly concerning is the fact that current trends in population growth suggest that the mega-cities of the future will primarily be concentrated in the third-world countries of Africa and Asia. The issues arising from such trends are multifaceted, particularly when it comes to the socio-demographic factors influencing population demographics and migrations. The speed, number and complexity of these changes have created a complex system of sensitive cause-and-effect relationships, most notably observable in the case of large cities and metropolises. The once reasonable dimensions of cities are disappearing under the guise of capitalism and neoliberalism, where social and spatial-physical aspects have become instruments for profit-making or capital accumulation. The growth of cities creates challenges in many fields; the continuous influx of poorer populations necessitates social care and the reproduction of housing settlements within areas of their purchasing power, thus re-entering a process of circulatory extraction from the periphery, a sort of urbanization machine through which rural areas transform into uniform suburban patterns [9]. A particular problem arises from the exchange of populations between these two environments, where identities and cultural patterns significantly intertwine. The population of urban centers, which has been present there for centuries and in recent decades moved to rural and suburban areas, while residents from rural areas are settling in urban centers [10]. Such a process is present in the cities of Western Europe where in urban historic parts entire quarters of resettled inhabitants, often from other countries, cultures and continents are formed. Moving out from traditional Italian houses in the central district of Brescia, where families from the Middle East or North Africa are settling, will influence the way that house, courtyard and even street are used.

3. METHODOLOGICAL FRAMEWORK

After the Second World War, the term and the concept of suburbs experienced a transformation and popularization primarily on the soil of North America, gradually spreading to other geographic areas of the planet [11]. The problems accumulated in traditional forms of settlements are not resolved through the hybrid offered by the suburb, as can be observed through global examples. There are many suburbs and their variations across cultures. Some are more successful in addressing certain issues, some only transform them but none has successfully solved or provided an alternative to the urban problem. Therefore, it remains important to examine representative regional types, the way they arise, their characteristics and their goals. Thus, a clearer understanding of the same phenomenon can be provided which is differently conceived in different conditions and cultures with varying levels of success in terms of human settlements.

Eight examples of suburbs were considered, chosen as representative from their respective regions/continents. The starting point for creating groups of suburbs is the classification of genetic regions established by L.Holzner and colleagues as far back as 1967, (North America, South America, North Africa, Tropical Africa, Europe, East Europe, Central Asia, Middle East, South Asia, Indochina, East Asia and Australia). Figure 2. [12]. These defined regions served as polygons for identifying representative regional types of suburbs, which were subjected to a multi-criteria analysis presented through diagrams. The criteria on which the analysis is based include: mode of formation (planned vs. unplanned); space it occupies (population density and degree of plot occupancy); level of organizational and functional autonomy (non-residential functions); network infrastructure (existence of road, sewage, water supply, electricity and optical networks); connectivity with the city (number and quality of connections-accessibility); green infrastructure and connection with nature; security aspects (for residents and visitors); and aspects of social interaction (greater number of interactions), Figure 3&5. To examine the established process, an approach based on the inductive-deductive method was used, starting with global types and then focusing on a specific area of the Banja Luka periphery. The research narrowed its focus to one settlement within the Banja Luka periphery, the settlement of Madjir (Figure 7), which is undergoing transformation from a rural settlement to a suburban one through processes of the 20th century.

Cultural differences (the culture of spatial behavior and the culture of space utilization) play also a significant role for this research since they have largely shaped spatial patterns through the use of the space by their residents. This refers to the norms, values, and practices that dictate how individuals or communities interact with and use physical space. This is crucial for understanding how people navigate and inhabit different environments, ranging from public spaces to private spaces.

4. REGIONAL TYPES OF SUBURBIA

It is understandable that widely spread and diverse continental phenomena can hardly be generalized and unified. However, some basic spatial-functional axes can be recognized as the way they are formed, the processes that condition them and the level of development they reach. Many global suburbs repeat the mistakes from American examples, where extremely isolated communities dependent on cars and fossil fuels evolve, requiring increasingly long distances to be traveled for everyday activities. It is largely linked to the fast lifestyle that appears in all segments, with the slogan "time is money," so the "fast" culture is also reflected through spatial categories and Herzog speaks of "fast urbanism." In it, inhabitants live at an accelerated pace in an expanded built environment, which has expanded from concentrated cities to sprawling peripheries. Once envisioned as a place for escape to a natural and quieter habitat, it is transformed into an extension of big metropolitan areas [11].

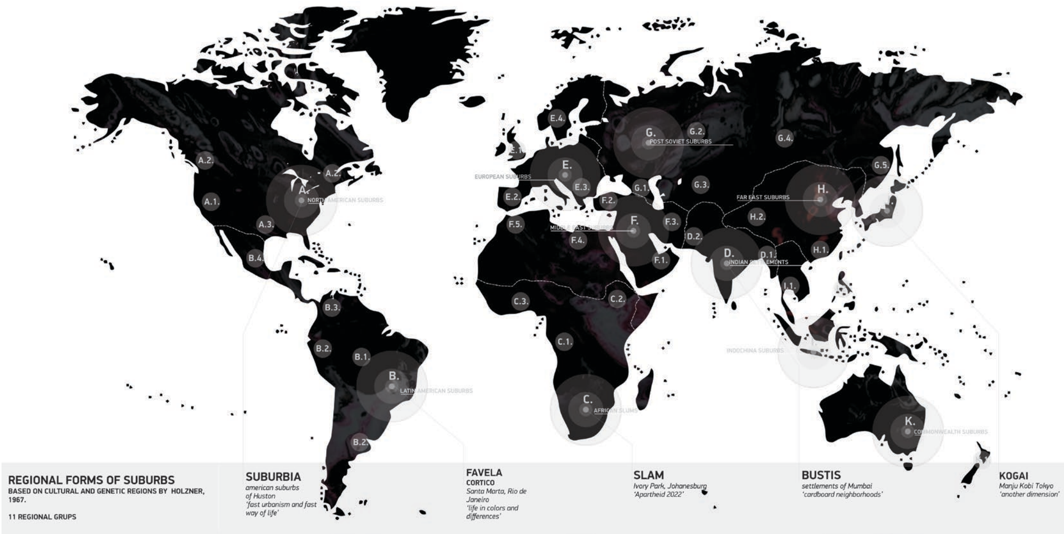

Figure 2. Regional types of suburbs based on cultural regions.

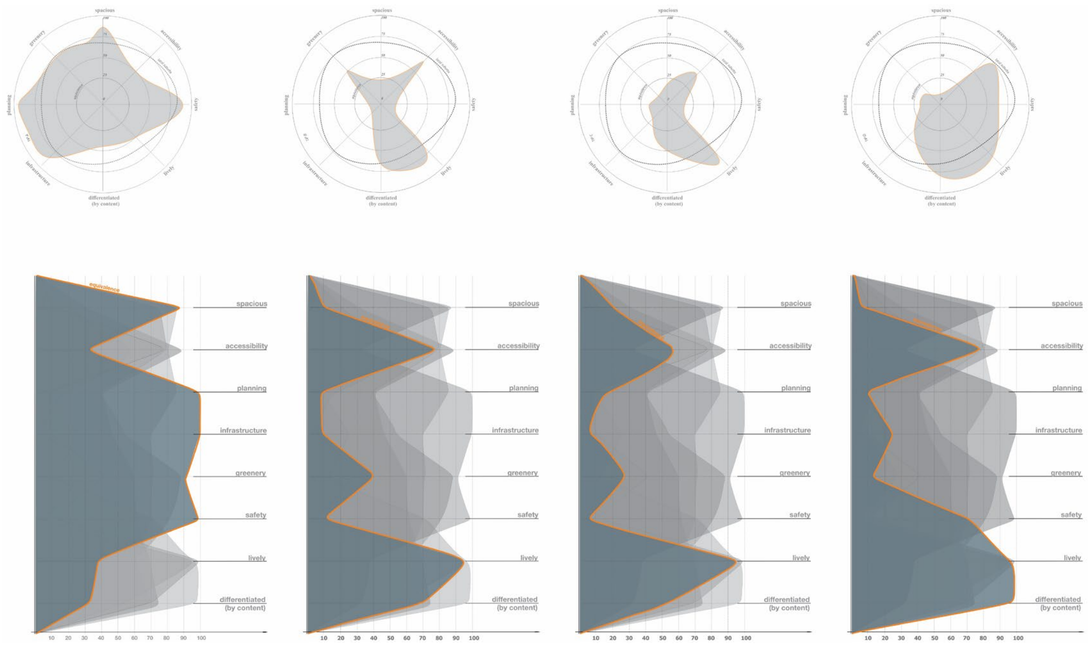

Figure 3. Multi-criteria analysis diagram of regional suburbs types A,B,C,D.

A) The N.American Suburb. Example of the suburb type A on the global network relates to the suburbs of North America, where such a concept was popularized and expanded to other parts of the planet, with its regional determinants.

It emerges as an alternative to densely built urban centers, where life has become expensive for some, noisy and fast for others, so they move into quieter suburbs. A significant factor in such a decision is the possibility of fast transportation and communication, which are the backbone of development not only of these settlements but also of the entire economy. In such a hierarchical structure, the automobile becomes the dominant factor in communication leading to the construction of more and more roads, while pedestrians become marginalized, deprived of the ability to cover all necessary distances [11]. These are planned settlements on vast territories that contain a densely distributed structure, with all necessary services. There are distinctly residential functions, with centrally located facilities serving several smaller settlements. A notable lack of identity is reflected through the uniform structure of settlements, identical forms, materializations, and very often identical residential buildings, thus creating a labyrinth that expands indefinitely into mega-urban forms.

B) Favelas of South America. Suburb type B on the global network refers to the suburbs of Latin America, better known as favelas and cortiços. The characteristic landscape of suburban settlement B is a densely built structure, where communication is subordinate to pedestrians, with a multitude of colors and events. The colors represent the character of the Latin American community and the result is a process of space appropriation. The Santa Marta settlement is home to 8000 residents who live in 500 wooden and 2000 brick houses. It has only one small market and three police stations, implying a security problem. The area of South and Central America are perceived as a regional whole with approximate economic conditions and cultural norms that have influenced the development of the regional form of suburbia, expressed through the favela. Brazil, as one of the fastest urbanizing nations in the world, certainly leads this group, where first such settlements were built in the 19th century. Rio de Janeiro is particularly interesting—a city of diversity, a global metropolis with many contrasts and inequalities in social and physical structure. Thus, settlements can often be seen, formed unplanned with low living standards, juxtaposed with high-rise settlements with different standards and characteristics [11]. Favela is an unplanned settlement on a small territory that contains a densely distributed structure, often with minimal urban elements and services. Unified in function and content, but differentiated by many other elements, it is always lively with a pronounced sense of place.

C) Slums of Africa. Suburb type C refers to settlements in the African continent, primarily to the part influenced by local cultures and identities. It is impossible to generalize Africa as a continent and typologically consider it uniformly due to its enormous diversity and local distinctions. In this sense, through this example, a parallel is drawn in relation to other global models. There are many connections with suburbs B and D, but there are still certain differences and unavoidable cultural and climatic influences. The research focuses on the Ivory Park settlement in the vicinity of Johannesburg, South Africa, which belongs to one of the most developed countries in Africa, thus differing in urban conditions from other parts of the continent. The settlements possess a certain degree of planning, with clearer traffic communications and formed blocks, with buildings constructed from perishable materials. A significant theme of these settlements is security, resulting in frequent introduction of police patrols and checkpoints [13]. The urbanity of the settlement remains at a low level, and there is still differentiation in the urban landscape and social structure. The concept of apartheid (a system of social segregation, separate development) originates precisely from the SAR, which is evident through urban planning practices and everyday life.

D) Settlements of the Indian subcontinent. Suburb type D represents settlements in the Indian subcontinent, which predominantly illustrate social disparities expressed through the physical structure of 'urban' settlements. The main economy revolves around the street, which serves as a place for socializing and meetings. The main characteristic is the multi functionality and ephemerality of architecture and urbanism. India, as one of the fastest-growing demographic countries in the world, faces the problem of urban overpopulation. Decades-long struggle with uncontrolled growth has not yielded significant results in practice. Moreover, social differentiation has never been more evident in terms of scope and structure.

A particular issue is the informal settlements formed by the migration of poorer populations without real economic means to build homes. The largest settlement of this type, not only in India but also in the entire Asia, is Dharavi. It houses more than a million residents in just 2 square kilometers, making it 277,136 residents per square kilometer [14]. Over time, the settlement develops its local economy, which annually amounts to over a billion dollars. The economy is based on the production of textile products and waste recycling, in which numerous residents of the settlement participate [15]. Life happens on the streets. There is a stronger sense of community and interdependence in everyday life. The picturesque landscapes of the spread and hanging clothes, with a multitude of colors, as well as poor collective hygiene, characterize the area.

Figure 4. A) American neighborhood; B) Favelas of South America; C) Slums of Africa; D) Settlements of the Indian subcontinent.

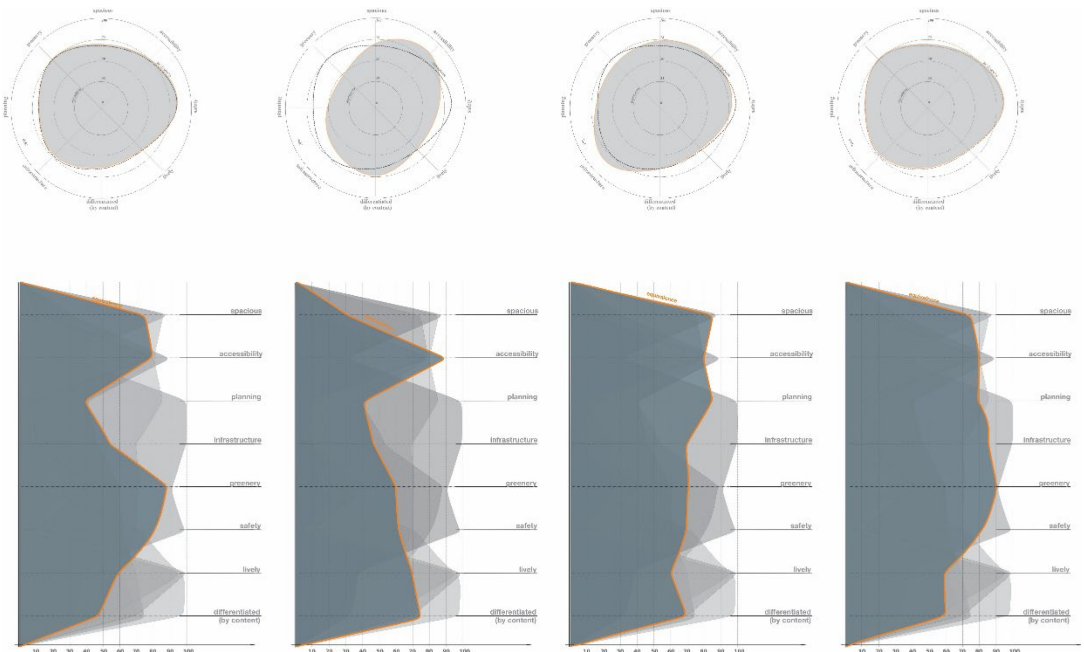

Figure 5. Multi-criteria analysis diagram of regional suburbs types E,H,J,G.

E) European suburbs. During the long urban development on the European continent, numerous settlements developed alongside the cities, outside city walls. This process was particularly present during the great expansion beginning in the New Age. Until then the class zoning of the city, where the city moves from the center where upper class is located towards the periphery and lower classes, loses such a hierarchical order. Citizens of old city centers increasingly rely on healthier environment in suburban areas outside the city center for their stay, which ultimately becomes their permanent residence. Perhaps the most striking example is found in England where 86% of the population lives in some form of suburb (43% in 20th-century suburbs, 23% in 19th-century suburbs, and 20% in dispersed settlements) [16].

During the development of European settlements through different social systems, new or modified existing suburbs also emerged. Generally, they can be divided into various regional groups: Eastern European (socialist) and Western European (capitalist); British and European Continental; Northern (Scandinavian), Central, and Southern (Mediterranean). For us, this last classification is the most significant, emerging under the influence of climatic and cultural factors. The proximity and influences of these regional types are visible in the local Balkan suburban form.

Brondby, Garden City, Denmark (North) Is a planned settlement that contains evenly distributed organic structures organized into circular clusters. The settlement is subordinate to natural environment, coexisting with it. There is a strong sense of community within the clusters, forming a multi-family group with individual housing, providing necessary privacy for each family.

Suburbia of Madrid, Spain (South) These settlements contain all necessary services and amenities for functioning of the community enabling that most needs are met within the settlement. However, the problem of social interaction remains pronounced, which is much greater in urban and rural environments that have a historical context.

Esslingen am Neckar, Germany (center) A settlement with a uniformly structured layout, equipped with necessary urban elements and services. Unified in function and content, it arises under the influence of modern suburban trends of moving away from the city and traditional urban-forming elements. In many cases, it lacks the liveliness of urban neighborhoods and spontaneous street events.

H) Chinese suburbs. Settlements in China that take on the character of suburbs are referred to as "urban villages." The emergence and genesis of such villages differ from all previously identified examples of suburbs. They originate as rural settlements, which are often older than the cities they are now part of. The economic opening of previously closed-off China to the world marked a turning point in all social and spatial spheres. Under the umbrella of economic prosperity in urban manufacturing centers, there has been a tremendous increase in the size and the number of mega cities. Today, China counts over a hundred cities with more than a million inhabitants [17]. Paradoxically, urbanization in China (or chengshihua) does not imply an increase in the urban population. With the increase in the number of inhabitants in the city, the number of its rural residents also grows. This is a reflection of the dual "hukou" policy from 1958, when households were classified as "urban" or "rural," a classification that persists to this day. Such a system grants different rights to the mentioned groups, so the population with "rural household registration" cannot access urban services, educational, and healthcare institutions despite permanently living in the city [18]. The most prominent example is Shenzhen, located on the border with Hong Kong, now one of the world's largest metropolises. Out of a total registered population of 12 million, only 2 million possess "urban household registration." Through rapid economic and spatial development, a small settlement quickly transitions from a township to a regional town and then becomes a million-person metropolis. By absorbing nearby rural areas and urban villages and incorporating them into its structure in an invasive manner, the number reaches 241 of incorporated villages into the urban fabric of Shenzhen in a couple of decades [18]. These villages, without arable land, have lost significance and purpose, becoming (involuntarily) marginalized components of the city and a source of the most favorable building land. Characterized by: their rural original character, which has invasively transformed into suburban; high population density; organic formation of settlements with empirical spatial organization; affordable housing space with a lack of infrastructure.

J) Japanese kogai. The case of the Japanese settlement known as "kogai" represents a unique type of suburbia, which can only partially be equated in certain aspects with it. It would be quite bold to say that it is the same term; their connection primarily stems from spatial aspects. The term "kogai" refers to a space where the city transitions into nature, and nature meets the city. It is a place where residents from immediate proximity enjoy views of natural landscapes. As such, it represents an indigenous Japanese type of suburbia, which has largely been lost due to the wave of internationalization and capitalism that engulfed Japan in the past century [19]. The "kogai" settlements are planned areas constructed along the railway next to parks, followed by parceling and land allocation for building residential units for the middle class. The first such undertaking is described by Cécile Asanuma-Brice in her book "The Century of the Japanese Suburb," and it concerns Manju Kobe, created in 1930 by O. Magosaburo, a city near natural landscapes where industry is located in the center of the settlement, surrounded by residential areas for its workers. The urbanity of the settlement is visible, where the quality of life for workers and families significantly increases, and education becomes more accessible. Magosaburo's radical move, which transforms the previously established principle that the company lives off its workers into a more humane form where workers live off the company, represents a significant turning point for the Japanese suburbia and its residents [19]. Such a model of urban development was replaced by the adaptation of the American suburbia after World War II. Although initially seen as beneficial, it radically changed the course of development of Japanese cities and their relationship with nature.

G) Socialist suburb. The Eastern European socialist example of suburban development emerged in the period after World War II, when all urban planning and market organization were executed according to the model of central state planning. A strong state apparatus implemented an economy based on price control and housing provision operated on a merit-based principle. During the period of economic collectivization and industrial development, there were forced migrations of population from rural areas to cities, leading to the emergence of numerous new cities as specialized industrial centers. The relocated population from rural areas often could not afford to purchase expensive urban real estate, so housing issues are addressed on the city outskirts, relying on cheap public transportation [20]. The process of accelerated suburbanization and the transition of rural population (not into cities, as desired) to suburbs is referred to in the literature as "Eastern European urbanization" [21]. During times of strong state control, planned settlements were built primarily to serve industrial facilities. This was the case with cities located in eastern or interior regions of the country, often for security reasons [22]. However, after the weakening of the system, unplanned and individual construction became more common. With the cessation of central planning, new actors emerged in the market as decision-makers in important urban planning matters. Cities experience a new wave of development, leading to rising property prices and the decline of non-competitive privatized industrial systems (leaving many brownfield areas), which has sparked a new wave of population migration and the growth of suburban areas. Green spaces and voids in socialist suburbs become construction land under new market conditions, often introducing new functions into residential areas. For example, in the Prague 11 district, we observe a heterogeneous structure of settlements and the filling of green areas with smaller individual objects. The abolition of socialist forms of public control, along with increased capital and market opening, has led to increased construction and the opening of small businesses, thereby adding functional complexity to what was previously predominantly residential areas. Good connectivity with the urban part of the city through public transportation is also crucial [23].

Figure 6. E). European suburbs; H) Chinese suburbs; J) Japanese kogai G) Socialist suburb.

5. BANJA LUKA SUBURBS

As was previously analyzed in this research, the structure of the population and their mentality are significant factors in shaping the space and identity of settlements, as well as in experiencing them. By observing the outskirts of Banja Luka, the influence of cultural aspects on the experience of the settlement can be seen and rural utilization of space often appears, distancing it from urban city quarters. Although the total population in the city's territory has decreased compared to the last population census in 2013 [24], certain settlements are experiencing enormous expansion.

Specific social conditions and urban development policies at the beginning of the century created favorable conditions for the emergence of parts of settlements and even entire settlements on the outskirts of the city, often built informally. A greater supply of land, more affordable land prices, and the lack of property taxation were incentives for the development of suburbia. The trend of the emergence of these settlements is not merely a consequence of recent events; it is a far more complex phenomenon. One of the significant influential factors is local migration, driven by economic, educational or other factors. Local migration typically involves the movement of people from rural to urban areas, resulting in the expansion of areas directly adjacent to urban city centers. Over time, a suburban ring forms around the densely built urban core. In the early stages of its development, in the mid-20th century, there was a connection to American suburbs characterized by their displacement from the city center (where daily activities rely on road traffic), relieved regulations, and building systems (resulting in settlements such as Budžak, Petrićevac, Rosulje). In the subsequent decades, planning shifted towards socialist ideology and centralized management, especially after a major earthquake. Only after the dissolution of the Socialist Federal Republic of Yugoslavia in the 1990s, the relaxation of the measures and state control occurs, even leading to a lack of regulation. An individualistic approach to spatial planning emerged, reflecting cultural aspects that significantly shape the use of space (resulting in settlements like Lauš, Motike, Debeljaci, Kuljani, etc.). The plot becomes a field for personal experimentation, and the construction of residential buildings reflects the social status. In such a system, the deviation from established construction procedures occurs where the entire process is based on individual decisions, often disrupting existing relationships within the context. This was the consequence of the lack of strategic planning and the low capacity of local communities to manage this process. [25]

In this sense, an analogy can be drawn with suburbs in South America which emerged under different climatic and cultural conditions but driven by similar needs. In the past decade, there has been a pronounced trend of urban infill on vacant green spaces and the expansion of existing settlements with heterogeneous structures. There is also a trend of hyper-construction of luxury properties near significant natural resources, leading to changes in the structure with the influx of a newly formed elite in certain settlements (such as in Prijecani).

Figure 7. Panorama of Mađir settlement.

The settlement of Madjir is situated on the border between spatial patterns (as shown in the diagram on Figure 8), with evident absence of central urban functions, informal spatial organization, weak infrastructure, and connections to the city, which significantly distances it from urban patterns. It possesses numerous unused lands, termed 'urban/non-urban rifts', once used for agricultural purposes, with significant natural potential. However, it faces challenges related to environmental preservation, further distancing it from rural forms. Trapped between two patterns with ambiguous characteristics, Madjir emerges as a product of a specific social and cultural context.

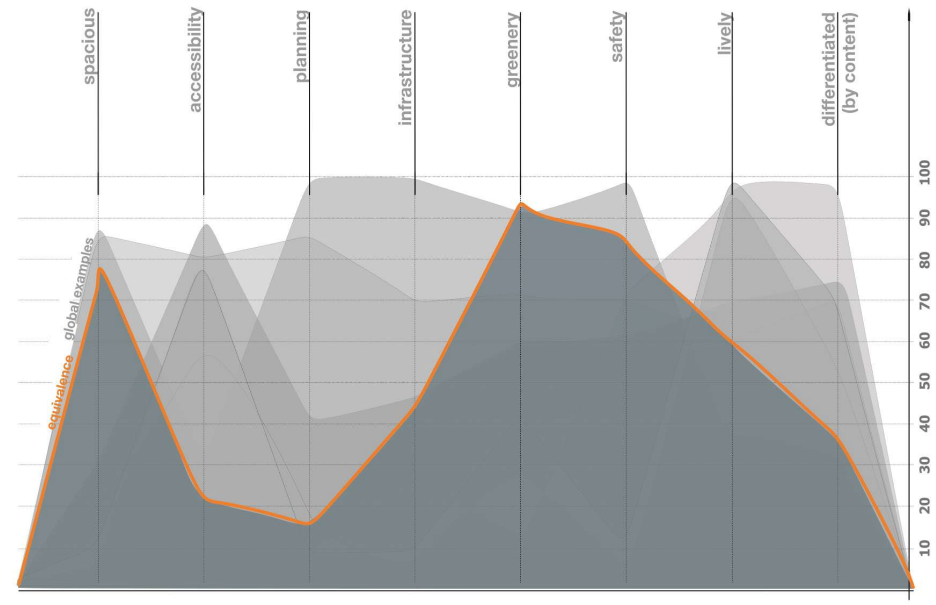

Figure 8. Analysis of the quality of the Mađir settlement.

1. CONCLUSION

In a rapidly growing world, urban development often becomes a non-synchronous factor, as evidenced by the phenomenon of suburbia. The globalized way of life and attitudes towards the environment, which spread to all spheres of society, led to significant urban explosion. Dominantly, it brings with it a suburban way of life. Through the method of comparative analysis, we have studied typical suburbs across the planet, from the globalized American neighborhoods appearing on various continents with regional variations, to the original types of the Far East.

Each of them possesses its own specificities, advantages and flaws, which in this research served to better understood the genesis of a suburban settlement around different regions. These examples have shown that the uniformity of function, density of development, and distance from the city influence social interaction, as well as the sense of security (comparison between American and Indian suburbia). The character of various elements. (the context, nature, neighbors and ultimately the house with the plot) of suburban settlements reflects the mentality and behavior patterns of the residents and the influence they have on shaping entire settlements which is more prominent in societies with weaker regulation and individualistic approaches to the construction. For example, in the case of Banja Luka, we can follow various directions of suburban settlement development in different periods though with very similar cultural determinants. It is concluded that primarily the degree of construction freedom and situational necessity have influenced the directions of development, while the cultural aspect is more in service of the relationship and care towards the space.

How can we overcome the pattern of urban sprawl that has become so dominant worldwide, including in the territory of Banja Luka? The answer might be in growth and new urbanism that should advocate for a proper form (as we can observe in examples of Scandinavian suburbs from chapter 3.5.), which will lead to slower expansion and a more humane process of urbanization. Factors contributing to urban lifestyle such as cultural values and behavioral patterns need to evolve if we want more sustainable cities. New approaches should leverage best practices from existing settlements and learn from their mistakes. The key may lies in recognizing significant elements and moments and influencing them in further development. The academic and professional community, planning and design institutions should embrace the phenomenon and continually engage with it, directing suburbanization processes to minimize environmental impacts and enhance community sustainability in every aspect possible.

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14

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HIGHRISE BUILDINGS IN HOUSING CONSTRUCTION: ECONOMIC EFFICIENCY VS SPATIAL BALANCE

Abstract

Nowadays, many growing cities around the world face very intensive construction in the housing sector. The pressure of the construction sector is reflected in the insistence on increasing the number of floors of residential buildings due to economic profitability, while the principles of spatial balance and sustainability are questionable. Therefore, this research seeks to discover which minimum number of floors of residential buildings ensures the economic profitability of the investment in housing construction. The methodological approach, based on the relevant principles of urban economy, ensures the development of a model for empirical testing of spatial and economic relations. The research polygon is the residential module from the regulatory plan of the residential settlement located in the area of a fairground in Banja Luka - Bosnia and Herzegovina.

Keywords: highrise building, housing construction, profit margin, optimal building height

ВИСОКЕ ЗГРАДЕ У СТАНОГРАДЊИ: ЕКОНОМСКА ЕФИКАСНОСТ ВС. ПРОСТОРНА РАВНОТЕЖА

Сажетак

Данас се многи растући градови широм свијета суочавају са врло интензивном изградњом у стамбеном сектору. Притисак грађевинског сектора огледа се у инсистирању за повећањем спратности стамбених објеката ради постизања економске исплативости и оправданости, при чему је поштовање начела друштвене правичности и просторне одрживости упитно. Стога се у раду настоји открити која минимална спратност стамбених објеката обезбјеђује економску исплативост инвестиције у изградању стамбеног објекта. Методолошки приступ, темељен на релевантним начелима урбане економије, осигурава развој модела за емпиријску провјеру просторних и економских односа. Истраживачки полигон је стамбени модул из регулационог плана стамбеног насеља смјештеног на простору сајмишта у Бањој Луци - Босни и Херцеговини.

Кључне ријечи: вишеспратнице, станоградња, профитна маржа, оптимална висина зграде

1. INTRODUCTION

Urbanization leads to the spatial and physical growth of cities both in terms of expanding their territory and in terms of their vertical growth and building density. The greatest pressure on the city in the process of urbanization is exerted in the domain of housing construction through the expansion of residential areas and the increase in housing densities. If privately owned urban land intended for housing constitutes 4/5 of the city's territory [1], it can be said that the construction control in the housing sector represents a key regulatory instrument on the path to achieving a sustainable city. The intensification of high-rise housing construction is often the result of economic pressures and the developer's demand for profit maximization. The question of urban sustainability requires a careful analysis to ensure that economic efficiency does not dominate over other aspects of urban space, as well as needs of the city and its citizens. Given the impact that multi-story residential structures make on urban infrastructure, socio-economic dynamics, and citizens' quality of life, the analysis of the economic efficiency of housing construction becomes crucial in terms of achieving spatial balance and viability. While the market often focuses on profit maximization, it is important to reconsider whether this strategy supports the balanced development of the city and its settlements.

The sustainability of growing cities as complex urban systems is an issue directly addressed by urban plans and planners. As an instrument of social production of space, urban planning represents an objective-rational and socio-communicative process of establishing new spatial relations [2]. Since planning unfolds within a communicative arena, involving actors with diverse (professional) viewpoints, it is necessary to adapt planning practices and methods to enhance dialogue in the collaboration process, simultaneously bringing the best planning solutions. This entails openness to new knowledge and continuous learning by all involved actors [3]. Misunderstandings and tensions evident in the relationship between investors, decision-maker (local administration) and planners are the key inhibitors of productive dialogue and obstacles to achieving consensus.

The prerequisite for breaking down communicative barriers in these relationships is the development of mechanisms for better understanding. Therefore, based on the application of principles of urban economy [1, 4, 5], urban planning parameters and other aspects of urban-morphological analysis, this research develops a model enabling the analysis of spatial and economic planning indicators in multi-family housing. It is expected that this spatial-economic model for analyzing alternative plan solutions, in its further development, will serve as a valuable tool for planners and decision-makers during negotiation processes with investors, aiming to achieve sustainable planning solutions that entail an optimal balance between private and public interests in urban spaces. In other words, its application would ensure better-informed decision-making and improved urban planning. The testing ground for the developed model is a residential plot in Banja Luka, the capital city of Republic of Srpska as one of the entities of Bosnia and Herzegovina. The plot is treated with a new regulatory plan within an area currently used for fair purposes.

The integration of economic factors into urban planning enables a more comprehensive approach to city development, taking into account both economic and spatial aspects. Through an interdisciplinary approach, this study aims to provide insights into the complex dynamics that shape urban morphology and the economy of residential construction, while simultaneously exploring ways to balance economic interests with the demands of spatial sustainability and social justice.

2. METHODOLOGY

The methodological approach of this research is based on the analysis of spatial and economic indicators using a specific plot as an example, where the regulatory plan envisages the construction of three residential row multi-story buildings in an area currently utilized for fairground purposes. The area covered in the plan undergoes a transformation in both, its purpose and building density during the planning process (Figure 2) [6]. Given that the aim is to examine the investment profitability of residential construction in correlation with the increase in the number of storeys, a case study has been conducted on a plot without changes in the number of buildings during the planning process. Instead, there was only an increase in the built density on the lot, manifested through the addition of underground and aboveground floors.

The analysis is divided into five key steps: a) calculation of planned building areas, b) calculation of urban parameters, c) cost estimation, d) revenue estimation, and e) calculation of return on investment. The steps of the methodological approach are illustrated in Figure 1, while an overview of the relevant parameters necessary for conducting the analysis is provided in Table 1.

The first step involves analyzing the achieved built density in terms of gross, net, net usable area of the building, and areas intended for sale. The areas' analysis is divided into the calculation of underground floors, ground floors, and aboveground floors, cumulatively summed up and expressed collectively for all buildings on the plot (Figure 1 – part 1a). The reason for introducing this differentiation lies in the variable dimensions of these three groups of floors. In case some of the underground or aboveground floors differ, i.e. are not typical, separate calculations are necessary for them.

Secondly, as a result of this analysis, urban planning parameters are defined at the plot level as site coverage ratios and floor area ratios, with distinctions between gross and net values of these coefficients (Figure 1 – part 1b). According to the Law on Spatial Planning and Construction [7], these parameters are defined as the share of aboveground floors in the total built area of the plot, or as net ones. However, this study introduces gross values of parameters that consider buildings integrally, encompassing both underground and aboveground floors in the analysis, all with the aim of understanding the actual state of overall construction.

The third part concerns cost analysis, specifically outlining the extent of direct investments in the realization of the building construction project (Figure – part 2a). Indirect costs, such as overhead costs, salaries of sales staff, taxes, etc., were not considered in this analysis. Given that land acquisition represents one of the major expenses, the unit price of construction land in this research was determined based on market prices in the vicinity of the location, using data obtained from the public Sales Price Register Data [8], for the year in which the regulatory plan was developed. The average unit price of construction for residential buildings was obtained from the decision of the city administration regarding the determination of the basis for calculating rent [9]. Specifically, key input for establishing this basis is the average final construction price per square meter of usable area for residential and commercial spaces in the Banja Luka. This data is derived from the main design documentations, submitted to obtain building permits, i.e., from the section related to the cost estimation of overall construction works. The costs of various types of fees that the investor is obligated to pay to the city during the process of investment realization were taken from the official decisions of the city administration for the year in which the regulatory plan was being developed [10].

The fourth part of the revenue analysis (Figure – part 2b) is based on the application of unit prices per square meter of residential space expressed in €. This unit price represents the market value per square meter and is obtained through the analysis of sales prices of residential space in the vicinity of the location for the year in which the regulatory plan was being developed [8], thus ensuring consistency in prices across both temporal and spatial dimensions. Differentiation between underground and aboveground floors was carried out during price calculation to achieve greater accuracy in the calculation.

In the final part of the analysis, an assessment of return on investment (ROI) was conducted through the definition of profit margin (Figure 1 – part 2c). ROI measures the profitability of the project relative to the amount invested. It indicates the percentage of return on the investment and is calculated by dividing the profit earned by the amount of direct costs [4]. As such, it represents the net profit margin, excluding costs such as sales agents' salaries, marketing expenses, sales tax, overhead costs, etc. Although the standard profit margin for a property development project, according to the literature [4, 5], should be 15–25% or more of the project's total cost, the research adopts a target and minimum profit margin of 20% of the total project costs. The results of the conducted analysis enable comparisons of planning solutions in terms of urban and economic indicators in phases before and after public consultation. Additionally, two hypothetical alternatives of minimum and maximum built density are introduced through the analysis to assess the impact of increase in the number of storeys on the economic efficiency of the investment.

Table 1. Spatial-economic parameters relevant for the calculation of revenue and expenses of building development

Unit prices		**Source**	**€/m2**
A	Average unit market price of construction land in the vicinity of the polygon for 2023	[8]	104
B	Average unit market price of the net usable area of residential space in new construction, with VAT in the vicinity of the polygon for 2023	[8]	1255
C	Average unit price of construction of residential buildings	[9]	515
D	Unit city rent price for the II urban zone of Banja Luka, expressed in €/m2 of the net usable area - valid from March 1, 2023	[10]	26
E	Unit price of the fee for the development of urban construction land for the II urban zone of Banja Luka, expressed in €/m2 of the net usable area - valid from April 11, 2023.	[10]	70
F	Unit price of technical documentation for multi-family residential building, expressed in €/m2 of the gross building area	[11]	15
Percentage parameters related to the calculation of revenues/costs			**%**
G	Share of the price of the accompanying services of the construction in the total price of the construction (%)	/	2
H	Contribution for the cadastre - % of the estimated value of construction works	[12]	0.03
I	Reduction percentage of unit prices (construction and sales) for utility rooms and basement space – underground areas	/	50
Correction coefficients for the calculation of areas			**%**
J	Share of the net floor area in the gross floor area of the aboveground floors	/	85
K	Share of the net floor area in the gross floor area of the underground floors	/	95
L	Reduction of the net area of the above-ground floors based on the installation of wall coverings	/	3
M	Share of the sales area in the net usable area of the above-ground floors (15% of losses on communications)	/	85
N	Share of the sales area of underground floors (parking spaces, storage rooms, utility rooms, etc.) in the net usable area of underground floors (50% of losses on communications)	/	50

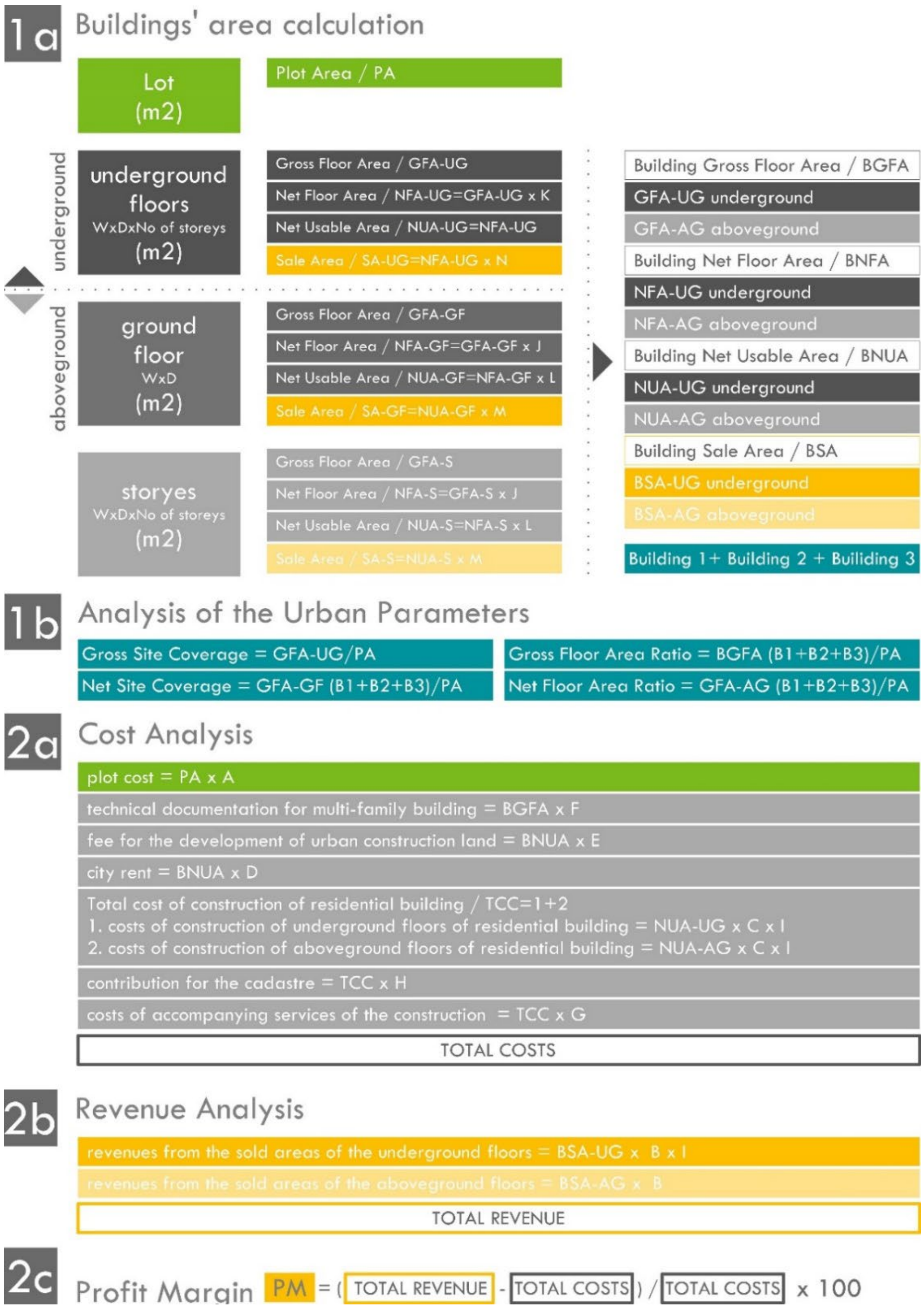

Figure 1. Methodological approach

3. RESULTS

The research results are examined on several levels in terms alternatives of: a) regulatory plan, b) spatial indicators, and c) economic indicators. The area covered by the new regulatory plan is currently undergoing a change in land use. From its former status as a fairground complex, this area is being transformed into a mix of various, often incompatible, uses (such as shops, wedding halls, indoor sports courts, recycling center, etc.). Some buildings are not in use, and most structures are neglected and in poor condition. The current regulatory plan envisages retaining the fairground function in this area, with improvements to spatial organization and infrastructure [13]. According to this regulatory plan, the concept of the spatial organization of the fairground is based on a pavilion system and low-rise exhibition halls (ground floor and gallery). The Banja Luka City Administration made a decision in 2022 to amend the regulatory plan for this area. The draft of the regulatory plan completely changed the land use of the area, converting the fairground complex into a mixed residential and commercial zone characterized by high-rise buildings. Following the public consultation process, as a tool for citizen and stakeholder engagement in the planning process, there has been a noticeable increase in construction density, both in terms of the number of buildings on parcels and in terms of increase in the number of storeys. Comparing the new planning solutions with the existing regulatory plan for the fairground complex [13], it is evident that there has been a significant increase in site coverage and floor area ratio in the new planning document [6]. Furthermore, within the iterations of the new regulatory plan, there is a visible trend of increasing overall built density, as a result of pressure from investors and landowners, which is presented in detail in Figure 2.

Figure 2. Spatial analysis of the regulatory plan at the lot level (Source: Authors according to [6])

The spatial-economic analysis was conducted using the example of a plot within a residential zone, considering not only plan alternatives (before and after public consultation), but also hypothetical simulations of the low-rise and high-rise buildings. The main research question is: what minimum number of storeys of residential buildings ensures the economic profitability of the investment in residential construction? The findings of this analysis show that the increase in the number of storeys, resulting from public consultations, leads to a drastic drop in profit margin, simultaneously raising questions about the profitability of such an investment (Figure 3 – line chart – columns 1 and 2). The main reason for the decline in profit margin in alternative 2 is the increase in the number of underground floors, which arose as a result of the need to meet the minimum number of parking spaces [14]. Second, the standard profit margin of 25% is achieved even with the significantly lower number of storeys - B+G+3, as shown in Figure 3 – line chart – column 0. Third, the profit margin achieved in variant 1 is difficult to attain with buildings having two underground floors, despite the significant increase in the number of aboveground storeys (Figure 3 – line chart – columns 1 and 3).

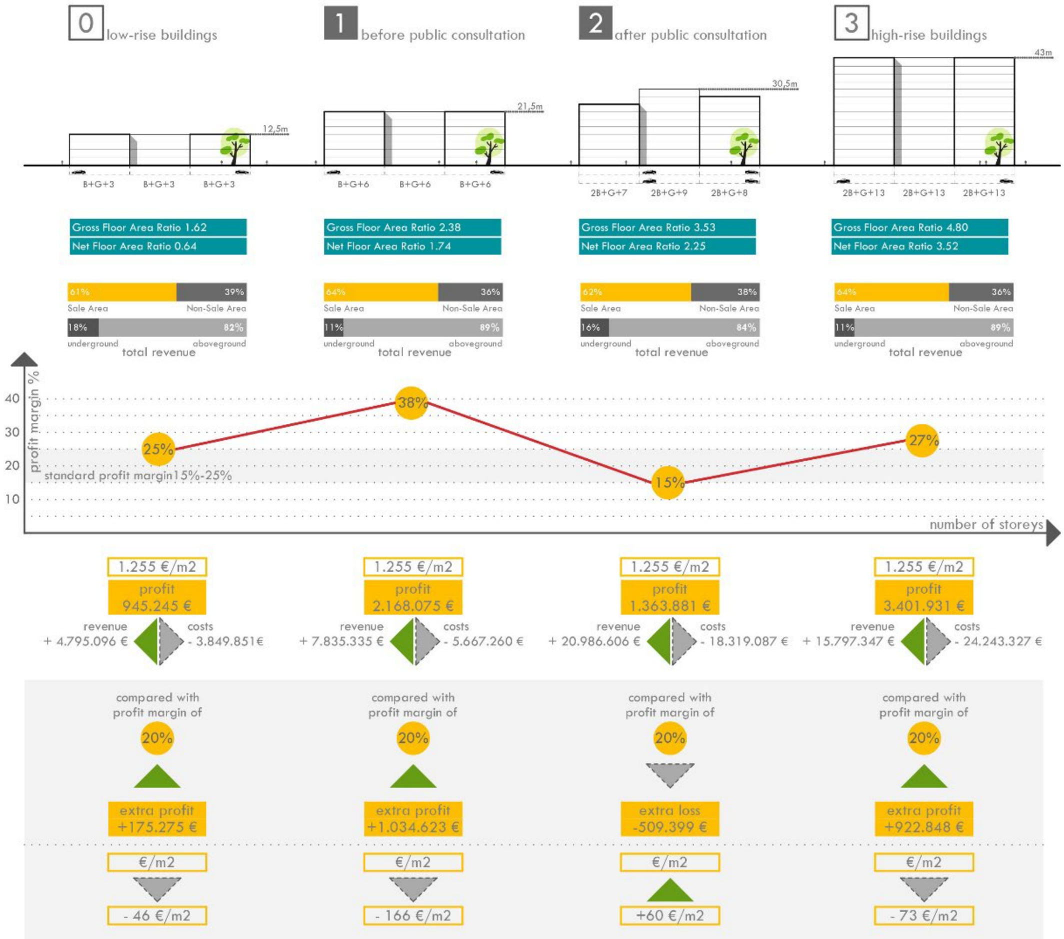

Figure 3. Analysis of economic indicators for the regulatory plan at the lot level

4. DISCUSSION

It is evident that urban spaces are undergoing a change in land use, with an increasing trend in building height and density, not only worldwide but also in the city of Banja Luka, especially in its central urban zone. Even if the changes are taken as an inevitable circumstance, the carrying capacity of plots and the extent of actions are questionable in the context of sustainability. This research has revealed weaknesses in urban planning concerning the application of urban planning parameters (site coverage and floor area ratio), as defined by the legislative framework [7, 14]. By considering only aboveground floors when calculating these parameters, a comprehensive image of construction is missing. According to the rulebook on general rules of urban regulation and subdivision [14], the maximum permissible (net) site coverage ratio for residential zones with higher densities is 0.7, and the maximum permissible (net) floor area ratio for the same zone is 2.5 [11], both of which are satisfied by the planning solutions. However, if we consider the gross floor area ratio, it exceeds the threshold values, reaching 3.53 for variant 2 (Figure 2). As the number of storeys increases, the requirement for parking spaces increases too, leading to the larger size and number of underground levels. The expansion of underground works increases total investment outlay, which yields a low return on investment due to the lower prices of underground areas and the significant share of non-saleable areas. Furthermore, enlarging the dimensions of underground levels diminishes the available open space for implementing greenery and other outdoor amenities essential for residential zones. On the other hand, increasing building height dehumanizes the space, enhances the flow of people, and reinforces activities, reducing safety and privacy within the neighborhood.

The standard of living is changing, transitioning from the concept of medium and low-density housing typical for Banja Luka to the concept of high-density housing. This approach aligns with the idea of a compact city, aiming to mitigate urban sprawl and preserve the natural environment. However, (re)assessment of the scope and typology of residential construction by urban zones, in correlation with the local identity of Banja Luka, is an imperative that the urban housing policy and city master plan must address. In the absence of a city master plan, as the key planning document regulating spatial production and ensuring spatial balance, it is certain that the trend of investor pressure for the increase of building density (number of storeys) will continue. The consequences of this tendency on urban morphology and the cityscape are irreversible, raising questions about the quality of living in these newly developed areas.

Regarding the housing market dynamics, it is evident that there has been a disbalance in the territory of Banja Luka over the past five years. Increased demand for apartments has led to a growth in investments in the housing construction sector. It is presumed that the reasons for this surge in demand stem from the needs of the population that has mostly moved abroad or lives in smaller neighboring cities, for real estate investments in Banja Luka - the main administrative and university center of the Republic of Srpska. Identifying this trend, landowners and developers strive to produce as many square meters of sales area as possible and ensure profit maximization by increasing the plot's built-up area. However, during this process, investors often do not adequately consider spatial aspects as influential factors in the profitability and feasibility of the investment. Ultimately, this oversight can lead not only to poor decisions, losses, and insufficient return on investment but also potentially leading to overbuilt-up space.

The research indicates that an increase in the number of storeys does not necessarily mean an increase in profit. On the contrary, the analyzed alternatives point to a decline in both profit and profit margin (Figure 3 – variant 1 and 2). In order to reach the profit margin attained at a lower number of storeys (variant 1 - B+G+6), the investor/developer must significantly raise the price per square meter (approximately €100 in variant 2 - 2B+G+8/9/10), which makes them non-competitive. Further increase in the number of storeys, aimed at boosting profits, does not yield a proportional increase in the profit margin. Even with a double increase in the number of storeys (Figure 3 - variant 3 compared to variant 1), the initial margin level cannot be achieved. This leads to the conclusion that the optimal number of storeys, which provides the highest profit margin, was achieved with buildings of B+G+6 storeys. Such a planning solution reaches the maximum level of permitted construction but also the maximum profit margin. Any exceeding of these thresholds has negative consequences in all aspects - spatial, economic, social, and environmental. Variant 1 also indicates the possibility of reducing the sales price per square meter of residential space. This would produce a drop in the profit margin but would ensure more affordable housing for social groups and individuals who acquire their first property, especially for young people and couples with moderate and lower incomes. Finally, under current market conditions, the hypothetical variant "0" with B+G+3 storeys provides the most balanced planning solution and the most equitable distribution of well-being. In this variant, the ratio of the sale price and achieved housing/living standards is most optimal, and the spatial environment is most humane.

5. CONCLUSION

The presented model of spatial-economic analysis at the parcel level serves as the initial basis for further development of the analytical tool for assessing spatial-economic indicators applicable on a larger scale, at the level of the regulatory plan - settlements. This research focuses on the profit of investors - construction entrepreneurs - who directly associate their profit with the sale area of residential buildings, often without considering the negative consequences for urban space and the quality of life of the population in these neighborhoods. This research demonstrates that such a standpoint is not grounded in relevant indicators of actual investor benefits. Indeed, the variant of the regulatory plan adopted after public consultations (Figure 3 - variant 2), during which the investor requested an increasing number of storeys for the planned residential buildings besides the negative consequences for the urban standard of living on a broader scale (reduction of green space per capita, increased infrastructural burden, worse bioclimatic conditions, etc.), simultaneously results in a drastic drop in profit for the investor. It is evident that such an analysis of planning solutions would be a strong argument in the hands of urban planners and city planning departments in negotiations with investors, aiming to achieve consensus on planning solutions that offer an optimal balance between private and public interests. This process implies further development of the spatial-economic analysis model of regulatory plans, wherein it is possible to monitor additional economic parameters, such as the city's revenue from private investment construction, the relationship between realized revenue and the percentage of investment in public infrastructure, and facilities of public interest, environmental considerations, and other aspects of urban space, aiming for more comprehensive support of sustainable urban development. At smaller scales, further research can be directed towards assessing the achieved housing standards in new construction in correlation with housing prices and the issue of housing affordability for domestic populations. Additionally, it is essential to investigate the impact of the increasingly pronounced trend of reducing the floor area of apartments and increasing the number of apartments per building on the profitability of residential construction projects, as well as the influence of this trend on a larger scale on urban blocks or neighborhood space. The development and application of specific spatial-economic analysis models in urban planning imply additional education for planners and public services dealing with the spatial development of the city, as well as work on raising the capacity of investors and residents in collaborative and participatory planning.

In circumstances where the pressure from the construction sector in residential development is increasingly manifested in urban space, and where tensions between citizens and stakeholders are growing, understanding spatial-economic relationships can significantly improve negotiation processes in urban planning, facilitate dialogue among all involved parties, and facilitate the presentation of plans itself. In the negotiating arena dominated by: a) representatives of local administration as decision-makers, b) investors as agents of change, and c) urban planners as experts and mediators, better-informed decision-making is key to achieving spatially sustainable planning solutions, economically viable investments, and a more equitable distribution of well-being.

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15

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IMPLEMENTING PARAMETRIC METHODS FOR ANALYSIS AND DESIGN TOWARDS SUSTAINABLE URBAN DEVELOPMENT: A CASE STUDY OF ČESMA SETTLEMENT

Abstract

Paper explores the implementation of parametric methods for urban analysis and examination of sustainable development strategies, with a specific focus on Česma, a suburban settlement in Banja Luka municipality. Field surveys combined with residents' engagement gather comprehensive datasets on Česma's current state. Utilizing the parametric software *Grasshopper* and *Rhinoceros 6,* various urban and rural factors influencing the settlement's dynamics are evaluated. Subsequently, by employing a *parametric decision-making process,* optimized potentials are detected to improve residents' living standards and urban development of the settlement. As a quantitative research method, parametric tools are essential in generating a comprehensive set of maps, 2D and 3D visual data. The collected data are subjected to qualitative analysis and adapted to context as well as sustainability and resilience criteria in the built environment.

Keywords: parametric tools, data visualization, Česma, Grasshopper, Rhinoceros 6, environmental sustainability, iterative optimization

ПРИМЈЕНА ПАРАМЕТРСКИХ МЕТОДА ЗА АНАЛИЗУ И ДИЗАЈН У ПРАВЦУ ОДРЖИВОГ УРБАНОГ РАЗВОЈА: СТУДИЈА СЛУЧАЈА НАСЕЉА ЧЕСМА

Сажетак

Рад испитује примјену параметарских метода при анализи и процјени одрживих урбаних стратегија, са фокусом на приградско насеље Чесма у општини Бања Лука. Теренским истраживањем и учешћем становништва, прикупљају се обимни подаци о тренутном стању насеља. Користећи параметарске софтвере, *„Grasshopper“* и *„Rhinoceros 6“*, процјењују се различити урбани и рурални фактори који утичу на динамику насеља. Затим, процес доношења одлука регулацијом параметара резултује оптимизацијом потенцијала који би могли подићи животни стандард становника и подстаћи урбани развој насеља. Као квантитативна метода истраживања, параметарски алати су кључни за генерисање значајног броја мапа, као и 2D и 3D приказа. Добијени подаци се затим подвргавају квалитативној анализи и теже прилагођавању контекстуалним условима, као и критеријумима одрживости и отпорности грађене средине.

Кључне ријечи: параметарски алати, визуелизација података, Чесма, Grasshopper, Rhinoceros 6, одрживост грађене средине, итеративна оптимизација

1. INTRODUCTION

The concept of sustainable urban development has increasingly become a focal point for researchers and practitioners alike, driven by the urgent need for cities to adapt to environmental, economic, and social changes. This paper introduces the Česma settlement, located on the outskirts of Banja Luka, as a case study to explore the application of parametric methods in enhancing urban sustainability. The historical context of Česma is important, from its earliest settlement in the 18th century to its development through various socio-political changes, underlining the importance of studying sustainable urban development in such a dynamic and historically layered environment.

Prior research has laid a solid foundation on the principles of sustainable urban development, highlighting the significance of integrating environmental considerations with urban planning and design. Despite advancements, there remains a gap in effectively utilizing technological tools in the planning process, particularly in suburban contexts. The main focus of urban analysis used to be mainly on the urban areas, city center, and other more attractive places in the city.

The core problem addressed by this research is the need for comprehensive tools and methods that support thorough analysis and sustainable planning in suburban settlements like Česma. The objectives include analyzing the settlement's current state, engaging with the community for insights, and employing parametric design methods to propose optimized sustainable urban solutions. The study combines extensive field data collection with parametric modeling. Significant data was collected through fieldwork at the Česma site, including photo documentation, dialogue with locals, and observations, thus constructing a detailed database. Moreover, the aim is to show that parametric analysis offers a visual representation of the desired characteristics of the whole settlement, allowing for a clearer understanding of the data gathered on-site without continuously sifting through extensive listed data.

This study was conducted as part of the parametric design course within the Master's program in Architecture and Urbanism. Both the analytical and designing aspects of parametric methodology were employed, with this paper focusing exclusively on the analytical phase. The research is divided into two main phases. The first phase focuses on analytical mapping and identifying existing potentials that have yet to be fully utilized and optimized. The second phase, to be detailed in later research, will present design proposals and iterations as a logical progression from the initial analysis. This divergence highlights a systematic approach to utilizing existing resources within the settlement, opening the way for innovative urban development strategies.

Additionally, this research investigates specific principles of sustainable urban development, including environmental, economic, and social sustainability. Environmental aspects consider green spaces and ecological balance, economic factors evaluate the efficiency and functionality of urban layouts, and social sustainability focuses on improving living standards and community engagement.

Digital tools like FME, *Grasshopper*, and *Rhinoceros 6* play a vital role in organizing and structuring collected data, enabling the analysis of various factors such as housing density, building heights, green spaces, residential block types, and other valuable urban parameters. This enabled the creation of specialized *Grasshopper* scripts that integrate urban planning parameters with geometrical nodes. These tools also help export significant factors identified through space syntax analysis, providing a comprehensive dataset for future planning and design interventions in Česma.

Parametric modeling offers a structured approach for exploring diverse scenarios for the development of the Česma settlement. By adjusting to new parameters, urban solutions are redefined, aiming for optimal livability and sustainability. Parametric design allows for more compositional variations through algorithm-controlled systems, providing flexibility and adaptability during analysis. This approach, highlighted by Dino (2012), underscores the dynamic and procedural nature of parametric modeling in achieving diverse design configurations [1]. It means that this multidisciplinary strategy enables the provision of practical insights and actionable recommendations for the development of suburban settlements, ensuring their resilience and continued vitality within the broader urban context.

By adopting an iterative approach that integrates data-driven analysis with design-driven synthesis, the aim is to develop holistic and contextually responsive solutions that address the multifaceted challenges facing Česma.

Ultimately, our research aims to contribute to the creation of a more livable, inclusive, and sustainable urban environment not only in Česma but also in other similar suburban settlements. This has implications for the broader field of urban planning and sustainable development, emphasizing the potential of parametric design as a transformative tool in the planning and design education landscape.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The growth and expansion of suburban areas continue to fascinate urban researchers, prompting a multifaceted examination of their emergence, inherent challenges, and latent potential for sustainable development. The literature review synthesizes key findings from prior studies, highlighting the evolving understanding of suburban sustainability, the role of technology in urban planning, and the potential of parametric methods to enhance the livability and environmental performance of suburban areas.

Robert Fishman's book traces the history of suburban development from its origins to its evolution. Suburban design initially emphasized privacy and nature connection, but now faces the challenge of sustainability and resilience [2]. The suburb plays a significant role in the city's economy by hosting key enterprises and generating money. Lewis Mumford observed suburbs as private yet collective living, offering an escape from city life, while still allowing people to work there [3]. Suburban areas should be strategically rethought as dynamic components of the urban fabric, capable of contributing significantly to the ecological and economic vitality of the broader urban landscape.

Theories related to sustainable urban development and resilience emphasize the need for a holistic approach that considers interconnectivity, environmental, economic, and social principles. The most common definition of sustainability implies meeting current needs without compromising the ability of future generations to meet their own needs. Urban systems that can adapt to changes and maintain essential functions are called resilient. By combining sustainability and resilience, designers and planners can create adaptable, equitable, and sustainable urban spaces while considering their broader impact on the planet and its inhabitants [4].

Schumacher suggested that incorporating urban morphology and planning on a parametric basis could offer a fresh socio-spatial perspective to parametric design that lacks attention to "social functionalities". This integration would prioritize practical planning necessities, such as socio-spatial cohesion, walkability, and resilience, over abstract formalism that currently dominates parametric urban design [5]. It would bring about a significant transformation in the domain of sustainability and resilience, as the practical needs of planning would be considered as primary themes for design research.

Subsequent discussions extend into the realm of urban planning technologies, with a focus on parametric tools such as *FME*, *Grasshopper,* and *Rhinoceros 6.* The research explores how these tools, through their computational and generative capabilities, allow for a nuanced analysis of urban and suburban spaces. This implies a wide range of urban parameters including the assessment of housing density, green spaces, and community engagement, moving towards a model where urban planning is not only about spatial configuration but also about fostering sustainable communities. The integration of new media in urban design education has enabled a more dynamic and communicative representation of the built environment [6]. The generative interface of parametric systems also provides an effective platform for "learning-by-doing". Speranza explains how digital parametric approaches in urban design education can improve the incorporation of everyday experiential phenomena by systematically examining urban traits. This includes considering experiences as temporal phenomena and exploring urban characteristics in an open-ended manner [7]. As a result, parametric tools can be used not only for urban design but also for ***detailed urban analysis and exploration of urban potentials for future development.***

This background research provides a robust foundation, indicating how tools like *Grasshopper* and *Rhinoceros 6* can be fundamental in analyzing urban potentials. Thus, the primary focus of this study is to delve into the application of these parametric tools for the detection and exploration of potential urban development opportunities.

Algorithms, which are composed of defined components, geometric and spatial operations, and their inter-relationships, play a crucial role in comprehending emerging urban spatial possibilities. Through parametric modeling, designers can access a wide array of customizable options that align with market limitations, while maintaining consistency and cohesion within public design frameworks. Parametric design involves fundamental design thinking operations. Its computational capacity to regulate the variability of form compositions is its primary advantage over analog techniques. The resulting "parametric morphologies" can serve as a basis for creating alternate scenarios and strategies integrating various aspects of planning [8].

Further, the theoretical framework section introduces key concepts and theories that guide the research. Space syntax theory initially developed as an architectural theory, investigates the social functions of spatial configurations. The initial software for Space Syntax analysis, DepthMap, was developed by the late Alasdair Turner. Despite its architectural origins, it is widely applied in urban analysis. The theory originally examines the interconnections between spatial units within buildings and the built environment, using the terms syntax and morphology in a linguistic sense [9]. Space Syntax Theory, particularly in this research, provides a methodological approach to understanding urban connectivity and its impact on social interactions and accessibility.

The Urban Strategy Playground research group at the Chair of Architecture Informatics at the Technical University of Munich is researching densification strategies. Their goal is to support governmental bodies in decision-making by integrating digital and traditional planning methodologies. They are collaborating with DeCoding Spaces, a German company of international architects and urban planners based in Weimar. The organization enhances architecture and urban planning with the DeCoding Spaces Toolbox for *Grasshopper*. This free tool facilitates analysis and generation in this study. There is a growing discussion about urban modeling and simulation tools, particularly in space syntax, solar radiation, and parametric urban design generation. However, the literature lacks a comprehensive approach that incorporates multiple analytical methods in the urban design process [10].

Space syntax methods use maps to display the longest sightlines and translate them into graphs. The graphs reflect the spatial configuration and strongly correlate with movement rates. This approach challenges traditional methods by relying on spatial geometry alone, emphasizing the environment's importance in predicting movement [9]. It is a very helpful tool used in this research to iterate and analyze the connectivity of the suburban settlement with the environment, especially the city center.

Ilić's research proposes using virtual environments for data collection to track pedestrian movements in urban public spaces. The study highlights the importance of space syntax theory, which links public spaces to the configuration of the urban network. Space Syntax theory in her work emphasizes the connection between common areas and urban design, which has enabled the identification of effective interventions to manage pedestrian circulation. Using parametric modeling and *Grasshopper* software, the study provides a framework for exploring alternative development scenarios for urban areas [11].

Lastly, the review seeks to consolidate findings from studies that have integrated the concepts of suburban sustainability, resilience theory, and the application of parametric tools. Despite the proven advantages of parametric design techniques within engineering and manufacturing processes, architects have not applied these methods in their creation tasks to address urban design issues at a higher level of understanding [12]. It critically assesses their methodologies, outcomes, and the gaps they leave unfilled, aiming to draw a nuanced understanding of how digital innovation intersects with the quest for sustainable suburban development.

2.1. ČESMA SETTLEMENT'S HISTORICAL, URBAN AND ENVIRONMENTAL CONTEXT

The settlement of Česma is a distinct suburban enclave of the city of Banja Luka, surrounded by rivers and challenged by inadequate transportation links. Despite its vulnerabilities, it offers a rare blend of proximity to urban conveniences while maintaining a sense of seclusion. Its historical evolution underscores a complex narrative of resilience and adaptation. The settlement's struggle with unauthorized constructions and the informal economy highlights the broader challenges of urban planning in post-conflict societies. The settlement offers a peaceful living environment with a blend of historical richness and contemporary challenges. Its community has faced demographic changes and property ownership transitions. Today, it is a resilient and adaptive community, integrating refugees and reorganizing families.

The settlement's development was hindered by industrialization and pollution downstream. The main street was established in the mid-1960s, but investments to improve it have been insufficient. The only connection to the city is via a bridge built by the Trappists. Suburban settlements emerged with public lighting and a bus line. The Česma-Madjir settlement was unplanned despite partial coverage in planning documents. The construction method indicated that it was a lawless playground during the chaotic process. Existing plans were only followed in certain principles due to the developmental expansion of the neighborhood. Urban planners could do nothing as the foundation and walls were already significantly underway, preventing them from taking any action or reaction to the situation. [13].

Banja Luka's General Plan designated this area for industry, urban greenery, recreation, and sports. Traditional rural-style housing wasn't included or considered necessary. Vernacular builders couldn't afford planning documents, architectural projects, or construction permits, leading to informal construction due to their financial situation.

The settlement is situated between the Vrbas River to the west and the Vrbanja River to the south and southeast, making it flood-prone. This combined with its unregulated infrastructure makes it a suitable research application for Sustainability and Resilience theory.
We may be able to simulate the settlement's standards with statistical data, using *Rhinoceros 6* and *Grasshopper* software. Česma settlement is a good candidate for applying parametric design. This method can help create sustainable and resilient urban environments that work with Česma's context. Our field observation is recorded with photographs and the diagram below. (*Figure 1*)

Figure 1. Photographs of the buildings in the settlement, with the diagram showing its' level of construction

3. METHODOLOGY

The research and data collection for this project was conducted as part of the master's program in "Architecture and Urbanism" at the Faculty of Architecture, Civil Engineering, and Geodesy. Multiple student and professor groups were involved in gathering data, with each group focusing on specific areas and thoroughly mapping and analyzing them.

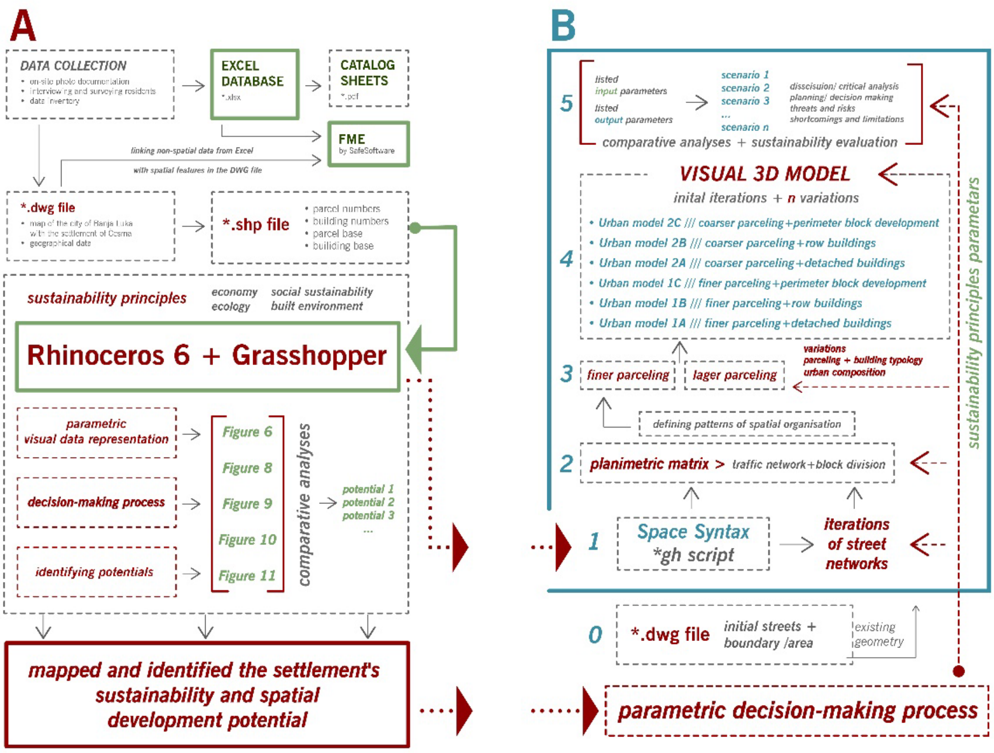

Figure 2. Methodology workflow A phase (left) and the B phase (right)

The methodological approach began with the selection of a location, Česma settlement, a suburb of Banja Luka. The Geodetic Archive of Republika Srpska provided a DWG map of Banja Luka and its settlements. The task was to map the existing condition and potential of the Česma settlement, providing detailed information for every parcel and building within the settlement.
Two main phases of the general research are:

- data collection, analysis, and visualization
- generating new proposals using parametric tools

The main focus of this research is the initial phase (*Figure 2A*), which involves mapping the existing conditions and identifying key parameters that will later influence the design process. Following data analysis, the second phase includes parametric design to generate and evaluate a range of development scenarios (*Figure 2B*),. Both phases are based on predetermined parameters that reflect sustainability and resilience objectives. The sustainability criteria include energy efficiency, economic impact, social-community well-being, and ecological impact. [10]

All data collected on-site, including photographs, internet research, discussions with local residents, and field notes, was entered into an Excel spreadsheet and categorized accordingly. The spreadsheet comprised several sheets, each serving a specific function. The mapping effort culminated in catalog sheets for the parcels and their associated buildings within the settlement.
These catalog sheets provide insights into ground condition mapping outcomes, offering a clear depiction of the existing state at the respective locations.
The main tools used for the methodology focus on using parametric design tools, specifically ***Grasshopper* and *Rhinoceros 6*** software, enabling the manipulation of design parameters influenced by urban, environmental, economic, and social factors. (*Figure 3*)
Unlike the GIS-focused Esri CityEngine, which transforms 2D data into 3D city models, *Rhinoceros* does not primarily handle geospatial data. However, its versatility across multiple disciplines, especially when combined with the *Grasshopper* plugin, has established it as a staple in urban design practices. *Grasshopper* extends the functionality of *Rhinoceros*, enabling complex urban development projects with flexible design and analysis tools that set it apart from traditional GIS software such as Esri CityEngine [10]. This approach emphasizes the simulation of human movement, interactions, and spatial accessibility by focusing on spatial configuration and urban dynamics. In contrast, traditional GIS methods prioritize static spatial data representation, geographical analysis, and spatial relationships. Furthermore, traditional GIS predominantly operates in 2D, whereas the parametric methods utilized here offer 3D presented data, allowing for a more dynamic and behavior-oriented analysis. Supported by theories of spatial cognition and architectural principles, and utilizing advanced tools like Grasshopper, this methodology presents a comprehensive and dynamic approach that extends beyond the static, geographically focused scope of traditional GIS.
For the purpose of creating a .shp file, we used *FME by Safe Software*. We merged an Excel database, containing details like parcel numbers and ownership information, with a DWG map of the Česma settlement to create a comprehensive spatial dataset. This process involved linking non-spatial data from Excel with spatial features in the DWG file, such as buildings and roads, based on common identifiers like parcel numbers. The resulting integrated dataset provided a detailed geographical context for further analysis and planning, showcasing FME's efficiency in automating complex data workflows.
Furthermore, *Grasshopper* models enable real-time analysis and simulation, enhancing the exploration of complex design alternatives. Consequently, simulation tools such as Ladybug, Honeybee, and *DeCoding Spaces*, were employed to assess designs based on essential factors like geometry, accessibility, visual integration, and environmental efficiency [10].
It has to be noted that these tools in urban analysis are dependent on the completeness and quality of input data, which represents a significant drawback. Incomplete or erroneous input data, encompassing building configurations, human behavior patterns, and spatial characteristics, may result in erroneous simulation and analysis outcomes. Furthermore, the parametric models' complexity may limit their applicability for wider use in urban planning by making them challenging to utilize without specific training and understanding. Another disadvantage of parametric design may be its high computational cost. The complexity of simulations necessitates significant time and processing power, which may present a challenge for projects with broader scope or shorter deadlines.

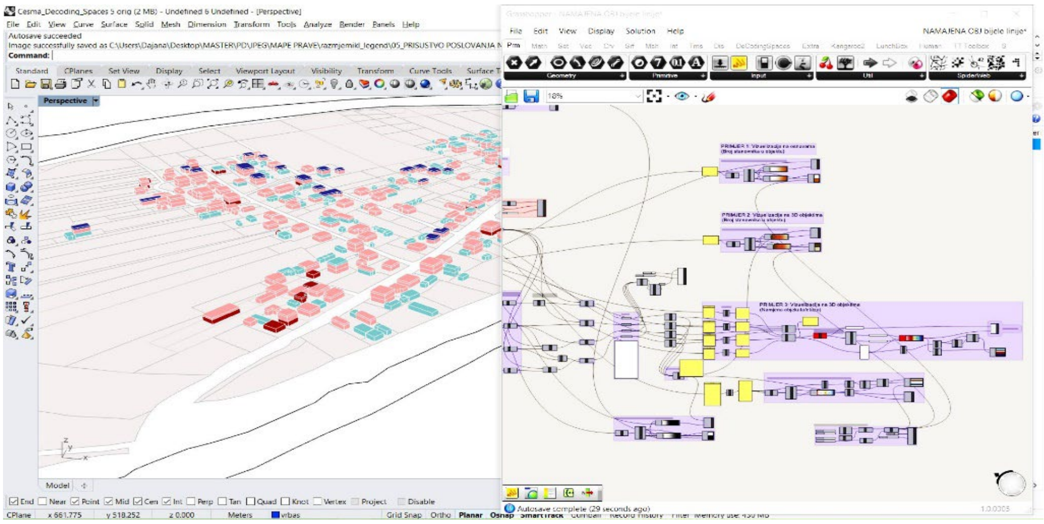

Figure 3. Part of the Grasshopper script and Rhinoceros 6 data visualisation

The objective of this process is to create a comprehensive data set on the current state of the Česma settlement. This will cover various factors such as housing density, green spaces, infrastructure quality, community needs, and aspirations, all of which are influenced by sustainability principles. The overall methodology outlined in this research represents a groundbreaking integration of parametric design with empirical urban research, aimed at advancing the practice of sustainable and resilient urban development. Through the case study of the Česma settlement, the paper demonstrates the potential of this approach to produce nuanced, adaptable, and sustainable urban design solutions that respond to the specific needs and conditions of suburban settlements.

RQ1. How can *Grasshopper* and *Rhinoceros 6* software, as parametric design tools, facilitate the planning and development process to achieve sustainable urban development in various settlements through the implementation of advanced data visualization techniques?
This research question examines the impact of *Grasshopper* and *Rhinoceros 6* software tools on the sustainability of urban and suburban development projects. It focuses on the ability of these tools to import data from Excel spreadsheets and Shape-files, generate maps based on specific criteria, and perform analyses to assess the potential of settlements like Česma. The goal is to understand how these software tools help identify sustainable development opportunities, engage stakeholders, and support evidence-based decision-making in diverse settlement contexts. By examining the case study of the settlement of Česma - considered as a test polygon - the research underlines the adaptability of these methodologies for broader application in other suburban or urban areas, highlighting the transformative potential of *Grasshopper* and *Rhinoceros 6* in urban planning and the pursuit of sustainability.

This analysis will initiate further research on exploring the role of *parametric tools* in supporting sustainable urban development through an iterative design process, generating multiple design options in the Česma settlement. The final goal is to establish a methodological framework applicable to different urban contexts, demonstrating the versatility of parametric design in urban development.

4. RESEARCH AND RESULTS

4.1. MAPPING AND DATA COLLECTION AT THE PARCEL AND OBJECT LEVEL

Due to the lack of detailed data on buildings and parcels in the area from government institutions, we initiated the creation of our own database (*Figure 4*). This effort led to the development of a catalog sheet for each parcel and building (*Figure 5*), while also producing geospatial .shp files essential for further research processes in *Rhinoceros 6/ Grasshopper*.

Before exporting the catalog sheets that contain all the important information about the parcels and building structures, the data collected during the visits to the Česma settlement were input into the Excel table. The table itself has sheets and each sheet serves a distinct purpose, from providing detailed listings of building levels to offering comprehensive data on land parcels and structures. The data listed, essential for identification, were subsequently utilized as parameters for later stages in the workflow. Catalog sheets for parcels and objects are directly generated from field visits, which involve mapping ground conditions through visual observation and discussions with the residents of the Česma settlement, supplemented by data from the land registry. These catalog sheets provide insights into the ground condition mapping outcomes, clearly depicting the existing state at specified locations.

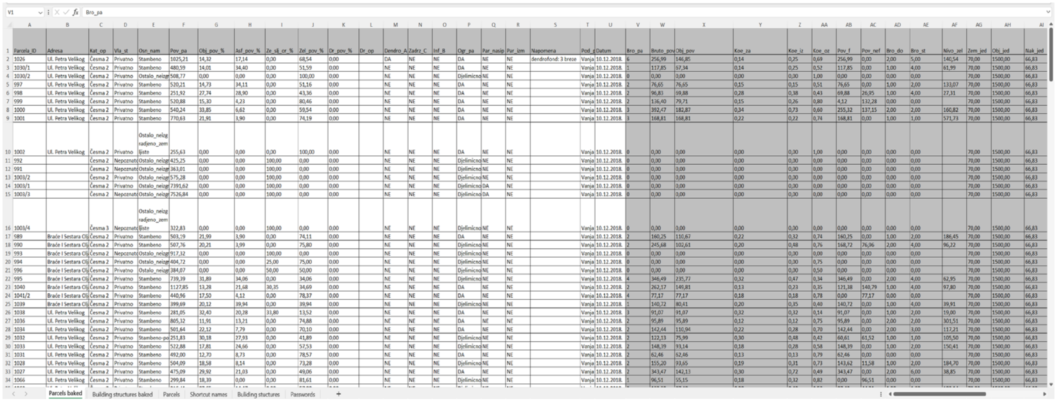

Figure 4. Excel data base (parcels and buildings)

The total number of catalog sheets for parcels stands at 278 for the whole area, and 90 for the part that is particularly analyzed. Additionally, the observed coverage yielded 321 catalog sheets for objects for the whole area and 77 for the part of the location.

Catalog Sheets for various parcels, provide comprehensive information such as parcel numbers, cadastral municipality, sketches of the parcels, addresses, ownership structure, primary purpose of the parcel (e.g., residential, business, undeveloped land), household numbers, population numbers, surface area measurements (in square meters) for the parcel overall and specifically for structures on the parcel, developed construction surface area, surface treatment of the parcel, occupancy and construction coefficients, greenery levels, satisfaction level with greenery (measured in square meters per resident), existing valuable tree resources to be preserved, above-ground infrastructure objects on the parcel, spatial features with retention recommendations (aesthetic, symbolic, ambient, etc.), parcel enclosure, parcel inclusion of defensive embankment parts, parcel location in relation to water streams and defensive embankments, fees for the arrangement of urban construction land (in KM), and total market value of the real estate.

This meticulous documentation provides an in-depth look at the parcels, offering vital data for urban planning, real estate assessment, and environmental considerations. Each parcel is uniquely identified and described, highlighting the importance of sustainable development, green areas, and the valuation of property within the urban and suburban settings of the specified cadastral municipality.

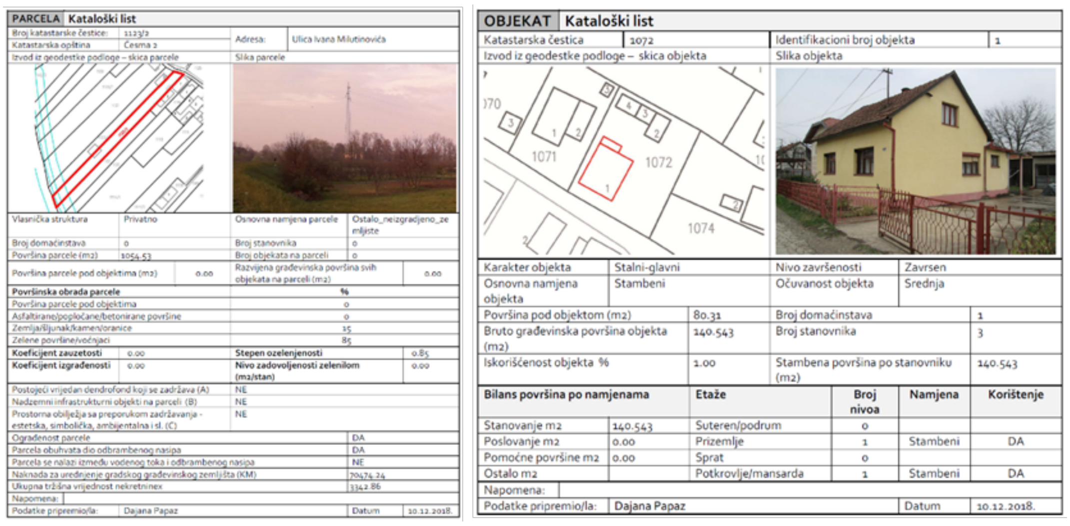

Figure 5. Catalog sheets (parcels and buildings)

Catalog Sheets for various building structures contain detailing information such as cadastral parcel numbers, sketches of the structures, object identification numbers, images of the objects, and their characteristics. Each entry provides specific details, including the nature of the object (permanent-main, permanent-auxiliary, or temporary-auxiliary), the level of completion (finished, partially finished), primary purpose (residential, auxiliary), condition of the object (good, medium, bad), the surface area under the object, gross construction area of the object, usage percentage, residential area per resident, and balance of areas by purposes across different levels (basement, ground floor, upper floors, attic/mansard) with specified uses (residential, business, auxiliary, other). Additionally, it lists the number of households, and the number of residents, and provides notes on the usage and preparation details including the preparer's names and dates. This detailed cataloging offers insights into the physical characteristics and usage specifics of various structures within the cadastral parcels, contributing valuable data for urban planning, real estate evaluation, and architectural considerations. Each structure is meticulously documented, reflecting its role and value within the urban or rural landscape, and indicating its occupancy, structural integrity, and functional distribution across its floors.

4.2. SPACE SYNTAX ANALYSIS

The purpose of using Space Syntax Analysis is to examine the integration level of the settlement with the surrounding environment.

Space Syntax analysis offers the possibility to check the integration of the settlement with the environment through mathematical logic and in relation to the given parameters. It works on the principle of calculating the distance from the central point of each segment (street) to every other segment individually, within the specified area. It also demonstrates the degree of street connectivity - how many times a traffic user passes through a particular street to access other streets in the city [10]. If the radius of 1km is considered - only the connections with segments within that distance are simulated.

Enclaves that function independently are singled out if they are not well integrated into the surroundings - this is the case with Česma - ***it stands out as a decentralized settlement.***

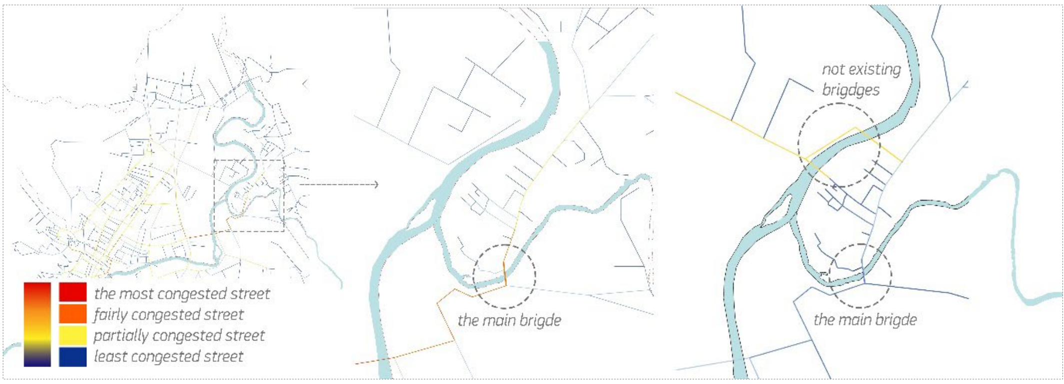

Figure 6. Space syntax analysis: a) city of Banja Luka with the Česma settlement, b) current state of Česma c) Česma settlement with new bridges added

The main bridge connecting Česma with the city center (*Figure 6*) is the most congested because the entire Česma settlement network depends on it. All other bridges and connections to the center are less congested because they are not the shortest route to the city center. Depending on the scope, different results are obtained. The scope is the radius, and the importance of streets is calculated within that radius. Angular measures (*angular*) show which directions are the most congested.

If the *length* parameter is set as the relevant measure, the metric shortest distances between paths are calculated, while *angular* prioritizes the least number of turns from point A to point B. In this case, the maps illustrate how proximity is prioritized in metric calculation, whereas angular calculation prioritizes directions regardless of distance. (*Figure 7*)

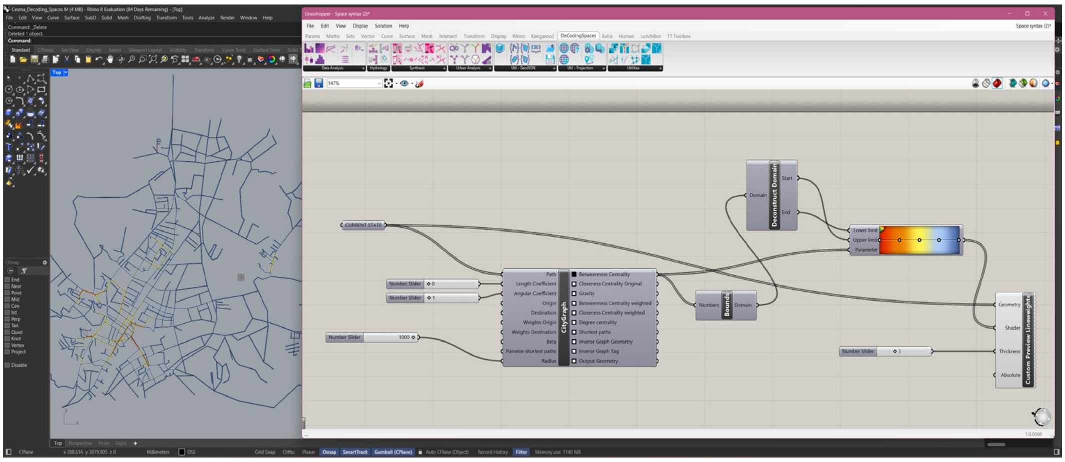

Figure 7. Space Syntax script in Grasshopper and Rhinoceros 6

In real context, users will choose their paths based on various parameters. However, given that traffic in Banja Luka is generally poorly managed, with significant congestion, it's evident that the shortest paths will be preferred. Depending on the coverage, different results are obtained. This coverage is referred to as the *radius*, within which the importance of streets is considered during calculation.

The analysis computes from every element in the system to every other element, but only up to 5km. The value of streets in a decentralized system is determined, revealing a different frequency distribution compared to the entire coverage. Česma emerges as a distinct system, existing independently, indicating decentralization as it is not fully integrated into the overall system.

The densest street system in the city center represents the best integration and logically, this part is treated as the center, the central component of the entire system.

A difference can be noticed between the current state (without bridges) and the potential state with new bridges in the Česma settlement. The difference is in its integration into the environment, the main bridge on the main street in the settlement is less congested, and traffic concentration shifts to the northwest. The analysis is very useful for the future planning of states and streets; it is clear that a reorganization of the street network within the settlement is necessary, followed by the regulation of bridges and connections with other parts of the city.

4.3. IDENTIFICATION AND ASSESSMENT OF SUSTAINABILITY PARAMETERS IN THE ČESMA SETTLEMENT

This section presents and analyzes the outputs of applying *Grasshopper* and *Rhinoceros 6* software to input data from the Česma settlement. These tools assisted us in visualizing complex urban and rural factors, revealing patterns and potentials within the settlement that could guide sustainable urban development. Our observations, based on the generated maps and data visualizations, aim to explain the complex dynamics of Česma. This offers insights into how parametric methods can inform and improve urban planning and design strategies.

The on-site condition regarding the ratio of built to unbuilt space was identified and evaluated. This condition was interpreted at the coverage area level by presenting key parameters. The presentation is given cartographically and through graphs. Results include parcel occupancy by buildings, construction level of the parcel, usage level of buildings within (a part of) the coverage area, and the relationship between residential and other functions at the building level. At the parcel level, the highest occupancy coefficient within the entire location is 0.83 for the most occupied parcel. The observed location is characterized mainly by residential and auxiliary buildings, then auxiliary ones which are the dominant backbone of the informal economy, especially at the level of the entire settlement. Housing is concentrated along the street, while auxiliary buildings in the back of the parcel serve agricultural purposes. (*Figure 8*)

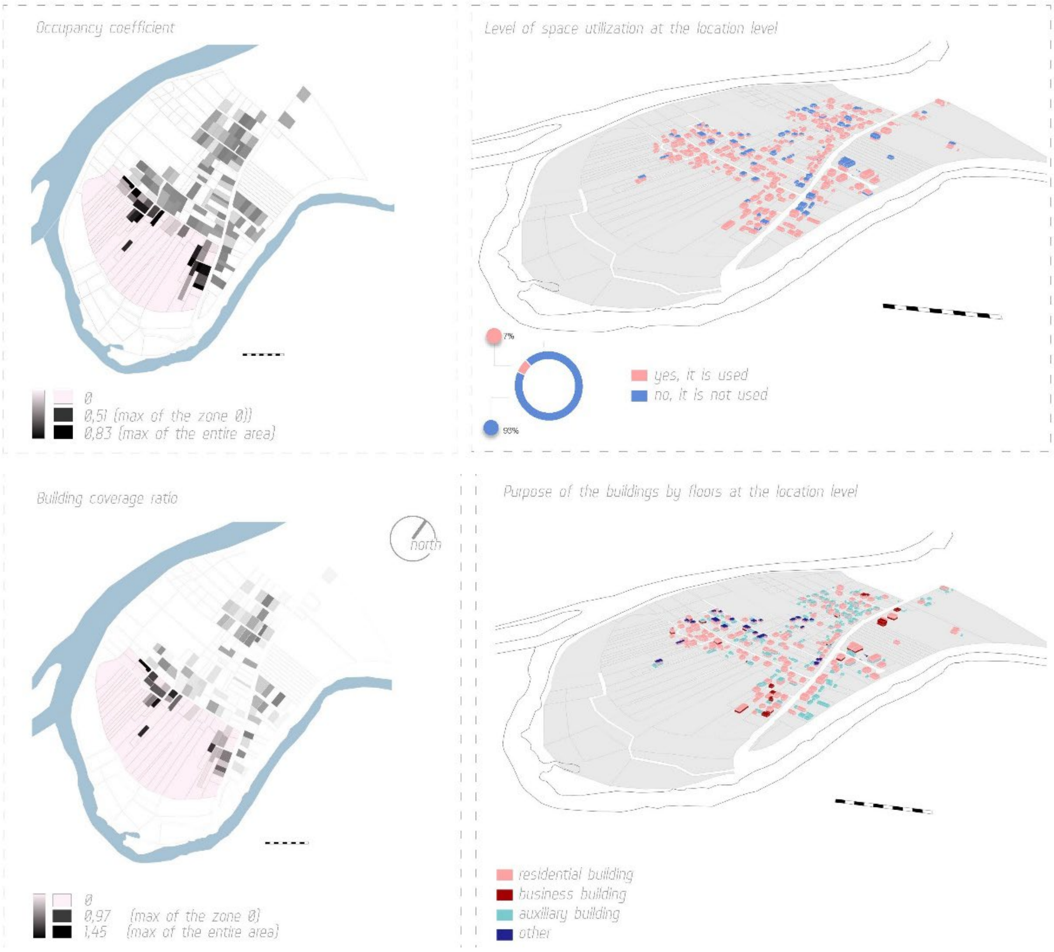

Figure 8. The maps of the ***Built environment, usage, and functionality*** *generated from the GH script*

Business buildings (mainly hospitality) dominate the entrance to the settlement itself. Maps and diagrams clearly show that the utilization rate of buildings is high, and a small number of squares are unused, however, if the number of inhabitants is considered in individual buildings, it is clear that "surplus of squares" is a case and it is one of the indicators of the current unsustainability of the settlement. The social state is low, and many rooms within the building are not used daily. (*Figure 8*)

The Greenery Coefficient represents the ratio of green spaces to the total area, while Greenery Satisfaction indicates the area allocated per inhabitant. The settlement is mostly undeveloped with a Greenery Coefficient of 0.65, and it is concentrated in the central part, away from the river. The average satisfaction with green areas is 89.04m² per inhabitant, depending on the number of inhabitants and plot size. A small number of residents + a large parcel results in lower green satisfaction and vice versa. 69% of the observed zone is green meadows and orchards, presenting potential for construction and improving greenery. Only 15% is under buildings, 9% of the area includes land, gravel, stone, and fallow land and 7% is paved. Although the settlement appears green, the tree preservation area of the settlement is poor. (*Figure 9*)

Regarding the state and evaluation of Social Sustainability, the area has a high population density concerning the built environment. Parcels near the embankment are suitable for agriculture but lack access roads and connections to the rest of the settlement. The built parcels along the street are closely packed, leaving most structures 'exposed'. Only a few buildings serve a commercial purpose. (*Figure 10*)

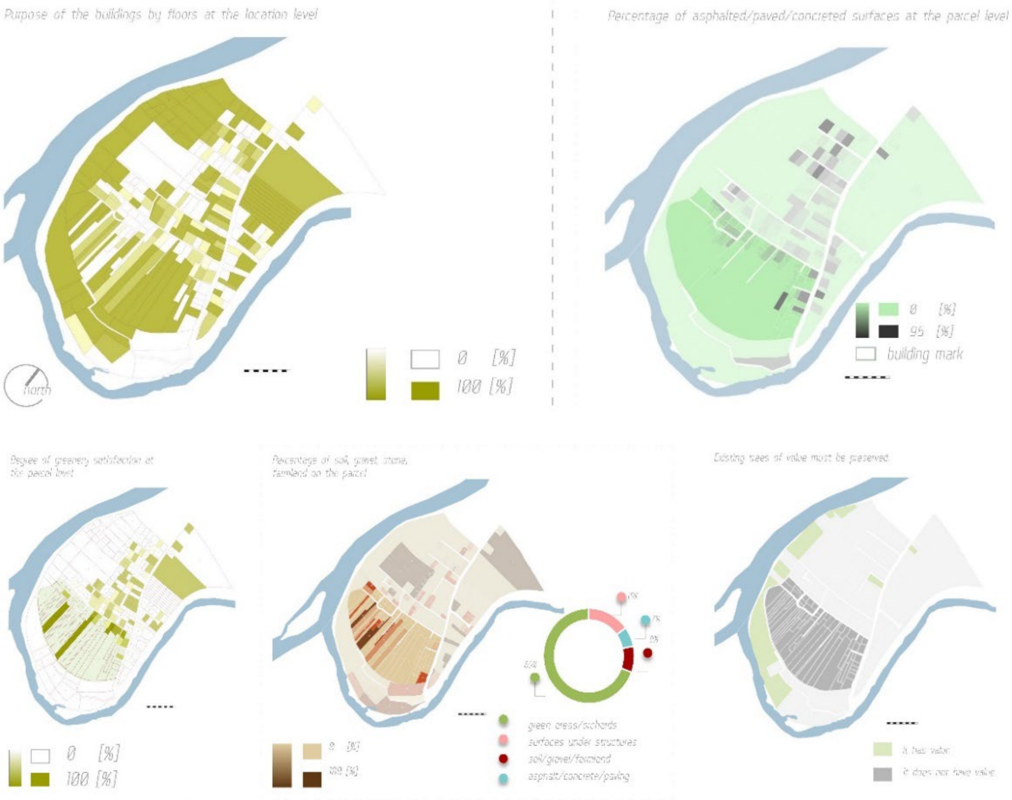

Figure 9. The maps of the Ecological sustainability of (a part of) the settlement generated from the GH script

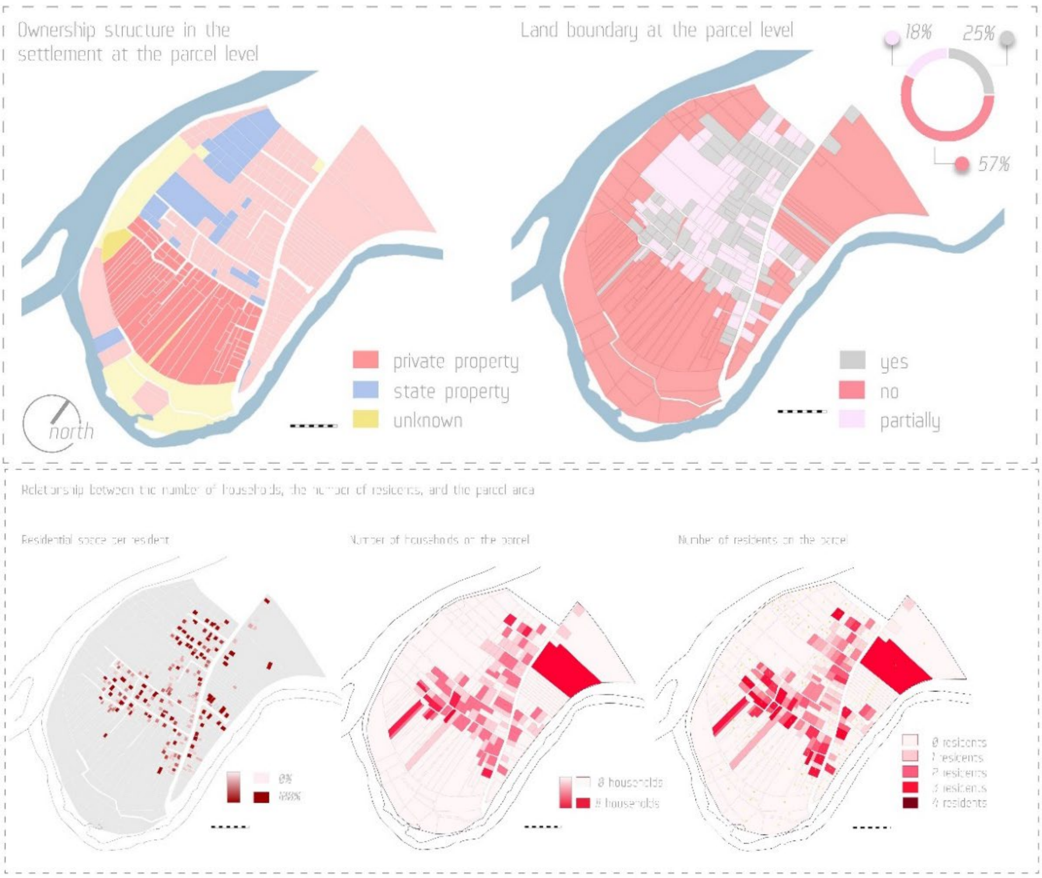

Figure 10. *The maps* ***of the Social Sustainability*** *generated from the GH script*

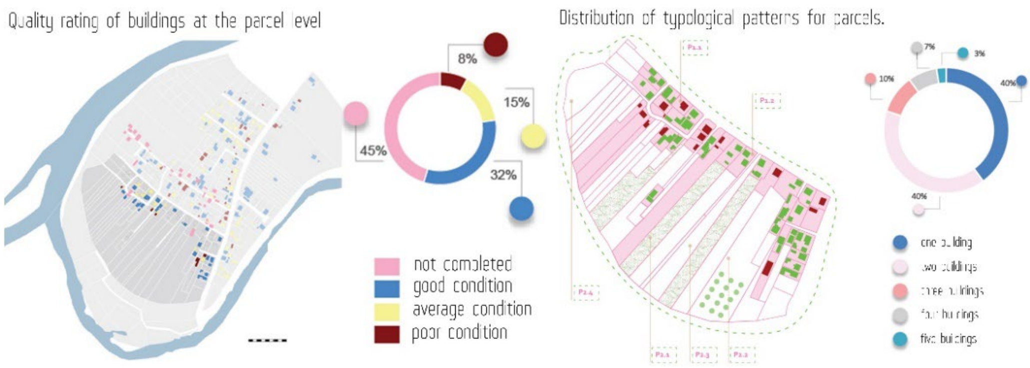

Figure 11. The maps of the quality rating of the buildings at the parcel level and the distribution of typological patterns for parcels generated from the GH script

The map distinguishes between two main categories of parcels: undeveloped and developed. Undeveloped parcels can be further divided into agricultural parcels, parcels with orchards, verdant meadows, and overgrown shrubbery. Developed parcels are categorized based on the presence of one or more buildings, as well as whether they are enclosed or open. Maintaining privacy is of great importance to the local population. (*Figure 11*)

The data visualization above reveals a clear dichotomy between built and inbuilt parcels, highlighting the need for strategic urban planning that combines housing needs with ecological preservation. The concentration of the settlement in central areas and the predominantly undeveloped surroundings presents a clear opportunity to design public spaces that support community engagement while respecting the natural landscape. The distribution of typological patterns among parcels suggests the need for careful consolidation that balances agricultural and green spaces with development. Additionally, the presence of auxiliary buildings as a foundation of the informal economy highlights the importance of incorporating diverse functions into the urban fabric to enhance livability and economic vitality. This analysis showcases Česma as a model for sustainable suburban development, promoting inclusive and environmentally conscious planning approaches that can adapt to the changing urban landscape.

5. CONCLUSION

This research paper emphasizes the importance of parametric decision-making processes in the sustainable development of suburban settlements, with a particular focus on Česma. The study utilized a detailed workflow that integrated field surveys, citizen engagement, and advanced software tools such as *Grasshopper* and *Rhinoceros 6* to navigate the complexities of urban and rural dynamics and uncover the inherent potentials within the Česma settlement. The utilization of parametric tools not only facilitated a comprehensive analysis of various urban factors but also enabled the creation of detailed maps and visual data. This serves as a basis for identifying areas of improvement and opportunities for sustainable development.

The research also demonstrates the effectiveness of combining traditional data collection methods with advanced computational tools to gain a deeper understanding of the settlement's current state and future possibilities. This study demonstrates how optimized potentials can be detected to enhance the living standards of residents and guide the urban development of the settlement towards sustainability and resilience by employing a parametric decision-making framework.

Although this workflow includes a great amount of automation in analyzing urban parameters, it is important to note that architects and urban designers still play a key role in decision-making in specific phases of the analytical and design process. The design-making process in this research phase is crucial, as the author interprets the results, providing a critical review and making informed decisions. This involves evaluating the given results and determining the best course of action based on the analysis, ensuring well-founded conclusions and design proposals. This methodology provides a more comprehensive and in-parallel insight into the location using visual data and enables us to compare the possible results that will lead to more grounded conclusions.

The paper lays a solid foundation for future research, highlighting the importance of parametric tools in urban analysis and design. The findings from Česma are an important reference for future studies that will investigate the use of these tools to develop iterative design solutions that align with the principles of sustainable urban development. This research identifies potential for innovative approaches to suburban planning, advocating for a harmonious integration of technology, community needs, and environmental sustainability to improve the quality of urban life.

The primary limitations of parametric tools in urban analysis include dependence on the quality of input data, the need for specialized knowledge and training, and computational intensity. Rhino/Grasshopper plug-ins may not account for all real-world variables, potentially leading to discrepancies between simulations and actual results. The process can be complicated for inexperienced users, and plugin calculations may not always be accurate, requiring validation against empirical data. One solution to these limitations is to develop a more user-friendly software or plug-in that simplifies the interface and minimizes the need for extensive manual calculations. The creation of such a plugin in Grasshopper is a consideration for future research.

In conclusion, the exploration of Česma through parametric methods has provided valuable insights into the settlement's development potential and showcased the transformative power of digital tools in urban planning. Moving forward, it is imperative to continue leveraging these technologies to foster sustainable and resilient communities, ensuring that our urban environments are prepared to meet future challenges. This research highlights the importance of an interdisciplinary approach that considers the complexity of urban systems. It advocates for strategic interventions that are informed, inclusive, and forward-thinking.

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16

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ORIGIN AND CONTINUITY OF THE SYMBOLIC FORM BY THE EXAMPLE OF MEMORIAL ARCHITECTURE IN THE CONTEXT OF THE YUGOSLAV IDEOLOGY

Abstract

The work represents a theoretical contribution to the study of the complex semiotics of the forms of the memorial architecture of Yugoslavia, with special insight into the usage and possible continuity of prominent symbolic forms by the example of three notable Yugoslav authors: Ivan Meštrović, Bogdan Bogdanović, Dušan Džamonja. Pointing out the connections of archaic symbols with the memorial architecture of Yugoslavia, the purpose of the work is to identify the potential continuity of the semiotics of the form, but also to indicate the turn of the artistic expression that appears under the influence of the new political context in need of dominant multiculturalism and the aspiration to preserve the multicultural state model.

Keywords: symbolic forms, origins of shape, memorials, Yugoslav ideology

ПОРИЈЕКЛО И КОНТИНУИТЕТ СИМБОЛИЧКЕ ФОРМЕ НА ПРИМЈЕРУ МЕМОРИЈАЛНЕ АРХИТЕКТУРЕ У КОНТЕКСТУ ИДЕОЛОГИЈЕ ЈУГОСЛОВЕНСТВА

Сажетак

Рад представља теоријски прилог проучавању комплексне семиотике форми меморијалне архитектуре Југославије, са посебним увидом у континуитет примјене истакнутих симболичких облика на примјеру три истакнута југословенска аутора: Ивана Мештровића, Богдана Богдановића и Душана Џамоње. Указујући на потенцијалне везе архаичних симбола са споменичком архитектуром Југославије, сврха рада је да пронађе потенцијални континуитет семиотике облика, али и укаже на обрт у умјетничком изражавању који настаје под утицајем новоформираног друштвено-политичког контекста у ком преовлађује изразита мултикултуралност и тежња ка очувању мултикултуралног државног модела.

Кључне ријечи: симболичке форме, порекло облика, споменици, југословенство

1. INTRODUCTION

The work represents a theoretical contribution to the study of the complex and ambiguous semiotics of the form of memorial architecture, with special insight into continuity and needs for implementation of notable symbolic forms used in various cultural objects on the territory of the former Yugoslavia. Pointing out the potential connections of archaic symbols with monumental sculpture and the architecture of Yugoslavia, the purpose of the work is to identify the potential architectural continuity of the used symbols and semiotics of the form, but also to point out the turn in artistic expression that arises under the influence of the newly formed socio-political context of Yugoslav identity in need for dominant multiculturalism and the main desire to establish and preserve multiculturalism as the most important and crucial part of the new state model. In this sense, the work makes a contribution to the interpretation and better understanding of the role of complex and ambiguous, but crucially commonly used archaic symbols, mythological representations and the role of general mythical consciousness in a new and yet unknown 20th century socio-political context, as well as possible influences on the formation of individual authorial expression of Yugoslav artists and architects in such specific period, in which, through an experimental design interpretation of symbols, the crucial aim was to strengthen the unity and overcome problems of sustainable multiculturalism by searching for symbolic representations rooted in the ancient past, completely separated from the primarily religious and nationally determined identities of the existing ethnic groups of Yugoslavia.

The research focuses on two different periods of making and shaping the Yugoslav idea, firstly, the period of the Kingdom of Yugoslavia between 1910s and 1940s, and secondly, the period of Socialist Federal Republic of Yugoslavia after the World War II. The main task of this research is forming a typology of dominant symbolic forms that would be used to comparatively show and then explain the possible connection and continuity in the relations between archetypal archaic, ancient and proto-historic architectural and sculptural symbols, applied material and artistic representations with the observed applied and identified semiotics of Yugoslav memorial architecture, in order to apply such a model through research of typology of certain selected works on the example of three different, but most prominent and influential Yugoslav authors: Ivan Meštrović, Bogdan Bogdanović and Dušan Džamonja. Result of the research, in that sense, is expected as the systematic presentation of correlative typologies of symbolic forms of an interconfessional character identified, analysed and presented in individual selected monuments created in the context of Yugoslavia and the ideology of Yugoslav unity.

1.1. THE IDEA AND THE SOCIO-POLITICAL CONTEXT OF ART IN YUGOSLAVIA

Two very different political periods of the implementation of the Yugoslav ideology and regimes stand out: the kingdom period before and socialistic period after the World War II. From the very beginning, Yugoslav thought appeared as a foundation of supranational category, that is, as a historical awareness of the need for unity and unification. Due to internal and international unfavorable circumstances, the Yugoslav idea often experienced deep crises. Socio-political organization was an actual topic in various situations throughout the existence of Yugoslavia along with the problems of growing ethnic tensions, strengthening of nationalism and separatism, various socio-economic factors, the influence of great powers, political emigration and others. In such social and political circumstances, two different approaches to art and architecture, especially in ideological context can be identified. In that way, architecture and art can be seen becoming the greatest weapon for the change used by the ruling regimes, used as a means of strengthening the ideology of unity and community. The idea of Yugoslav art was closely related to the rise, duration and decline of the Yugoslav idea. Since the middle of the 19th century, Yugoslav artists have been connected and organized in order to present the cultural and ethnic closeness of the Yugoslav people.

2. THE CULTURE OF MEMORY IN YUGOSLAVIA

The idea of the unity of the southern Slavs is closely related to the idea of Yugoslav culture and art. A special type of ideological manipulation takes place through emphasizing the importance and role of collective memory. Individual memory can hardly ever be independent, in fact, it always represents a part of a wider collective framework. The collective groups do not have memory, the memory in them does not exist by itself, but it is the same collective group that determines the memory of its members. Collective memory, therefore, is nothing more than activities carried out in the present regarding certain events of the past. In this way, every collective memory is the processes of social modelling of the past into the socially and politically acceptable forms of the present and future, which would mean that the process of establishing collective memory is actually a process of reconstructing the past of wanted or unwanted events from the past [1].

Since the end of the World War I, memorial architecture has taken on an important role in not only the processes of overcoming collective traumas, but more importantly the crucial role in shaping the new national multicultural identity based on celebration of common homeland, ancestors and the king himself. Later, the memorial architecture of socialist Yugoslavia was one of the pillars of support of its unique regime and a specific characteristic that defined its international position. People needed to overcome the burden of history in general, and the history of World War II in particular. The entire history was understood and presented as a centuries-long struggle of the Yugoslav people for freedom and the great desire and aspiration towards establishing common state. Consequently, the World War II became a focal point of historical discourse. The emergence of the states that bore the name of Yugoslavia imposed the need to break with the current state and establish new systems that will be able to serve the unique goals of the state apparatus, which also includes an ideological component [2]. Precise naming and terminology represented the basis of the new ideology, while monuments as public spaces became the places of its spatial manifestation. Generations of Yugoslav architects played a key role in building that discourse. They were not the first to come up with the idea of a memorial park as a mean to unite post-traumatic communities, but they did devise a unique way of overcoming the past and manipulating with the creation of the new historical meaning. Socialist monuments provided space for the emergence of a community, which, defining the participants in the war as fascist occupiers, collaborators of fascism, victims of fascism and anti-fascist fighters, avoided viewing criminals, victims and heroes of war through their national, ethnic or religious identities. The state's ideological apparatus applied the same or similar principles of implementing its political ideas showing that memorials are inextricably linked with the politics of memory and collective identity. The importance of the culture of memory is thus perceived as a powerful means of creating the future, in such way building the identity of individuals or groups. Artistic frameworks in which ideology is articulated corresponds with already known symbolic schemes. It can be argued that the artistic expression of memorial architecture objects through the abstraction and interpretation of applied archaic symbols becomes interconfessional and supranational in that way overcoming the identity crisis of national defects and ethnic differences.

Figure 1. Opening ceremony at Podgarić, 1967.

3. THE PHILOSOPHY OF SYMBOLIC FORMS

In both periods of Yugoslavia, current regimes and public policies found mechanisms to promote a certain political idea, and the key of all the instruments were monuments, which for almost the entire 20th century represented a visible model of the cultural performances of Yugoslavia. It is important to point out the ways in which ideology was spatially manifested through such monuments, which were used as a function of symbolic and aesthetic communication, to identify the historical framework of those symbolic forms, their roots of primitive mythology and theoretical framework of connections, influences and sources of symbolic and aesthetic in such architecture as a whole.

3.1. ARCHITECTURE AS A MEDIUM FOR AESTHETIC COMMUNICATION

Still, the question about the true symbolic side of memorial forms remains. In particular, symbolic content can be understood as the basis of the creative process and communication between the man and the environment. Here, the importance of semiotics is in defining the used symbol, without any interpretation, as a complex and ambiguous category. Architectural monument through its abstract form should communicate the very essence of the memorial, its universal idea of revolution, freedom, eternity, victory. The architectural work as a whole, as well as each of its elements, most often carry the meaning of an adequate form of their visual manifestation. By itself, the symbolic system of an architectural detail directs the formation of a certain structure and type in space in accordance with functional requirements. At the same time, the process of transferring meaning from the symbolic system to the structure is guided intuitively. This would mean that the primary spatial type is a product of an onto-psychological impulse, which in the process of further shaping establishes a connection with an adequate function and a socio-culturally conditioned form [3]. The form that gives the symbol its expressive power is essentially related to the aesthetic manifestation of the work. Aesthetics here refers not so much to the meaning itself, as to the power of the form and its properties to support a sensibly determined meaning through expressive expression. This means that one could allow the thought according to which the symbolic meaning can be clothed in different forms. Regardless of the fact that it is devoid of metaphysical meaning, in the modern architecture of the twentieth century, the symbol is still at the center of communication between man and the environment. The freedom to use symbols in this context is not contrary to its transcendental property, which derives its strength and value precisely from man's need for identification and communication with the environment [3].

3.2. THE INFLUENCE OF ARCHAIC SYMBOLS

After the World Wars of the 20th century, there was global recognition of the importance of memorial architecture and the concept of collective memory. Analyzing the Yugoslav monuments, it is very easy to see a clear connection with archaic symbolism, using basic but variously interpreted archaic symbols. The decision to use such symbols that can widely be acceptable is not surprising. It can be assumed that this kind of interpretation of primal symbols as a sculptural form came from the desire to use this kind of common symbolic "code" in order to overcome cultural differences and avoid possible ethnic tensions in the already troubled socio-political context of Yugoslav society. In various works and interpretations of Yugoslav authors, a clear application of the ancient sculptural form can easily be identified, as well as the use of traditional archaic symbols and abstract motifs such as the sun, mausoleum, symbolism of the hero, light, darkness, fire, use of stone, the duality, wings and horns, mounds, pyramids, pagan dances, rhythms, fantastic beasts such as sphinxes and griffins etc. Evidence of the development of such primal symbols and rituals comes mainly from prehistoric and antic people. On the other hand, those symbols represent the core of human mythical imaginations when it comes to sacred and divine places, which such monuments aim to represent. The numerous primitive symbols of the cave, fire, hand axes, and representations of animal figures probably connected these people with the rhythms of their bodies and nature, leading them to respect the forces that influence them. Such symbols are at the core of cultural identity, shaping all aspects of life. They use all sources, living and non-living, and appear in all conceivable forms: as images, metaphors, sounds and gestures, through architecture and sculpture, through ritual or custom, the objectification of myth and legend. They come from prehistoric primordial times and as such have survived recorded in the collective memory and consciousness. It was during this period that the mythical imagination was awakened and the creation of art began. The beginning of mythology and symbolism meant that people were beginning to make a connection with concepts that was deeper than their everyday experience.

4. CHOICE OF CASE STUDIES AND TYPOLOGY METHOD

The aim of this research is to represent a possible connection and continuity in the use of identified archaic, ancient and prehistoric symbolism and primitive mythology motifs in the context of 20th century Yugoslavia. Ivan Meštrović, Bogdan Bogdanović and Dušan Džamonja are chosen as the authors to be analyzed in case studies. The chosen authors are important because of their crucial role of representing Yugoslav ideology in different yet very successful ways, as they are widely considered as very important and influential, but mostly because of their different political context and interpretations of the same idea of shaping the Yugoslav culture, through approaches to sculpture and architecture and its' correlation to Yugoslav context, which can thus be considered very exceptional when it comes to researching the possible relations between ideology and aesthetics within the territory of the former Yugoslavia.

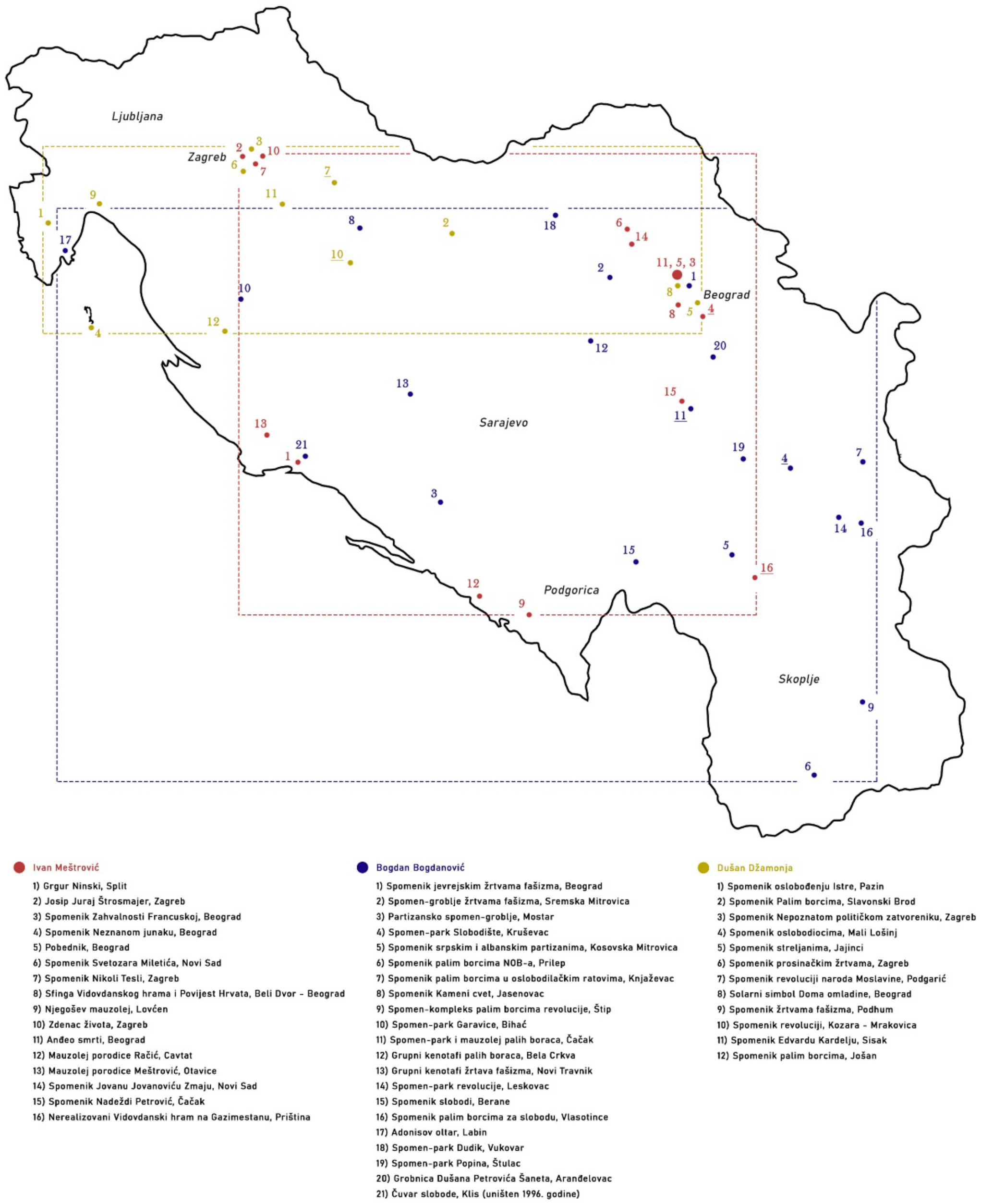

Figure 2. Map with the most notable examples of memorial architecture by selected authors

Work of collecting, systematization, mapping, analyzing and forming a research typology of the author's monuments are based on two groups of criteria. The first group of monument research criteria includes: Size of the covered territory (as part of a larger monument complex-park or individual), positioning (part of the building or independent), applied material, spatial symbolic form (visual identification of the object). The second group of criteria: Typology based on achieved primary symbolism of formal appearance using the previously collected information (identifying symbolic forms in both micro and macro scales, from ornaments to land art correlations, such as described solar motif, flame, beast, temple, water, dromos, bird, horn etc.). Research of such typology has been made through a detailed relevant case study of each author, explaining their general biographical artistic background which is, along with the, at the time, current political situation crucial in making their original artistic expression, resulting with diagram-table and accompanying map of the monuments that are the subject of research.

Figure 3. Methodology diagram of the research

5. CASE STUDY: IVAN MEŠTROVIĆ

Ivan Meštrović (1883-1962) was a Yugoslav sculptor and architect. He graduated from the Academy of Fine Arts in Wien, and then was a professor at the art academies in Zagreb, Syracuse and South Bend. He was born into a rural Catholic family, and his religiosity was shaped since his childhood days. Meštrović grew up on the South Slavic epic tradition and epic folk poetry. Meštrović was occupied with the idea of a common Yugoslav/South Slavic epic culture, so folk poetry and mythology became an important source for his creativity. His artistic interpretation of epic folk songs had special importance in establishment and maintenance of Yugoslav identity. Emphasizing the Yugoslav identity also required the creation of a specific architectural expression. The poetics of Meštrović's art, based on the common tradition of South Slavic peoples, had the potential to overcome inter-confessional and national differences in a common state. The period between the two wars is, despite numerous criticisms, marked as the period of Meštrović's greatest rise. The life and activities of Ivan Meštrović were closely connected and marked by the rise and fall of the Yugoslav idea and Yugoslav cultural policies [4].

5.1. VIDOVDAN TEMPLE

The Vidovdan temple is the first and most famous monumental work of Ivan Meštrović, an imposing sculptural-architectural composition consisting of more than eighty artifacts, supposed to be about 250m long and about 200m wide. Deeply anchored in the tradition of late symbolism and secession, the work was recognized not only as an original and exceptional example of Central European artistic movements, but also as a kind of narrative unit in which the poetic quality became indistinguishable from the political content. Conceived as a meaningful architectural framework, thematically related to the tradition of the Kosovo, its consequences and its mythologizing, the Vidovdan Temple was supposed to be raised in Gazimestan (area of the famous Battle of Kosovo) as a symbol of martyrdom and the glorious ending of the centuries-long struggle for the liberation and unification of all South Slavs. The temple was planned to be richly decorated with sculptures that would represent historical and mythical heroes and heroines, slaves and widows, who were gradually but irreversibly included in the recognizable ideological structure in the process of solving the “national question” of the South Slavs [6].

The architecture of the temple is the unique amalgam of Egyptian, Greek, Roman and Orthodox principles of building temples. The temple is considered as a reflection of the divine world, an earthly copy of the heavenly archetypes and a presentation of the cosmic image. The entrance to the temple is based on the architecture of a classic Egyptian temples, placing the high entrance door with a frieze decorated with nine symmetrically arranged horses and plinths on top, using the symbolic number nine as a motif from the poem “Death of Jugović's mother”. The huge main gate has two smaller entrances, symmetrically on the left and right. The most striking monument of the temple is a series of caryatids (atlases) - sculptures in human (mostly female) form, which stretch along the entire length of the temple decorating it on both sides. The caryatids are represented as half-naked women without expressed sexual attributes presenting the symbolic interpretation of widows, mothers and sisters of fallen heroes. It can be considered that the entire monumental and neo-primitive artistic expression in Meštrović's work relies precisely on classical Greek sculpture. The corridor was planned without a ceiling, so the sky could be seen. The main corridor ends with a five-story tower that has a square shape at its base with each floor made of twenty white marble caryatids-atlases (this time muscular men), whose dimensions decrease with each new floor, holding the floor above, symbolizing the souls of Kosovo's heroes holding the sky and watching every side of the world while rising to the heavens. Through the tower you can enter the main dome part of the temple that resembles the Roman Pantheon. Meštrović planned to decorate the interior of the temple with the main sculpture of 5m tall Marko Kraljević surrounded by multitude sculptures of epic heroes and martyrs, including Prince Lazar, Miloš Obilić, Banović Strahinja, Srđa Zlopogleđa and many other historical and non-historical characters. In addition to this large central part with a huge dome, on the left, right and front sides there are three smaller halls - niches, again vaulted with domes, that can also be entered from the outside via the stairs and the pair of entrance doors. If the temple is viewed from above, it can be clearly seen that an Orthodox cross with three equal arms is inscribed at the base of the temple surrounding the main dome. This architectural motif is taken from Orthodox church architecture, where the base of the foundation of each church looks like an inscribed isosceles cross. On the outside of the entrance there is a colonnade of columns that actually supports the caryatids that are on the inside of the main corridor. A direct connection with archaic symbolism was also established by the use of the motif of the Sphinx, which appears as one of the main motifs in Meštrović's work, as well as a planned part of the Vidovdan temple, symbolizing the guardian of the Yugoslavism and the mother of a nation whose identity did not rest on religious, ethnic, linguistic or historical differences [7]. The exterior of the temple is decorated with reliefs depicting scenes from the Battle of Kosovo in a two-dimensional technique similar to those found in ancient Egyptian and Persian art.

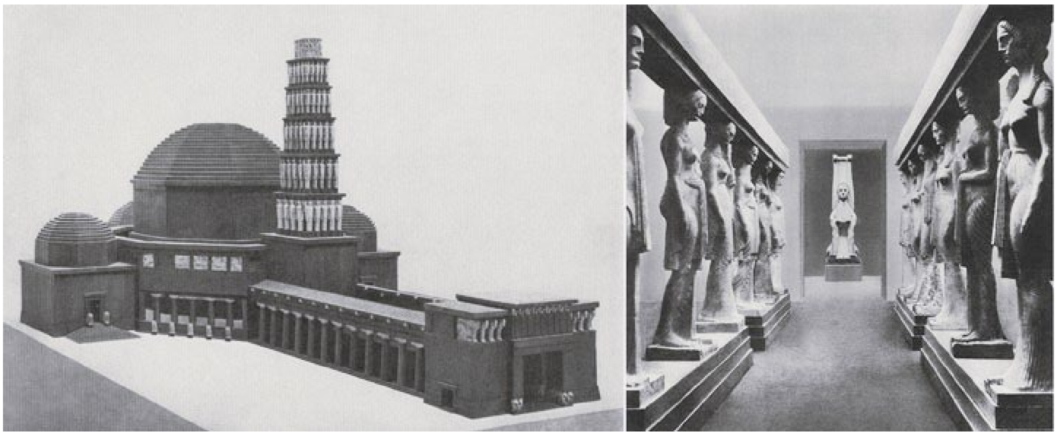

Figure 4. Model (left) and interior of the Vidovdan temple (right)

5.2. MONUMENT TO THE UNKNOWN HERO

The Monument to the Unknown Hero, located on Avala Mountain on the outskirts of Belgrade (Serbia), is a memorial to the suffering of Serbian people during World War I. At first it was a grave of the unknown soldier who died there during the retreat of the Serbian army in 1915. After the war, the construction of monuments in honor of unknown heroes across Europe became popular as the members of the Allied Forces began building similar monuments, which made King Aleksandar Karađorđević to decide to construct a similar structure in Serbia. The monument instantly caused some nationalistic controversy, as people believed that the unknown hero who fought and died for the Kingdom of Serbia was used to propagate an idea of a unified Kingdom of Yugoslavia.

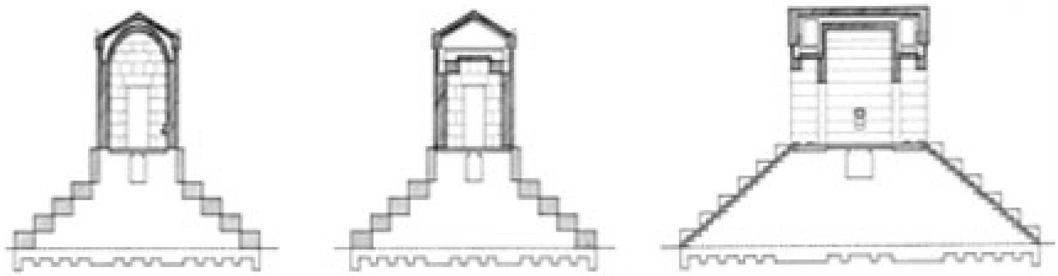

Figure 5. Drawings of the section of the Monument to the Unknown Hero on the Avala mountain

The mausoleum is reached by cascading staircase, which provide exceptional views from the base to the top of the monument. The approach to the monument is designed so that you can walk through it along the longitudinal axis of the sarcophagus, through two gates, emphasized by doubled pairs of monumental caryatids that face the passage itself, thus indicating the importance of the direction of the visitor's movement. The form of the memorial resembles a passable monumental sarcophagus raised on a five-step pedestal, a symbol of Serbia's five-century slavery under the Turks. Thus, in this monument-mausoleum, the symbolic forms and meanings of the ancient temple, altar and the tomb are permeated, making unique sarcophagus which highlights the continuity of the frequent form of grave marker, especially of rulers or important persons throughout history. In particular, the early antique tomb of the Persian ruler Cyrus in the old capital of Pasargadae, in today's Iran, served as a model for the design of this monument [8]. Moving towards the entrance, the massive sculptures of 4m high caryatids are carved from a single piece of stone made of the same material as the stone blocks of the monument, designed as dressed in different folk clothes of Yugoslav people decorated with rich jewelry. Monumental barefoot female guardians, with a dignified and unemotional expression and attitude, calm and serious, but non-static, standing in contrapposto (one leg loosely supported), with arms close to the body in various positions. They are youthful, eternally young women, symbols of the mothers of all fallen warriors who refer to the ideas of eternal, timeless glory and the idea of Yugoslavia, the unification of all nationalities in the Kingdom of Yugoslavia. The symbolism of the guardian caryatid is also reflected in connection with the female archetype as a symbol of safety and (new) birth. In this sense, the grave becomes a place of metamorphosis of body into spirit and rebirth, in this case the birth of a nation. The tomb with the remains of the unknown hero is located in the crypt, underneath the monument. The inscription at the top of the sarcophagus reads, “Aleksandar I King of Yugoslavia to the Unknown Hero” [9].

6. CASE STUDY: BOGDAN BOGDANOVIĆ

Bogdan Bogdanović (1922-2010) was an acclaimed architect, professor, philosopher and writer famous for the dozens of anti-fascist sculptural monuments and commemorative works that he created across the the Yugoslav region from the 1950s to the late 1980s. In his monumental work, he steered away from employing either traditionalist or modernist aesthetics, and instead opted to utilize ancient symbols and motifs from ancient and neolithic cultures. This gave his work a sense of timelessness and connection to the past while still being firmly rooted in the present. Very important formative influence came from his erudite reading of the history of art and architecture, anthropology, mythology, ethnology and religion, which provided a rich background in his built and literary work. Based on the development of archaic visual forms, Bogdanović introduced complex symbolism and humanistic meanings into the sculptures. His monuments throughout the Yugoslav territory became general symbols of war horrors and suffering, which, by design, transcended dogmatic-ideological and republican-national frameworks. Bogdanović himself has never denied that the confidence he had with the ruling Communist Party was necessary in order to realize his works: “Architects were always building churches, mosques and monuments for the ruling regime. They were building for the Pope, sultans, kings. When you look at this architectural richness, you are not thinking for whom it is built, it is important that it's built” [10].

6.1. SLOBODIŠTE MEMORIAL COMPLEX

This memorial in Kruševac (Serbia) commemorates the hundreds Partisan soldiers and civilians that were executed in the city between 1941 and 1944 during the German occupation of Yugoslavia.

There are four originally planned primary areas spread across the complex's 13.5 hectares: Valley of the living ones, Solar Gate, The Home of Slobodište (Owl) and the Amphitheatre. The whole complex has the symbolism of a temple (lobby, entrance, hall and sanctuary), the basic relief elements are mounds, and the entire space is shaped in arches and circles. The modernity of the composition is an astonishing synthesis of a complex interlacement of symbolic interpretations. Monumentality is dealt with a very sophisticated and conceptual approach where still the result is a shocking short circuit between archaic and contemporary. When Slobodište was erected its completely disruptive and new formula for the existing memorial scene in Yugoslavia gain attention, especially because of its main topic consisting in a very deep manipulation of the landscape. The architectural design is embodied in the nature itself which is clearly visible in two artificially modeled craters representing a large symbol of Infinity. The courageous the choice of the architect put this memorial very close to land art since the large scale of the symbol (slopes reach 16 meters of height) seems to create a metaphysical dialogue with elements of the environment (sky, land, wind) and at the same time, being mimetic, is silently immanent in the landscape stimulating a deep reflection about eternity into the visitor [11].

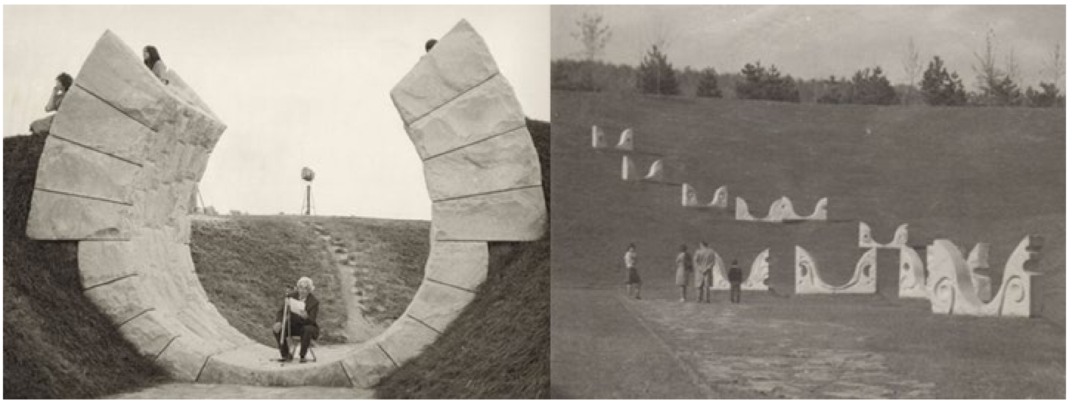

Figure 6. Slobodište memorial (Left: Bogdanović reading at the ceremony; Right: group of stone bird monuments)

Bogdanović designed each element of this complex to be part of an otherworldly journey for the viewer. Firstly, the “Solar Gate” is clearly representative of a passage into the other world, defined with the Gate as the portal from the profane to the sacred environment, especially as it is directly set into the mass-graves mounds where the executed victims of Kruševac are interred. Formal similarity inspired author Vladimir Vuković to compare the stone gate to the reverse omega sign. Omega is the last letter of the Greek alphabet, which in our culture has a universal meaning of the end. Bogdanović, reverting the symbol, turning it upside down, used the principle of anagram, and can be interpreted as the end, which, in terms of the eternal renewal of nature, marks a new beginning. From that perspective, Bogdanović seems to be leading the visitor on a symbolic journey through a “door” out of the realm of living and into the realm of the afterlife. Then, as you walk up the path, you reach the “Valley of the Living Ones” which is dominated by a series of emerging stone wings or “horned birds”, as Bogdanović used to call them [12]. There is a flock of 12 stone birds aiming towards the sky, and at the entrance there is a circular stone with the inscription "Under this sky, man, stand up". In fact, it is the symbolic liberation of souls from those executed victims escaping their mass graves, rising up finally into that afterlife, representing a clear semantic association of freedom, flight and hope as the core of its symbolic meaning. The wings are engraved with various abstract forms and designs. The design of these wing sculptures evolved from his conceptual studies of the sacred bull motifs of the Minoan civilization, which he eventually remodeled into the shape that we now see at the memorial site [11].

6.2. MAUSOLEUM OF STRUGGLE AND VICTORY

This memorial in Čačak (Serbia) commemorates the over 4,600 Partisan fighters and civilians who died during the World War II in battles during the liberation of Čačak.

The primary element of the memorial complex is a 12m tall stone and wood triple-parted megaron monument, adorned with 620 carved heads of mythological beasts - gryphons. A long stone-paved pathway runs through the middle of the monument making it passable. Ancient Greek megaron organization has its own symbolic meaning with numerous sources indicating that it was used in two central ways: first and foremost, it was used for religious ceremonies, initially structurally designed to allow for religious ceremonies to be held in the central room of the building while also being used to support residents as a dwelling space. Just downhill from the megaron, there is a much smaller dolmen-like structure sitting in front of a 5m tall mass burial mound, where hundreds of the fallen soldiers and civilians killed in Čačak during the war are interred [13]. Considering Bogdanović's deep interest in the idea of physical/celestial alignment and his history of writing about ancient traditions, the very interesting way of positioning of the memorial can be noticed. The whole complex is actively engaged with the surrounding landscape in some context of alignment, overlooking the city with special correlation with Sun during summer and winter solstice, dates that have deep symbolic meaning across many cultures, recognized and celebrated since the stone age, operating as one of the oldest human holidays. Another way in which author Vladimir Vuković suggests the triple gates of this mausoleum can be understood as a series of portals which lead the viewer through a journey into the afterlife to experience and explore the places of darkness and horrors of war. Each of these portals, Vuković explains, is constructed of stone carved creatures topped by a clay-tile roof, giving the appearance that the portals are destroyed homes infested by demons. Yet, as you are led along the path through the darkness of these portals, the light of hope and freedom can be seen beckoning from the other end [14].

Figure 7. Mausoleum of Struggle and Victory in Čačak (Left: Gryphon heads ornaments, Right: Megaron architecture of the Mausoleum)

Bogdanović often explored this concept of using his monuments to take visitors on a journey through the afterlife in order to facilitate their connection with the dead. Finally, one of the most fascinating and unusual aspects of this monument is its series of hundreds of gryphon heads carved of stone which are set into the side of the megaron/temple. Usage of wild or mythological beasts in temple decorations is a common praxis from the earliest times of human history [12].

7. CASE STUDY: DUŠAN DŽAMONJA

Dušan Džamonja (1928-2009) was one of the most influential and visionary sculptural artists during the days of the socialist Yugoslav era. While the early work of his career was figurative, by the late 1950s he began to experiment with sculptural approaches of "free spatial construction" that combined the organic and inorganic worlds. Through this method, he would take inorganic materials such as metal, glass, stone or concrete, from which he would sculpt forms that resemble the organic world, while, at the same time, also taking organic materials like wood and crafting them into form-defying inorganic creations. Furthermore, Džamonja concentrated on combining simple shapes and forms (such as curves, spheres and ovids) into highly complex and inspiring designs. In that way, he used solar and circular prehistoric motifs using combination of two main materials – symbol of duality. Its forms are clear and feasible, both as macro-urban units and as visionary projects, not only monumental but also utilitarian architecture. [14].

7.1. MONUMENT TO REVOLUTION OF PEOPLE OF MOSLAVINA

This monument in Podgarić (Croatia) was built to commemorate the community's rebellion and uprising against fascist occupying forces in the greater Moslavina and Zagreb region during the World War II [15].

The primary element of the monument complex is a large winged abstract sculpture, about 10m tall and 20m wide, with a central sphere plated in aluminum panels. Along the approach pathway to this sculpture is a series of earthen mound crypts which house the remains of the roughly 900 fallen Partisans. Through the middle of the mounds is a concrete portal-like archway, at the center of which is an engraved bronze plaque. According to Džamonja, the primary intention of the monument was to represent the "wings of victory" overcoming death and defeat, an overt allusion to the Partisan rebel's conquest over the invading occupiers. It is interesting to note that the "wings" of the sculpture are asymmetrical, with one wing having two edges, while the other has three. This imbalance gives the sculpture a dynamic shape, as if the wings are in motion or as if it is a giant bird preparing to take flight. Meanwhile, the ribbed square base which grounds the sculpture is described by some sources as representing the conduit into the landscape from which the "wings of victory" derive their energy, as if the sculpture itself absorbs the spirit of those fighters who perished here. It seems that the basic idea was to make the monument as impressive and monumental as possible. The sculpture is given the primary role, it is essential, basically the most important component of the project cycle, and everything is subordinate to it. Visible from all sides, strong contours and lines in concrete symbolize dynamics, flight and power, while the metal core is a poetic transposition of firmness and unity. The location of the monument has the following important features: elevation, dominance over the rest of the landscape, visibility from all sides, along with numerous variants and possibilities for approaching it [14]. It was a deliberate effort to guide the visitor along a circuitous route to the monument from a desire that his interest gradually grows as he approaches it, obliging him to see it and experienced from different sides, which would not be achieved along a straight direct route. Meanwhile, deeper symbolic meaning of elements of the site can be observed which hint at various potential artistic inspirations from a range of ancient and historical world cultures [15].

7.2. MONUMENT TO THE REVOLUTION - KOZARA

This monument in Mrakovica (Bosnia and Herzegovina) on the Kozara mountain is dedicated to the Partisan fighters, fallen soldiers and civilian victims who died in the bloody Kozara Offensive in the spring of 1942 [16].

The monument complex consists of three main elements, the primary monument structure, a memorial wall to the rear of the monument and a small museum. The primary monument is a cylindrical monolith approximately 33m tall, comprised of 20 vertical fins with intermittent curved bulges whose outer-faces are covered in strips of polished stainless steel. Džamonja conceived the monument complex in two parts - the access and central plateau of the monument, which are spatially separated by 200 meters and visually divided by a forest barrier and height difference. Since a wide staircase leads through the forest from the access plateau to the monument, Džamonja has thereby achieved the psychological preparation of the visitor, whose view of the monument is clearly growing, that is, it is slowly rising in front of him as he approaches the top. The monument is composed of twenty vertical segments that form a cylindrical whole. Each of the segments is profiled with deep cutouts, protrusions of the motif in the negative, which in the total sum of the whole have a symbolic meaning. While indented and shadow-covered negatives symbolize death, positives represent victory and life. An additional impression on the positives was achieved by incorporating stainless steel lamellas, which added a dimension of light to life that contrasted with the negatives that are in the shadows [16]. The horizontally placed blocks, which are placed around the central monument, symbolize the pressure and aggression of the enemy who tries with brute force, but fails to destroy the life and victory that rise to the sky, embodied in the vertical monument. Meanwhile, the tall narrow fins that make up the circular chimney-like tower are spaced in such a way that the average person is able to just barely squeeze into the hollow center of the structure. Inside this strange environment, one feels trapped, confined and encircled, almost as though some dark and oppressive force is bearing down upon you.

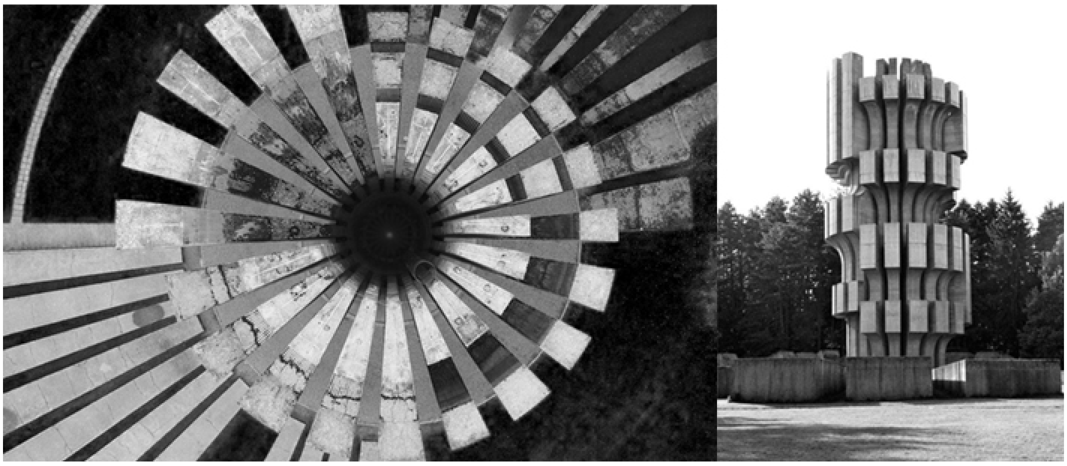

Figure 8. Monument to the Revolution – Kozara

This imposing atmosphere forces one to recall the similar oppressive feeling of the Axis forces bearing down on Partisan rebels and peasant fighters at this spot during the Battle of Kozara. Then, as you look upwards through the eerie tunnel-scape of the tower, the circle theme is seen again at the top of the monument where all of the fins converge, which reinforces not only the claustrophobic nature of the structure, but also seems to be a reference to the traditional kolo (circular) folk dance which is historically significant in the Kozara region [15]. This is a very illustrative example of how the intangible cultural heritage, common to all South Slavic peoples, is translated into a material architectural symbolic form. In fact, up until the 1990s, an integral part of celebratory events at this monument was performing large kolo dances in the grassy field in front of the sculpture [16].

8. COMPARATIVE ANALYSIS AND VALORIZATION

Symbols are at the core of cultural identity. As such, they have power to write history, connect the incompatible, shape reality. The role of memorial architecture can be interpreted as an instrument for building community awareness, its way of communicating with its own past. Symbols play a vital role as objects on which thoughts and prayers can be focused or representations of beliefs imprinted in the cultural identity. The common bearer of memory becomes a symbol - a monument, meaningful and easily understood by all people, which even in very wide circles of free association, even when talking about death - betrays faith in life and humanity in general, showing strong bond of Yugoslav unity in order to overcome the horrors of the wars. A common method in the design of memorial complexes and the monuments themselves was reflected in the ancient doctrines of temple architecture. In this way, special ambient units would be singled out and would lead the visitor on a personal transcendental journey. In this sense, the memorial becomes a place of a mystical rite of “transition” between worlds, contact with the spirit of the ancestors and the homeland, thereby contributing to the strengthening of national identity.

Table 2. Comparative typology

author	Ivan Meštrović		Bogdan Bogdanović		Dušan Džamonja	
memorial						
	Vidovdan temple (unbuilt)	Monument to the Unknown Hero	Slobodište memorial complex	Mausoleum of Struggle and Victory	Monument to Revolution of People of Moslavina	Monument to the Revolution Kozara
year	1911.	1938.	1960.	1980.	1967.	1972.
location	Gazimestan (Serbia)	Avala (Serbia)	Kruševac (Serbia)	Čačak (Serbia)	Podgarić (Croatia)	Mrakovica (Bosnia)
territory	individual	individual	complex	individual	complex	complex
position	independent	independent	group of memorials	independent	independent	independent
material	mostly stone	gabbro granite stone	carved stone blocks	gabbro granite stone and wood	poured concrete, rebar, aluminum sheets	poured concrete, rebar, steel plates
form-shape	temple	mausoleum	mounds, birds	megaron	wings	tower
primary symbolics	temple, caryatides, sphinx, heroes, female motif, myth of Kosovo, sky	temple, mausoleum, unknown hero, female motif, caryatides, pedestal	horns, gate, sun, mounds, birds, temple, omega	temple, megaron, mausoleum, solstice, antic temple, beast motif, gryphon	solar motif, great eye, wings, winged sun, pedestal, power	rhytm, kolo dance, duality, light, darkness, tower, pillar, sun
comparable symbolic influence examples for analysis						
	Erechtheion, 5th century BC (Greece)	Tomb of Cyrus, 6th century BC (Iran)	Minoian Horns of consecration, 15th century BC (Greece)	Maian stone Beast, 9th century (Mexico)	Winged Sun inscription, 12th century BC (Egypt)	Kolo (dance of Illyrian origins)

The symbolism of natural phenomena, flora and fauna has been essential to symbolic conceptualization since protohistoric times. Especially significant are animals, which acquire new forms and mythological characteristics and as such are especially worshiped and placed in the rank of deities or guardian spirits. Throughout history, the role of mythological beasts has been to guard and protect, so they are associated with places such as temples, treasuries or cemeteries (monuments) or are often represented on weapons, money and vases. In Meštrović's work, the Sphinx stands out as an important motif. In Egypt, sphinxes were represented in stone sculptures in the form of a reclining lion with a human head. It is often the case that the sphinx is positioned so that it always watches over significant necropolises. Furthermore, Sphinxes had an important place in Greek mythology, where the motif of a sphinx with wings appears (like Meštrović's sculpture).

Inspired by ancient architecture, Meštrović used entire architectural forms or individual elements from the archaic period in both analyzed cases. Vidovdan temple is consisting of various interpretations of Egyptian, Greek, Roman and even Orthodox architecture. The entrance gate and long hypostyle hall of caryatids is a mixture of Ancient Greek and Egyptian architecture, while the large “pantheonic” dome surrounded with three smaller ones can be found in the architecture of the orthodox churches. For the Avala monument in particular, the early antique tomb of the Persian ruler Cyrus in the old capital of Pasargadae, in today's Iran, served as a model for the design [8]. Representations of human pillars (caryatids or atlases), that appear all around Vidovdan temple and guard the entrance of the Avala monument, have their origin rooted in the tradition of ancient Greece, and certainly the most famous preserved example are the caryatids from the Erechtheion temple on the Athenian Acropolis. They might not only be holding the ceiling, but especially in the case of Vidovdan temple, the ceiling is negated – representing the sky (heaven) is what they are carrying and striving for. The sky is a key universal symbol that represents the direct manifestation of transcendence, power, eternity and holiness. It is a metaphor for heaven, the home of gods and immortals, in this case emphasizing the greatness of the sacrifice of Kosovo's heroes and martyrs whose figures rise to the heavens. In fact, it is a common case of painting the ceilings of pagan temples with heavenly objects and symbols, thereby evoking the importance, mysticism and sanctity of the place itself. Ancient architecture influence can also be seen in numerous Bogdanović's works. In particular, organization and architecture of monuments in both examples shown in the case study are related to archaic archetypal doctrines. While the monument in Čačak shows an example of ancient megaron architectural organization, arguably precisely following the surrounding views and positions of the celestial events, in the case of Slobodište the complex is organized by the influences of protohistoric mound shapes, evoking the chthonic ambience of the place.

Figure 9. Sphinx motif continuity (from left to right: Egyptian, Persian, Greek, Meštrović)

In Bogdanović's work, griffins and "horned" birds stand out as crucial symbolic sculptural forms of beasts. Similar carved zoomorphic heads can be seen in the temples of southeast Asia, specifically Angkor Wat, or in the temples of the Mayans, with the most famous example being the Temple of Kukulcan at Chichen Itza, which is decorated with a series of serpent heads. Interestingly, the Kuklucan example is a notable comparison not only because of its serpent heads, but also because the Mayan temple is a structure that, like the Čačak mausoleum, is designed around the idea of alignment with surrounding landmarks and celestial events. The gryphon, as a representative of these mythological beasts, is present in almost all ancient cultures, even though they originate from the East, most likely from the territory of the ancient Scythians. It is a mythical four-legged winged monster, the size of a wolf, with the legs and claws of a lion and the head of an eagle. Gryphons were considered dangerous demons, who were servants of the gods, and over time they lost their chthonic character and turned into a symbol of wisdom. Since these miraculous creatures combine the strongest bird (eagle) and the strongest quadruped (lion), they have become a symbol of the greatest animal strength [17]. The Gryphon symbol is recognizable in almost every culture. To the Persians, Babylonians and Assyrians, the gryphon has the head, wings and claws of an eagle (a symbol of alertness and keenness) and the body of a lion (a symbol of strength). In ancient Greece, he was sacred to Apollo (the sun), Athena (wisdom) and Nemesis (threat-revenge). The symbol of the gryphon has made its way from the far mystical East to Christian symbolism. In medieval Europe, the griffin represented the strength, protection and power of the sun, so it was also interpreted as a symbol of Christ himself and the resurrection (especially in heraldry) [18]. On the other hand, the motif of a flock of stone birds in Slobodište unequivocally symbolizes the ascension and "flight" of the souls of the dead to heaven, the final victory of life over death. Since the earliest protohistory, there has always been a close connection between the human soul and the stone. Stone is a material of extraordinary symbolism in folk beliefs related to the soul of the deceased, which is believed to continue living in the tombstone after the physical death. It is particularly significant for the Bogomil and Stećak culture in the territory of Yugoslavia, which is closely related to the controversies surrounding the establishment of the Yugoslav identity and is often promoted through art as the national religion of the Yugoslavs [19].

Figure 10. Gryphon motif continuity (from left to right: Minoian, Persian, Orthodox, Bogdanović)

The shape of the Bogdanović's stone birds evolved from his conceptual studies of the "Horns of Consecration", mysterious symbol of the Minoan civilization probably representing horns of the sacred bull, which he eventually remodeled into the shape of the birds (wings) that we now see at Slobodište [13]. The symbolic motif of Džamonja's "wings of victory" has a striking resemblance to the ancient symbol of the "winged sun", a motif which was used across a wide range of archaic civilizations (Egypt, Persia, Assyria). Continuously observing these cultures, the symbol is generally representing the solar motif in function of communicating holiness, energy, power and supreme divinity. The archetypal symbol of the winged sun, which occupies a central place in Dzamonja's work, stands out as particularly interesting. In many cultures, the symbol of the spherical Sun is compared to the all-seeing divine eye, the principle of authority and great power. It is the eye of the the Egyptian god Ra, Greek god Zeus, later the Roman Jupiter, the Hindu Varuna and the Scandinavian Odin [19].

Figure 11. Winged solar disc motif continuity (from left to right: Assyrian, Egyptian, Džamonja)

This connection between the Sun and the deity is archetypal and cults dedicated to the Sun are common in archaic traditions. While there are many interesting examples of ancient sun discs that bear stylistic similarities to Džamonja's sculpture, one of the most interesting is a 9th century BC Assyrian relief carving which depicts the warrior Gilgamesh with a winged sun disk held above his head by two representations of Gugalanna, the Bull of Heaven. The idea of a direct connection to heaven and divinity is a common symbolic thread among ancient depictions of sun discs and is a theme that directly relates to the events memorialized in the Podgarić monument [14]. Furthermore, numerous ancient cultures use extended wings to symbolize the protective forces of heaven. Most notably, in ancient Egypt, the goddess Isis, who is generally depicted with spread falcon wings, was the deity who carried lost souls into the afterlife and had the ability to resurrect the dead.

9. CONCLUSION

Based on the material analyzed in the case studies, results of this research show that selected celebrated Yugoslav memorial architecture authors, both architects and sculptors, were extremely inspired by adoption of archetypal ancient and proto-historic symbolic motifs. Although these symbols are spatially manifested in the most diverse forms, from ornamentation to land art, the key to their symbolic function is created through archetypal thoughts and feelings, a specific product of collective memory, so that their essential concept and meaning can be in that way fully understood. Through presented examples, this research indicates that various archetypal archaic symbols had specific cultural and political significance in shaping the Yugoslav identity in both of the two different contexts under socio-politically different periods and regimes. It is particularly interesting to point out the socialist context where, with the key use of archaic symbolism for the purpose of narration and emphasizing the Yugoslav national consciousness, the authors very successfully avoided the use of direct and concrete religious and ethnic motives of the people of Yugoslavia, thus linking them to the pagan archetypal archaic images of the general human collective memory, this time through the new interpretation of the original modernist expression. The design approach used by all the mentioned authors is significant because it represents a unique example of author's artistic interpretation of a previously known symbol, specifically fitting it into a contemporary context. The present motifs were used exclusively to strengthen the sense of belonging to the community of the new context of the Yugoslav nation and ideology.

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17

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AUTOTELICITY AS A CAPACITY OF ARCHITECTURAL CONCEPT: ARCHITECTURE OF CREATIVITY IN CHILDREN'S SPACES

Abstract

This paper explores the intricate relationship between architecture and creativity, with a particular emphasis on the concept of autotelicity. Autotelicity, defined as a state where an individual fully immerses themselves in an activity within a spatial context, is examined as a crucial element in the creative process and appreciation of architecture. The investigation revolves around how autotelicity can form the basis for architectural concepts and how architecture, in turn, can encourage user creativity through this lens. Through case studies of children's spaces, this research aims to illuminate these concepts and provide fresh insights into how architecture influences our spatial perception while fostering creative thought and behavior. The emphasis on autotelicity underscores architecture's potential to inspire creativity and enjoyment in everyday spatial use.

Keywords: autotelicity, architectural concept, creativity, children's spaces

АУТОТЕЛИЧНОСТ КАО КАПАЦИТЕТ АРХИТЕКТОНСКОГ КОНЦЕПТА: АРХИТЕКТУРА КРЕАТИВНОСТИ У ПРОСТОРИМА ЗА ДЈЕЦУ

Сажетак

Овај рад истражује сложен однос између архитектуре и креативности, са посебним освртом на концепт аутотеличности. Аутотеличност, дефинисана као стање у којем појединац потпуно урања у активност унутар просторног контекста, испитује се као кључни елемент у креативном процесу стварања архитектуре. Истраживање се окреће томе како аутотеличност може формирати основу за архитектонски концепт и како архитектура, заузврат, може подстицати креативност корисника. Кроз студије случаја простора за дјецу, ово истраживање има за циљ да освијетли ове концепте и пружи свеже увиде у то како архитектура утиче на наше просторно поимање док подстиче креативно мишљење и понашање. Нагласак на аутотеличности истиче потенцијал архитектуре да инспирише креативност и уживање у простору кроз свакодневне обрасце кориштења.

Кључне ријечи: аутотеличност, срхитектонски концепт, креативност, дјечији простори

1. INTRODUCTION

The overarching research question posed in this study is how the concepts of autotelicity and flow, as central elements in Mihaly Csikszentmihalyi's theory, can influence the fundamental principles underlying architectural concepts and, ultimately, spatial design to discover optimal user experiences, satisfaction, and creativity in everyday life [1]. This inquiry builds upon conceptual frameworks from previous research, particularly concerning the concept of autotelicity in architecture, observed through the lens of the relationship between concept and percept in the broadest sense [2]. The fundamental inquiry revolves around how the engagement in activities within a space can foster the emergence of the 'autotelic self.' This leads to the pivotal question of how to integrate daily creative activities, through experience and mediated by space, into architectural concepts so they become an integral part of the design process.

This study particularly focuses on examining the concept of autotelicity in spaces intended for children, aiming to explore through embodied architectural concepts the elements that stimulate creativity, engagement, and satisfaction among children in their daily use of space. In other words, the study will shed light on the architectural dimensions that encourage processes of identification through creative behavior. Children, as users, represent the prime example of active space utilization. Through engagement and creativity, facilitated by nonverbal modes of communication, they acquire direct spatial experiences, where space itself is perceived as a venue for intense interactions. It's worth emphasizing that the exploration of the concept of autotelicity in architecture is not exclusively tied to spaces for children and their imagination. However, the mechanisms and elements identified in children's patterns of creative space utilization can serve as a significant basis for integrating such concepts into everyday architecture.

The underlying hypothesis of this research is that autotelicity, as a capacity within architectural concepts, stimulates involutive processes that enable the manifestation of creativity in users' everyday lives, thereby creating a sense of satisfaction and enjoyment in architectural experience. It starts from the assumption that architecture, through its concepts, principles, processes, and elements, shapes users' forms, spatial relations, and characteristics, and by means of activities in certain spaces, can activate and stimulate flow processes and the "autotelic self" in users, thereby integrating with space and fostering identification through creative behavior.

The primary objectives of this study are to theoretically explain the concept of autotelicity in architecture, as well as the key terms relevant to this discourse. Subsequently, through a case study methodology, the study aims to examine architectural concepts and strategies that promote autotelicity and contribute to the creation of architectural spaces fostering creativity, user satisfaction, and particularly focusing on spaces designed for children.

The methodological approach in this study is based on theoretical research and case study investigation. The first part of the study establishes the theoretical framework of key concepts and draws conclusions as elements and procedures for establishing a theoretical platform for further investigation within the case study in the latter part of the study. Furthermore, through provided examples, the study identifies the principles of architectural concepts that lead to the emergence of autotelicity, practically demonstrated through the analysis of architectural examples, including those specifically designed for children. This exploration aims to illustrate how architecture can shape our everyday experiences and contribute to the quality of life through creativity and architectural innovation.

The anticipated outcomes of the discussions in this study are summarized in the conclusion, focusing on a better understanding of the role and practical application of the concept of autotelicity in design strategies and implementations in contemporary design methodology, particularly in the context of spaces catering to children's needs and imagination.

2. THEORETICAL FRAMEWORK

„Throughout our day, whether at home or at work, we humans adapt and innovate, improvise flexibly, at times acting from our "*gut feelings*", at times from options we imagine and systematically try out, one after the other." [3]

Autotelicity, as conceptualized by psychologist Mihaly Csikszentmihalyi, lies at the heart of understanding creativity. According to Csikszentmihalyi, autotelicity refers to the inherent satisfaction derived from engaging in an activity for its own sake, independent of external rewards or goals. This concept emphasizes the intrinsic motivation that propels individuals to immerse themselves fully in challenging and enjoyable activities, leading to deep concentration and fulfillment [2]. It is necessary to be able and mentally engaged to incorporate pleasure into everyday life. The intensities produced by the flow are a challenge for the individual. Csikszentmihalyi speaks about „the autotelic Self“ which implies the ability of an individual to translate potential dangers into challenges of pleasure and thus preserve inner harmony [2:209]. Within this state, the "autotelic self" becomes the driving force, urging individuals to engage in activities purely for the experience, thereby experiencing complete engagement and enjoyment. Csikszentmihalyi's theory extends beyond psychology, finding applications in various fields, including education, arts, sports, and beyond, offering insights into how individuals can achieve optimal experiences through total immersion and commitmentHere, it is necessary to pose the research question: Can architecture, through the intensities it brings together, effectively activate this type of individual capacity?

In contrast to art, architecture is imbued with utility, necessitating a distinctive perspective on creativity. Here, creativity transcends mere observation; it becomes inseparable from the activities it enables. Kevin Lynch's insights underscore the active role of observers in shaping their perception of the world, highlighting the symbiotic relationship between observation, imagination, and creativity [4]. By producing such transitions within high-intensity locations, it is possible to let things happen, including what was not originally intended: „Created by and for humans, these interventions arose both intuitively and rationally; They are inspired by both the physical context (place, location) and the social context.“ [4:13]. The experience of architecture encompasses more than just physical structures; it embodies a complex interplay of sensory perceptions, emotional responses, and cognitive interpretations. At its core, the architectural concept serves as the blueprint for this experience, shaping spatial qualities, defining functions, and evoking meanings [2:73]. Contrary to passive observation, architecture prompts active engagement, inviting individuals to interact with and interpret their surroundings. This interaction fuels a continuous dialogue between the built environment and its inhabitants, where each influences and enriches the other.

The manifestation of creativity, whether by individuals or groups, is profoundly influenced by the environment. Exploring the dynamic interplay between architectural concepts and spatial experience unveils how the creative energies embedded within architectural works—products of authors' ingenuity—can catalyze reciprocal creative processes in daily usage [2:110]. This dynamic interaction underscores the dual nature of creativity in architecture, where design intent converges with lived experience. Innovation within architecture involves a delicate balance of embracing and challenging past experiences. Resistance to conventional norms serves as fertile ground for imaginative leaps, allowing true creativity to flourish. This perpetual quest for novelty underscores the intrinsic connection between creativity and everyday existence [5]. Central to this exchange is the notion of creativity, which permeates both the conception and utilization of architectural spaces. The design process, driven by creative exploration and innovation, gives rise to tangible manifestations of ideas and intentions. Yet, equally significant is the creativity inherent in everyday activities within these spaces, where users adapt, personalize, and reconfigure their environments to suit their needs and desires.

The intensity of architectural stimuli can catalyze creative responses in users, prompting them to experiment, improvise, and reimagine their spatial interactions [4;5]. This reciprocal dynamic between design intent and user experience underscores the multifaceted nature of creativity in architecture, where innovation thrives on the interplay between intentionality and adaptation. In essence, the architectural concept serves as a catalyst for creative engagement, fostering a symbiotic relationship between form and function, intention and interpretation. By nurturing an environment conducive to exploration and expression, architecture not only shapes our physical surroundings but also enriches our lived experiences, imbuing everyday life with meaning, significance, vitality and pleasure.

Bernard Tschumi explains architecture of pleasure as a moment when conceptual ideas and spatial experience unexpectedly coincide, when the rules of architectural culture are deconstructed, and when the usual boundaries of architectural design are crossed [6:77]. What makes architecture so desirable is the difficulty of its discovery, with revelation being part of the pleasure of architecture. However, every interaction between architecture and its users can be perceived as a form of violence because the use of space entails the intrusion of the human body into a particular space, i.e., the intrusion of one entity into another. This idea of violence is not literal but metaphorical, indicating the intensity of the relationship between people and the spaces surrounding them. On the other hand, when De Landa speaks of "intensive properties" through "critical thresholds," he is essentially describing processes in which there is a "transition from quantity to quality" at any given moment. This implies moments of change [7]. From the perspective of architectural concept, this raises another research question: Can we call this threshold a point at which architecture fosters creativity in everyday use, and if so, what defines this threshold?

The actualization of concept-percept relations points precisely to the aforementioned critical thresholds of architecture intensity [2:76]. By producing such transitions within high-intensity locations, it is possible to let things happen, including what was not originally intended: „Created by and for humans, these interventions arose both intuitively and rationally; They are inspired by both the physical context (place, location) and the social context" [4:13]. The intensities that enable the pleasure of architecture are thus related to the conceptual-perceptual potentials - high energies that enable the formation of intensity nodes.

Thus, architecture of creativity entails a dynamic process, where pleasure becomes an integral part of everyday activities. Regardless of the repetitive characteristics of certain activities, the experience of space can always be differently stimulated by the architectural concept. The actualization of the concept and experience of space points precisely to the mentioned critical thresholds of architectural intensity.

Representation of the principles of autotelicity through direct experience in architecture implies simultaneously placing the architectural concept on par with experiential interpretations, which are not necessarily the author's intention on one hand, but are a consequence of the openness of the concept and the dynamic interplay between concept and percept on the other hand [2:76]. The context in which the concept-percept occurs is a key condition for the possibility of the mechanism of experiential knowledge transfer. Therefore, a good example on which this relationship can be analyzed are spaces used by children, namely kindergartens, for two reasons: 1. because children have specific perceptual mechanisms, 2. because the mechanism itself occurs in the everyday real environment in the relationship between space-teacher-child.

Children perceive space in a specific way, characterized by concepts such as sensory impressions, affectively colored relationships, concentration/identity, materialization of space/awareness of time, symbols/over-words, wholeness/humanity and space (affectively colored relationships, visual fields, games of fields, previous constancy of perceptions) [8]. Starting from the fusion of mental and physical boundaries of the body and environment, Bloomer and Moor call for the necessity of experiential interweaving of perception and experience through various activities [9]. Perception of space in this case can manifest as an "embedded" experience, which involves immediate, sometimes uncontrolled reactions of children to their surroundings, stemming from an accumulated sense of semi-conscious ego, rather than from subjective consciousness. Such a state arises from the unity of "proto-me," sensory impressions, perceptions, and reactions, which will be differentiated into intentional perception through later stages [10].

On the other hand, adults, in direct interaction with space, exhibit more complex mechanisms that are predominantly culturally conditioned. Therefore, the intensity of activity and the transition of the critical threshold are more dependent on rational relations. In the case of children, through subconscious learning, accumulated in the body and memory, and carried out through play and creation, the potential for activation of conceptual-perceptual nodes is intensified. Unlike children, where stimuli are most often directly translated into pleasure, in adults, such a feeling is very often deliberate and conscious, channeled through individual senses and culturally conditioned.

Creative architecture in this case, considered in children's spaces, reveals itself within the everyday pedagogical practices of kindergarten spaces. Relying on Malaguzzi's theory, where the space itself within the children's environment is actually the "third teacher," placed in the center of the constructivist dialogue of the child (student), teacher (parent/educator/school), and the environment itself, we can point out the importance of architectural concepts that, in conjunction with immediate children's experience, represent a crucial potential for realizing the autotelic self [11]. Expressiveness, but also what it produces through different types of opposition / unification of body-environment intensities, indicates a positive tension that can be an indicator of auto telicity. Palasma, connoting "an experience that summarizes combinations of the individual and the collective, the conscious and the unconscious, the mental and the physical" [12:55], speaks of erasing body-space boundaries by constructing activities and atmospheres that encourage engagement in space itself. Running, peeking, crawling, lying down and sitting in the space of the "children's street", therefore, can be indicators of the self-sufficiency of the space itself.

Realizing the autotelic self implies the necessity of intertwining everyday surroundings with imaginary layers and processes, through which the intensity of experienced interpretations can be achieved. Therefore, the ways in which creativity will manifest and to what extent depend on the characteristics of the space itself, immersed in the everyday kindergarten activities (pedagogy), which through engagement and purposefulness has the potential to produce flow and stimulate internal motivation through intrinsic satisfaction produced by the knowledge transfer process.

In order to explore the dynamics between architectural concepts and the realization of autotelicity in everyday experiences, a qualitative case study approach is employed. This methodology allows for an in-depth examination of specific cases to uncover underlying patterns and insights. The selection criteria for the case studies are twofold: first, the architectural projects must exemplify innovative design approaches that actively engage users in creative activities; second, they should represent diverse cultural contexts to capture the nuanced interactions between space, culture, and creativity. The chosen case studies include three preschools: Njiric + architects – kindergarten Medo Brudno in Zagreb, 2008; ATG kindergarten by Hibinosekkei in Niigata, Japan, 2021; and Nordtvet Farm Kindergarten by Morfeus Arkitekter in Oslo, Norway, 2019. These examples offer distinct architectural interpretations and pedagogical philosophies, allowing for a comparative analysis of how different spatial environments facilitate creativity and the emergence of the autotelic self. The analysis will focus on four key dimensions: 1) the architectural concept and its integration with pedagogical principles; 2) the cultural and educational context informing the design process; 3) the spatial organization and its impact on user behavior and experience; and 4) the ways in which the space fosters creativity and the autotelic self. By examining these dimensions across the selected case studies, this research seeks to shed light on the intricate relationship between architectural design, everyday experiences, and the realization of autotelicity in educational environments.

3. CASE STUDY

Spaces for children, where pleasure is derived from the process of activity itself, independent of external goals and rewards typical for adults, provide a good spatial framework where the connection between space-activity-user is intense and immediate. The children's "autotelic self" is placed at the center of the spatial relation concept-percept and is manifested through children's immediacy, engagement, and satisfaction immersed in the creative activities of everyday life. In spaces of creative architecture, those that invite play and engagement, children attribute new meanings to spatial elements and actively use them through the creative potential of play, making space not only a participant but also an initiator of specific events. Preschool spaces point to those dimensions of architectural concepts which, through the relationship of space-activity-user and through specific architectural elements, encourage processes of identification through creative behavior.

Therefore, children's spaces represent a prime example for exploring the concept of creative architecture, one that stimulates autotelic processes through its embedding in real space. Regarding spatial characteristics, everyday practices, and children's experiences, the next section will discuss the spaces of three preschools that, through creative architecture and architectural concept, stimulate the realization of children's autotelic selves.

3.1. NJIRIC + ARCHITECTS – KINDERGARTEN MEDO BRUDNO, ZAGREB, 2008

The Medo Brundo Kindergarten, designed by the architectural firm Њ и р и ћ+, represents an intriguing example of incorporating real-life experiences into the architectural concept. Built in Zagreb in 2008, this kindergarten embodies the concept of acquainting individuals with real-life activities and fostering creativity and engagement.

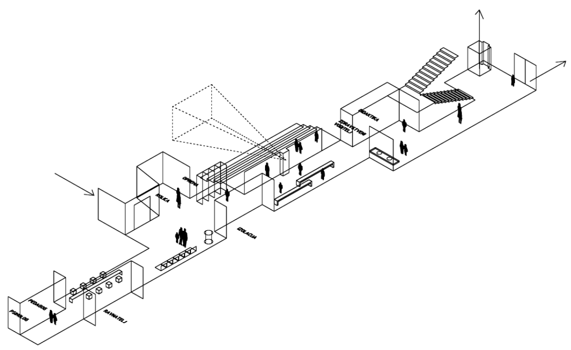

Figure 1. Njiric + architects – kindergarten Medo Brudno, Zagreb, 2008: Children street

The architectural concept revolves around introducing and mixing various activities to promote interaction and engagement through visibility and boundaries. The design repeats the local urban matrix on a micro scale, transitioning functional units within the interior space and courtyards. At the heart of this micro-urbanism lies the "Children's Street" [13], around which different spaces such as courtyards, dayrooms, administrative offices, kitchens, and administration areas are arranged. " Transparency of the partition to this street, allows constant exposure of units, as well as their interaction with each other. The dynamic flow of this street "and the multitude of interspaces, supported by intense transparency and color coding, seek to create a scenario of a true urban experience for children” [13].

Figure 2. Concept:"Introduction to real life"

The concept is based on a kind of "introduction to real life" through open exposure to various kindergarten activities., fostering creativity through open engagement. The expressive nature of these activities, along with the intensity of the interaction between body and environment, indicates a positive trend towards autotelic tendencies. The atmosphere of the "Children's Street" serves as a unique collage of activities, promoting diversity within everyday activities and stimulating creativity by provoking a new layer of environmental perception.

Pleasure is thus not made possible by conventional use but is provoked by a concept that gives a new layer to the perception of the environment by activating creativity [2:80]. For instance, children actively engage in building displays that become part of the administrative space atmosphere, allowing them to compare and present their work with children from other areas. Similarly, activities in the kitchen, sewing rooms, and workshops are exposed, creating a unique atmosphere defined by the architectural framework that enables the production of diverse events intertwined and contained within each other. The experience of ordinary every day stay in the kindergarten is enriched by such unpredictable factors, and the dynamics of such internal intensities give architecture and experience an autotelic dimension. Creativity in this case is not a mere creation characteristic exclusively for kindergarten and children's imagination.

Figure 3. Creative Architecture- Enjoying Understanding Everyday Processes

The experience of everyday life within the kindergarten is enriched by unpredictable elements and dynamic internal intensities, giving the architecture an autotelic dimension. Creativity is encouraged at all levels, fostering an atmosphere where intense differences contribute to internal harmony and stimulate creativity. Children, administrative staff, teachers, educators, and parents are exposed to a form of autotelic potential through their involvement in everyday activities, contributing to the creation of a diverse atmosphere. This integration of creativity into everyday activities becomes an integral part of the architectural concept's identity, where change becomes an integral part of repeating characteristic daily activities.

Moreover, this analysis sheds light on the negative aspects of indirect learning through observation and virtual involvement in processes, emphasizing the importance of direct physical engagement in daily creative activities, particularly focused on children's activities. In essence, the autotelic experience in Medo Brundo Kindergarten is not merely about the activities themselves but rather the profound sense of fulfillment and satisfaction that individuals derive from their immersion in the present moment. It is a testament to the transformative power of architecture in shaping environments that inspire joy, creativity, and self-discovery.

3.2. HIBBINSEKKEI+YOUJI NO SHIRO-ATG KINDERGARTEN, NIIGATA, JA, 2021.

The concept of "Participation in Real Life" at the ATG Kindergarten, designed by the architectural duo Hibbinosekkei, exemplifies architecture where the potential of creative architecture is realized through direct participation and enjoyment in activities, specifically children's involvement in real-life scenarios. This concept is deeply rooted in Japanese culture, emphasizing children's participation in adult activities. In relation to the concept, the author himself states: "In Tokamachi, there is a traditional event called 'Honyara-do' that has been passed down from generation to generation. 'Honyara-do' is a place where everyone gathers to eat, play, enjoy, and learn, a scene that has continued in this area for a long time" [13]. According to that, kindergarten's design is based on the principles of autotelicity, where the space itself embodies the process of collective-individual engagement.

Figure 4. Hibbinsekkei+Youji no Shiro-ATG kindergarten- Niigata, JA, 2021.

The architectural concept emphasizes openness, accessibility, and participation in all activities, embodied in a massive cubic volume structure that houses community gatherings under one roof. Despite the spaces being organized within a simple spatial form, there is a duality of content manifested through interaction with the environment, achieved through a rich entrance foyer and an artificial-hill slide connecting the ground floor with the outdoors. And as Hibbinosekkei says: “We designed an environment where children can practice and challenge various play activities harmoniously with the external environment throughout the four seasons” [14]. The kindergarten features numerous integrative spaces, both indoors and outdoors, designed for spontaneous exploration, play, and creative engagement.

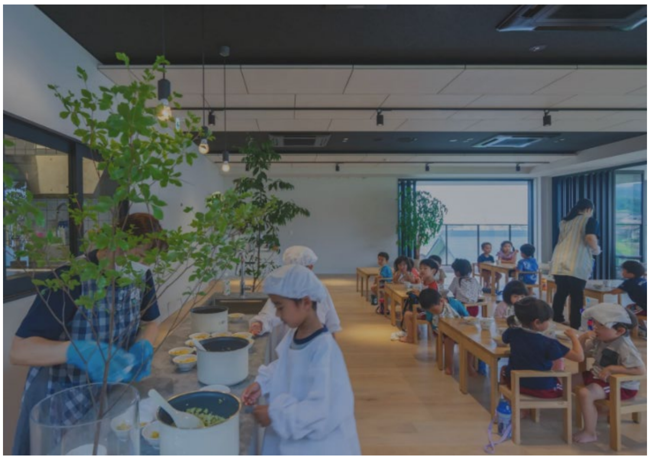

Figure 5. Concept - Children's Participation in Real Life

The kindergarten consists of spaces of various sizes, purposes, and atmospheres, offering a multifaceted potential for daily enjoyment in creative processes. For example, the entrance leads to a significant foyer with dominant steps leading to the dining area on the upper floor, serving as a central space for multifunctional integration. The foyer integrates various semi-scaled functions suitable for children's work and play, materialized through natural elements such as wooden flooring, shallow water pools, sand, available for all inhabitants of the house. Internal shared spaces such as cloakrooms, pocket libraries, mini playgrounds are accessible to children and adapted for their independent exploration and progress. However, the most significant place is occupied by the dining room and kitchen, where children participate daily in meal preparation and serving, also used as a studio or space for physical activities, performances, etc., all in constructive collaborative action between children and adults, where children are considered equal function bearers.

Children participate in daily interactions through work and play, for example, in the kitchen, where they participate in cooking, setting the table, and washing dishes. But the challenge of instrumentalization of children's learning, strong emphasis on group activities according to social norms suppresses individual creativity in terms of producing new meanings. Anyway, Creative behavior is manifested through design, emphasizing participation in real life. Despite these challenges, the concept of autotelicity fosters an environment where children engage creatively with their surroundings, promoting genuine participation in everyday activities. This integration of negative aspects highlights the importance of continually reassessing and refining educational approaches to ensure that children's creative potentials are fully realized within the kindergarten environment.

Figure 6. Creative Architecture-Pleasure in Engaging in Everyday Activities

3.3. MORFEUS ARKITEKTER-NORDTVET FARM KINDERGARDEN,OSLO, NO, 2019.

The concept of the Nordtvet Farm Kindergarten by Morfeus Arkitekter is based on the principles of contemporary pedagogy, known as the Reggio Emilia approach, which at its core embodies a constructivist standpoint that space itself is the "third teacher" in children's learning and development. Through an appropriate spatial framework, a relationship is established between the known and the unknown, upon which the potential for children's abstraction rests. Therefore, the authors themselves state: "We wanted to appeal to children's imagination and understanding of the world and design a kindergarten where the building itself is a mentor" [14]. The space that invites play and engagement is enriched by children with new meanings of spatial elements, actively using them through the creative potential of play, making the space not only a participant but also an initiator of particular events.

Figure 7. Morfeus Arkitekter-Nordtvet Farm Kindergarden, Oslo, NO, 2019.

Functionally, the ground floor of the house houses kindergarten units that could be described as undersized compared to Central European standards but are in line with Norwegian pedagogy, which emphasizes children's outdoor activities. Therefore, the emphasis is on integrating and intertwining outdoor activities, as well as users, which are not only children but also locals who have embraced this house as an extension of the local community. Design and availability have ensured that the kindergarten functions as a popular public urban space, becoming a favorite meeting place in the neighborhood.

The appearance of the house with its emphasized roof volume, broken up into a series of gabled roofs, contributes to an architectural relationship with the farm buildings. The materialization of the house stems from the principle of sustainable wood construction, and 3D-based prefabrication has facilitated the realization of a building with complex geometry and a varied sequence of rooms. The compact form of the ground floor and the split roof, which is connected to the ground floor by a circular connection, form a series of multi-scaled spaces adapted for various activities and games that can take place simultaneously. In this way, the house itself is perceived as a toy, a place that abounds with variable spaces, including hiding places where children can play unnoticed by adults, and places for growing food and caring for animals such as chickens and rabbits.

Figure 8. Concept - Children's recreation of The Real Life

In the case of the Nordtvet Farm Kindergarten, daily activities are delegated to the children themselves, giving them the capacity not only to interpret but also to invent spatial and material qualities and processes that translate their dreams and fantasies, simultaneously making them more real and better. The space that offers hiding places provides real potential where children, through internal motivation and creative engagement, by intertwining bodies, space, and activities, transition into a state of Flow, building an autotelic self. Thus, the kindergarten space becomes a place where children recreate everyday life, offering new patterns of active everyday creation. Recognizing spaces that offer new creative patterns, and production of imagined meanings stimulated by play in a specific location, can be marked as genuine creative architecture.

Figure 9. Creative Architecture-Pleasure in the Integration and Creation

4. DISCUSSION

The discussion of the analysis of various approaches to architecture in kindergartens has explored how creative architecture can stimulate autotelic processes in children, providing them with the opportunity to fully engage in everyday activities.

In Medo Brundo kindergarten, we observed that creativity is encouraged through exposing children to real-life activities, creating a dynamic atmosphere that promotes various forms of play and creative expression. The design of the kindergarten facilitates continuous interaction between children and space, encouraging their ability to create new layers of meaning in the environment.

On the other hand, ATG Kindergarten in Niigata emphasizes the importance of children's participation in real life through the integration of various activities within the architectural space. Through open and accessible spaces, children are encouraged to explore, play, and participate in daily activities, thereby stimulating their creativity and independence.

Nordtvet Farm Kindergarten in Oslo represents an exemplary instance of modern educational philosophy, where the kindergarten environment is embraced as the "third teacher" in children's development. Through seamless integration with the natural surroundings and an emphasis on sustainable practices, the kindergarten transcends its role as merely an educational institution, becoming a hub for community engagement and fostering a profound connection between children and nature. Encouraging outdoor play devoid of adult supervision, the kindergarten nurtures children's independence and creativity, allowing them to immerse themselves in unstructured play that mirrors the rhythms and experiences of everyday life. This emphasis on nature and outdoor play not only promotes physical activity and exploration but also instills in children a deep appreciation for the natural world, enriching their learning experiences and fostering holistic development.

Through these examples, we see how different design approaches can foster creativity and engagement in children's everyday environments. These case studies illustrate the importance of integrating real-life activities, promoting participation, and creating multifunctional spaces that encourage exploration and expression. Through these examples, we observe how various architectural designs embody the capacity for autotelicity, fostering pleasure derived from immersion in everyday activities. This embodiment of autotelic capacity through architectural concepts encapsulates the essence of enjoyment, thereby facilitating optimal engagement and self-expression in children's daily experiences.

5. CONCLUSION

Autotelicity as a capacity of architectural concept represents a complex interplay between autotelicity, architectural design, and the experience of everyday activities. This research delves deeply into the theory of autotelicity, exploring its application in architecture through concepts such as the experience of pleasure through engagement and flow state transition. Special attention is given to the autotelic self of children, their specific mechanism that propels them into a state of flow, and how architectural concepts can stimulate this state of creativity and satisfaction.

Drawing from Csikszentmihalyi's concept of autotelicity, the study illuminates the intrinsic motivation driving individuals to immerse themselves fully in activities, irrespective of external incentives. Since the "autotelic Self" implies the inner harmony of the individual, it is necessary to point out the instability of the concept of autotelicity. As previously noted, the tension is that state of condition for actualization, in this way becomes a field of instability of autotelicity: "Most enjoyable activities are not natural; they demand an effort that initially one is reluctant to make" [2:68]. This intrinsic drive is not only relevant to psychological phenomena but also finds resonance in architectural experiences, where the design of spaces can either hinder or encourage the attainment of a state of flow.

The insights derived from theorethical platform underscore the active role of perception in shaping spatial experiences, emphasizing the symbiotic relationship between observation, imagination, and creativity. This perspective informs architectural practice, prompting designers to consider how users perceive and interact with their surroundings, thereby influencing the potential for creative engagement. The exploration of "intensive properties" and "critical thresholds" within architectural experiences highlights moments of change and discovery that are integral to user engagement [7]. Bernard Tschumi's concept of architecture of pleasure further elucidates how architectural interventions can evoke profound emotional and sensory responses, transcending conventional boundaries to foster meaningful interactions between individuals and their environment [6]. Innovation within architecture necessitates a delicate balance between honoring tradition and challenging conventional norms. By embracing this perpetual quest for novelty, architects can create environments that not only reflect the dynamic interplay between creativity and everyday existence but also inspire users to explore and adapt to their surroundings.

Spaces for children, such as kindergartens, provide fertile ground for exploring the manifestation of creativity within everyday pedagogical practices. Integrating principles that can foster autotelic capacity into the architectural design of these spaces encourages children's engagement and self-expression, creating an environment where creativity and satisfaction spontaneously manifest.

In conclusion, the research of examples such as the Medo Brundo Kindergarten, ATG Kindergarten, and Nordtvet Farm Kindergarten highlights the importance of creative architecture in fostering autotelic processes in children. Through proper space design and integration of real-life activities, architecture can become a catalyst for children's creativity and independence, providing them with the opportunity to explore, learn, and grow in a stimulating environment conducive to autotelic experiences. By creating spaces that inspire intrinsic motivation and engagement, architects play a vital role in nurturing children's innate curiosity and imaginative faculties. The integration of elements that encourage flow state transitions and pleasure through engagement further enhances the potential for children to immerse themselves fully in their activities, leading to more profound experiences of creativity and satisfaction.

The same methodological framework could have been applied to many other cases, highlighting the quality of the methodology rather than its limitation. This underscores the potential for broader applicability and generalizability of the findings beyond the selected case studies. By demonstrating the robustness of the methodology in capturing the complexities of architectural design and its impact on user experiences, this research contributes to advancing the understanding of autotelicity in various educational settings.

Ultimately, this research emphasizes the crucial role of architecture in fostering creativity and enriching everyday experiences for individuals of all ages. By embracing innovative design strategies rooted in principles of autotelicity, architects can create environments that not only serve functional purposes but also inspire and empower users to engage with their surroundings in meaningful ways. Through prioritizing user engagement and considering the intrinsic motivations of individuals, architects contribute to the creation of environments that facilitate personal growth, exploration, and fulfillment. Thus, the fusion of autotelicity and architecture of creativity serves as a cornerstone for the development of spaces that resonate with users on a deep and profound level, enriching their lives and fostering holistic well-being.

Architecture can thus become a realization of the potential of its own change. The acquisition of space through the creativity contained in everyday activities can therefore be observed precisely through the dynamics of its conquest, and not through conquest for something to be finally adopted. Autotelicity is thus the capacity of the architectural concept to encourage participatory processes that manifest the creativity of everyday life and thus create pleasure.

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18

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FROM A TRADITIONAL OFFICE TO HYBRID WORKSPACE AND TELEWORKING: EXPERIENCES PRE-, DURING, AND POST-PANDEMIC PERIOD

Abstract

The paper deals with the analysis of the changes in the working environment, from the traditional offices (conventional workplace), through the hybrid space, up to the virtual environment. The experiences of previous research in different periods, pre-, during, and post-pandemic caused by Covid-19 virus, were used. The focus of the paper are changes in the spatial-functional aspect of work spaces, which arise as a result of the transformation of the of living and working. An overview of reference works that dealt with research in the context of the topic is given.

The aim of the paper is to draw conclusions based on some experiences from different environments about the percentage of acceptance and adaptation to nowadays working environments, supported by information and communication technologies, as well as encouraged by long duration of the global pandemic.

Keywords: hybrid work environment; post-pandemic period; traditional office; teleworking

ОД ТРАДИЦИОНАЛНИХ РАДНИХ ПРОСТОРА ДО ХИБРИДНИХ И РАДА НА ДАЉИНУ: ИСКУСТВА ПРИЈЕ, ТОКОМ И НАКОН-ПАНДЕМИЈСКОГ ПЕРИОДА

Сажетак

Рад се бави анализом промјена радног окружења, од традиционалних канцеларија (конвенционалног радног мјеста), преко хибридног простора, све до виртуелног амбијента. Коришћена су искуства претходних истраживања у различитим периодима, прије, у току и после пандемије узроковане вирусом Covid-19. Фокус рада је на промјенама у просторно-функционалном аспекту радних простора, који настају усљед трансформације у начину живота и рада. Дат је преглед референтних радова који су се бавили истраживањем у контексту теме.

Циљ рада је да се на основу неких искустава из различитих средина донесу закључци о проценту прихватања и прилагођавања на савремене радне амбијенте, подржане информационо-комуникационим технологијама, а подстакнуте додатно дугим периодом трајања глобалне пандемије.

Кључне ријечи: хибридно радно окружење, пост-пандемијски период, традиционалне канцеларије, рад на даљину

1. INTRODUCTION

Initial function of work spaces has changed throughout time, become complex and transformed with regards to the specific requests of business, development and improvident of constructive systems, heating, cooling and ventilation systems, as well as information and communication systems 4.[1]. Industrial revolution radically influenced the change of the traditional office models, while in numerous European countries, there are large administrative buildings which represent the areas for performance of tasks in railway, banking, retail, healthcare, insurance, oil industry and telecommunications 4.[2]. The development of steel constructions and new constructive possibilities has become a milestone in the development of skyscrapers, while the steel construction with huge transparent parts ensured the penetration of great amount of daylight in the internal part of the inner volume, along with minimum need for artificial lighting. This has boosted the possibility of increasing the number of employees in offices, i.e. ensured the possibility to a large number of people to use the same office space.

Particularly important was the release of the space with the appearance of the first system of mechanical cooling in 1900s. The society fully departed from passive models of conditioning of interior spaces for work 4.[2], 4.[3].The concept of an office was particularly developed with the development of information and communication technologies. This developmental way has dramatically influenced the deletion of borders between traditional cell offices, the appearance of landscape and combined manners of work, final shift of work into the homes and hybrid spaces 4.[4], 4.[5]. It is necessary to take a look at the conditions in the light of the pandemic caused by Covid-19 virus, conditions of visual, audio and heat comfort in the office and during the work from home. The research process indicates numerous advantages and short-ages of hybrid models as the result of pandemic conditions of work, and, accordingly, all realistic parameters of its survival in post-Covid era will be problematized and questioned.

The sustainability of work spaces may be achieved by a multiple approach involving the adoption of new models, along with the respect of anticipations and requests of the users of working spaces, which moved in unconventional, hybrid and home spaces during the Covid-19 pandemic. The purpose of the research is also the identification of working conditions in the light of the pandemic caused by Covid-19 virus.

2. GENESIS OF OFFICES (TRADITIONAL VS. OPEN PLAN VS. COMBI VS. TELEWORKING - HOME HYBRID OFFICE)

Decades ago, the office was transformed into a separate entity denoting spatial, physical and constructed environment in which people perform business activities 4.[6]. Nowadays, office is identified with a random unit, workplace, material entity of an employee, whose position and size depend on the position in the building, work organization and hierarchical positioning 4.[7], civil engineering regulations and socio–cultural values of the relations.

It is important to point out that the labour market has not been facing for the first time the challenges such as pandemic. Along with computerization era during 1980s-1990s and the emerge of e-commerce and the e-business in 2000s 4.[8], 4.[9], the employers faced similar problems of market pressure and resistance of workers due to the lack of acceptance of new business processes. Although the challenge was huge at the beginning, new challenges on the labour market actually contributed to continuous improvement of work processes.

Observing the geneses of work spaces from »cellular offices«, grouped around central atrium or corridor 4.[10], via »open plan offices« or »landscape offices« formed as spaces which negate prescribed conditions for lighting, aeration and thermic characteristics of a space, combined systems of cellular and open plan offices, we have come to »collaborative spaces« which may ensure individuals the opportunity to choose not only the place of work and performance of tasks, but also the conditions and direct interior and exterior environment. Each of these systems has its advantages and short-ages that may be stated, ended up to *teleworking* / hybrid home office.

The treatment of conventional (traditional, cell) work and physical spaces has been the subject of numerous researches in design theory and practice. This issue has been additionally actualized due to the overlapping of Covid-19 pandemic and digital society pretentions. There are plenty indirect and direct factors that influence the change of spatial and functional perception of the working environment. For example, market competitiveness in the light of actual pandemic on the global level has radically encouraged employers worldwide to question conventional paradigms of business process management 4.[11]. Besides that, there is an ongoing issue of the development of mechanisms for the alignment of human resources with the organization, strategies and goals of business environment 4.[12]. This issue and other ones are frequently related to the limited scopes of conventional, spatial and functional organizations of the working time and attractiveness for the needs of productive professional environment.

Due to the development of technology and science, business environment has evolved in time from precisely defined architectural design principles for specific business purpose to more emphasized resilience and adaptability of large-scale spaces, encouraged by the modern information times. In addition to this, from the aspect of environmental conditions of working space, there are increasingly defined issues such as the criteria of energy performances of a building, acoustic, light and heat comfort, parameters for the creation of healthy work environment, and the like.

2.1. DYNAMICS OF ACCEPTANCE OF WORK ENVIRONEMENT CHANGING

The research conducted in the United States among more than 1200 permanently employed workers who worked from home during the pandemic has shown that almost half of examinees want to continue to work from home. More than 45% said that their employers actively think about the follow-up or they are open for this strategy. Among the examinees, 40% regularly worked from home at least one day per week before Covid-19 pandemic 4.[13]. Particularly important research was done by Ipsen and others 4.[14] who analyzed data from 29 countries – experience of the employees (H=5748) during early »lockdown« phases, which they grouped into six key factors that represent advantages and disadvantages of the work from home. Identified disadvantages are the following: work uncertainty, inadequate work tools and limitations of a »home office«, while advantages are: good balance between business and private life, greater work control and improvement of work efficiency.

The genesis of working spaces is done from *cellular - traditional* offices type, grouped around a central atrium or corridor 4.[10]. It leads us to *open-plan offices* or *landscape offices*, which are formed as spaces that negate the prescribed conditions for lighting, ventilation and thermal characteristics of the space. *The combined system* of cells and open-plan offices led us to *collaborative spaces*, that gives the opportunity to choose not only the working place i.e. performance of work, as well as the conditions of the internal and external environment.

2.2. TRADITIONAL, "PRIVATE", "CELLS" OFFICES

Traditional office was a standard way of work organization in companies for long. Closed work stations, »private« offices, »cells«, arranged alongside façade wall, internally connected by longitudinal corridors, in one-fold, two-fold and multi-fold tracts (Figure 1). The lack of operational flexibility in an organization and impossibility for more people to stay in smaller work »cells« and, simultaneously, impossibility of teamwork existence and monotony in the perception of a work place were the main shortages of this type of work organization. The size of a work station necessary for one person in a defined working environment is called spatial density. Spatial density defines the scope of closed work space of a beneficiary and the distance from other beneficiaries 4.[15]. This unit which defined a 1.5m distance was changed during the pandemic to 2.0m distance between two beneficiaries. The shortages of traditional offices are the following: huge part of the space was dedicated to communications and was inefficiently used, more construction material is spent for their creation, more cabling is needed, as well as the need for equipment per offices, difficulties in spontaneous and unplanned communications on joint activities and others 4.[16]. Traditional manner of organizing works spaces followed the era of increased control of work of the workers, and thus the era of more transparent manner of work was accompanied by the development of offices so as to achieve support more innovative and fluid manner of work, connection, interaction and cooperation 4.[17]. Technological progress was accompanied by the arrangement of architecture and interior. Conversely, during the pandemic, traditional offices have proved to be the most secure from the aspect of social distancing of the population, zoning and arrangement of work positions 4.[18].

The traditional office was the primary type of work organization for a long time. Closed work units, "private" offices - "cells" are distributed along the envelope of the building, connected along longitudinal corridors, in single, double and multiple tracts (Figure 1). Such offices are characterized by inflexibility in the organization. Also, it is not possible to increase the number of employees or make a different functional organization inside single "cells".

The position of the body during work, dimensions of the furniture and equipment are defined by the size of the workplace and the required area for performing work tasks. The size of the workplace needed for one person in a defined work environment is called spatial density. *Spatial density* defines the range of the user's closed workspace and the distance from other users 4.[15]. If we consider that the design module defined for the business facilities is M 7.5, we can anticipate the necessary office area for one, two and more workplaces, as it is done in Figure 2. As the spatial density changes with the pandemic emergence prescribed distance between employees is more than 2 meters. It means that office reorganization in terms of the new disposition of furniture and equipment is almost impossible. The introduction of screens and shift work, with much better control of the microclimatic characteristics of individual cells, with less circulation of the number of employees, are optimal solutions for pandemic working conditions.

Figure 1. Functional tract of traditional "cell" office system: a) single tract b) double tracts c) multiple / three tracts d) multiple tracts

The building envelope is the primary element for achieving lighting (visual) and thermal comfort. It is part of the building front, that is located between two constructive elements - column or wall and two slabs. The construction with columns fully enables the release of the building envelope as an independent element of the construction / assembly, with the implication of ecological, sustainable and bioclimatic parameters. The depth of the room (tract) influence intensity of daylight per room depth. If the space is designed with the constant ceiling height (height from floor to ceiling), as well as the position and surface area of the window, the change in the depth of the room will also lead to the change in the intensity of the daylight by the depth of the office.

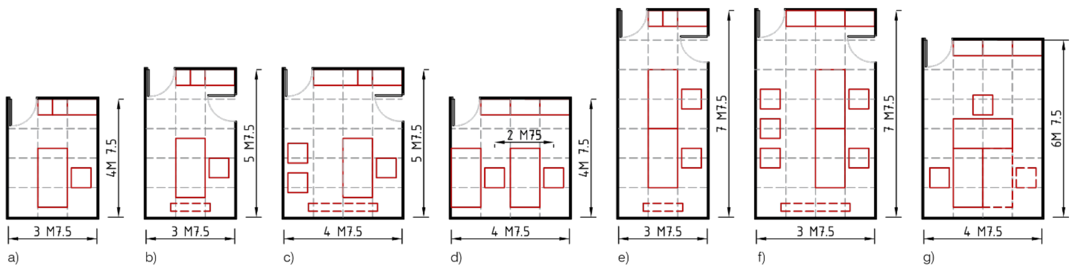


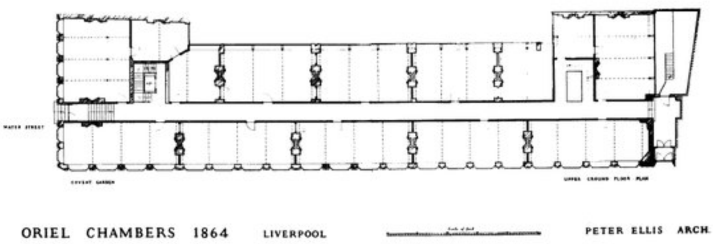
Figure 2. Dimensioning and organization of "cell" offices in relation to the number of workplaces: a) office with one workplace b) office with one workplace and internal communications c) office with one workplace, internal communications and and space for clients d) office with two workplaces e) office with two workplaces f) office with two workplaces, internal communications and space for clients g) office with three workplaces etc..

The traditional work units are unchanging and monotonous. It is not possible to organize team activities, spontaneous and unplanned communications at joint activities, etc. Gou 4.[16] states that the disadvantages of traditional offices is inefficient use of communication space, which takes a large part of the office area. As a result, the quantity of built-in construction material is greater, as well as for equipment needed per offices.

The »I« space in the office, dedicated to individual work, has been gradually re-placed by the »WE«, so its ratio of 70-80% was reduced to 20-30% 4.[19]. Office design was supposed to be adjusted to new requirements of the beneficiaries and space transformations, so the traditional »cellular« manner of work was very soon substituted by collaborative and open one, with the excuse that the work is done more efficiently if the space is more transparent. New manner of organization of a workplace encourages interaction and socialization instead of unplanned encounters. The position of work stations alongside the office and the use of the full space of the office is the concept that has initiated the development of an open plan city 4.[1]. Overemphasized concept of the open plan offices, with the tendency to ensure as many work stations as possible within the assigned spatial frameworks, with fully transparent facades of strict rectangular forms, was particularly developed after the Second World War 4.[20]. Despite being flexible in organization, work spaces have become noisy anonymous rooms, overwhelmed with the clamour of the employees and the noise produced by the work equipment 4.[21].

2.3. FROM OPEN TO COMBINATED AND COLLABORATIVE OFFICES

Driven by innovation and efficiency, the office represented a measure of class affiliation, position in the company, and relationships with other employees on similar or the same work assignments. Social interaction was prohibited and employees were kept in separate rooms. In traditional organizing of work spaces, the control of workers was increased. New more transparent way of working was followed by the development of offices, supported by more innovative working solutions, connection, interaction and cooperation 4.[17]. The new office design encourages interaction and socialization, unplanned meetings and encounters. The Oriel Chambers (Liverpool) can be considered as a milestone in development of skyscrapers and a more transparent way of work organization (Figure 3.a.). The steel construction, curtain wall and large spans allowed the unhindered penetration of natural light with minimal need for artificial lighting (Figure 3.b.).

a) 

b) 

Figure 3. a) Floorplan of Oriel Chambers, Peter Ellis (1805-1884) 4.[22]b) The first curtain wall on Oriel Chambers in Liverpool, Peter Ellis (1805-1884) 4.[23]

The positioning of workplaces according to the depth of the office and the use of its full area initiated *open plan* buildings development 4.[1]. Technological progress was accompanied by improvements as well in interior design. A step further was architect Frank Lloyd Wright's Larkin Building (Figure 4.a.). Employees were placed in the atrium of a six-story building, facing the same direction, in a dark space with artificial lighting (Figure 4.b.), machine conditioned with recycled air 4.[24].

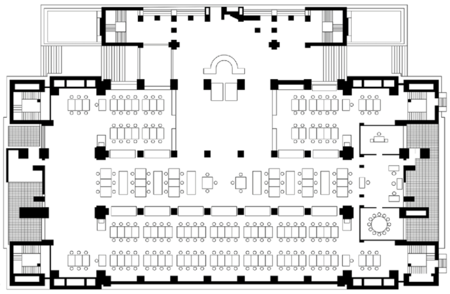
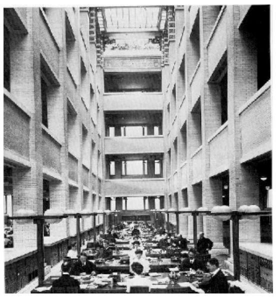
a) 
b) 

Figure 4. a) 1st floor layout for Larkin Building (1904-1945), Frank Lloyd Wright 4.[16] b) Open plan offices in the atrium of Larkin Building (1904-1945), Frank Lloyd Wright 4.[20]

Open plan office (Figure 5.b) is a large office surface without partition walls. The space is equally available for all beneficiaries, while the zoning is achieved by covers, cupboards, tables, constructive elements and decorative interior elements. Dimensions and openness of the work space are defined by the ratio of the total surface of available space against the total length of its internal walls, including the covers and transparent barriers 4.[25]. By the use of cooling chambers in 1930s and fluorescent lighting in 1940s, the depth of the office tract was not anymore conditioned by daylight and natural ventilation 4.[26]. Exoskeleton and buildings with lateral communication nucleus have ensured fully flexible interior spaces on the floors, without respecting the need for day-lighting, humans as the benchmark, creation of small communities in which the beneficiaries feel comfortable, consideration of environment, aeration and the like. The challenges of additional cooling and ventilation of the space, as well as the placement of cables, emerged with the networking, so this type of offices had to find new architectural, more expensive and less flexible solutions.

Bernstein and Waber 4.[27] in their article »Truth about open plan offices« analysed facial expressions of the employees and their interaction by the use of sensors for monitoring eyesight. They discovered that the interactions of people »face to face« decreased for 70% when companies shifted from traditional to open plan offices, in favour of electronic interaction via computers. Virtual space has replaced physical one, while the reduced privacy lowers interaction of the employees and proxemics. It was in 1990s when the standards for architectural design of business buildings emerged, when the grounds with limited tract depths were designed, with prescribed amounts of daylight and possibility of observing environment from the work station 4.[28], which makes the employees less frustrated, more patient and productive and in better health conditions 4.[29]. This puts aside the design of façade shell as the element of control of a heat and visual comfort and its significance in early phases of architectural design, emphasizing HVAC systems that will »replace« these shortages 4.[30]. Still rigid and orthogonal arrangement of workplaces did not allow individuals to have a personal impact and to adjust the work station to a specific beneficiary. Calisi and Stout 4.[29] state that noise is the greatest problem of the open plan offices, accompanied by visual openness/the lack of privacy, temperature and air quality. They came up with the conclusion that the employees lose even 86 minutes on a daily basis being obstructed in work by the noise made by voices, equipment, HVAC system, mobile phones, etc. which obstructs analytical thinking or creativity 4.[31]. Diskette Behavioural Research 4.[32] conducted research with 2660 examinees, related to their current and wanted working environment in order to identify a work position in future. The greatest number of the examinees (35.5%) favoured traditional closed offices compared to the open plan offices (23%) and the offices with one work station (18.1%). The number of those who opt homes as the working environment should not be neglected (17.4%), as well as those who would choose unconventional spaces such as cafés (6%), which indicates that the work is increasingly perceived as a flexible category in terms of the location. Studies have shown that the productivity of employees decreased for 14% by movement from cellular to open plan offices, initiated by high level of noise. The movement of the employees from the open plan into cellular offices resulted in the increased productivity for 16.9%, while the shift to individual work spaces resulted in the increased productivity for 21.9% 4.[33]. Drawing attention of an employee from the assignment which requires concentration at work is closely related to the level of noise in the working space.

At the end of 1950, landscape office system became developed. Seemingly chaotic configuration of desks and space for the employees was designed on the basis of work formats, ergonomics of employees and the work done 4.[34]. Fully airconditioned internal space was developed in 1970s into the system of office cabins accompanied by cubic forms of modular furniture system 4.[17]. Such space is characterized by nonhierarchic exchange of information and knowledge, better contact of the employees, changeable and adaptable functional organization and furniture. These typologies change the way of thinking, the employees do not have their own territory and thus they do not have responsibility, all problems of open plan offices become vivid, with particular emphasis on ignoring psychological aspects of the employees 4.[35]. This manner is very similar to today’s co-working spaces. The space is fully mechanically air-conditioned, while in the 1970s it developed into a system of office cubicles, as well as the cubic forms of the modular furniture system 4.[17]. In this manner employees have their own personal / private space, with more adaptable functional organization. A step further is the organization of the furniture and equipment necessary for joint work placed in the central part of each floor 4.[28].

»Democratization« of work spaces was done only in 1980s and 1900s, when cellular type of workplace organization became transparent and further organized alongside façade shell, but also grouped around the central zone which contains furniture and equipment necessary for joint work 4.[28]. In this way, the surplus of equipment is excluded from the space of permanent stay of the employees, became centralized, which facilitated air-conditioning of the space, reduced costs and required infrastructure.

Combi office (Figure 5.c.) is a solution which combines all advantages of cellular and open plan offices, balancing appropriately the ratio between joint spaces and spaces for individual work. A step further was also made in the control of the lighting. The control of lighting is frequently done on the level of a work unit, from the desk, which resulted also in energy saving 4.[36]. Localized controls of lighting and air-conditioning are positioned on the desks of the employees and, thus, they do not need to leave the work station. Localization of the control excludes the use of sensors and negatively influences uniformity of the background and image in the whole space 4.[37].

Figure 5. The genesis of workspaces a) traditional system in three tracts b) open plan office / open system c) flexible - combined system

With the advent of portable devices and computers, the office becomes virtual, changeable, and the employee is freed from time and place. Smart use of information technology resulted in a series of alternative solutions that ranged from telecottages to working in alternative places, such as coffee bars 4.[28]. The theory also developed is: » Your Office Is Where You Are« 4.[24]. Work is based on activities and changes at an accelerated pace, and no one has a fixed job position, which supports the vision of a polycentric city. Professional and freelancers of similar interests began to join together around the same space, sharing costs and giving each other professional support. That's how *collaborative work spaces* were created.

Collaborative work spaces are created by six factors, such as: transport, size of a city, sustainability, technology, demography and cultural and sociological characteristics 4.[17] »The third place« 4.[38] might be found on several locations, it is closer to the place of residence and is not a formal office. More agile corporate mechanism opts for »outsourcing«, much more taking into account security and health of the employees due to everyday commuting 4.[39]. Corporate hierarchy hardly exists, but in collaborative spaces everyone has their own desk, with the focus on the work they perform. These spaces have actually been made as the link between conventional and unconventional work spaces, so we have all become freelancers due to Covid-19 pandemic. Landscape and collaborative spaces have been replaced by isolated private cabins 4.[40], covers, which simulate transparent walls of independent work units.

Collaborative work spaces are based on 4 sustainability perspectives such as: new work (flexible access to the space and resource sharing), incubator (togetherness), social responsibility towards resources (sustainable and effective energy consumption) and environmental responsibility (focus on environment factors) 4.[41]. As opposed to home conditions, collaborative spaces positively influence social interaction, exchange of knowledge and individual creativity of associates 4.[39], supported by actions that contribute to the sense of community, support, encounters and engagement. This model has fully denied the concept of cellular offices, building a community for uncertain future. Under pandemic circumstances, their functional organization would have to be examined, as well as the possibility of aeration, the possibility of daylighting and the environment would have to be considered, as the redefining of management aspects in order to actively use mediation mechanisms via digital interaction 4.[42].

Remote work has been accompanying the development of digital technologies for ages, which has largely contributed to the changes in work organization 4.[43], both on local and international level, satellite offices or work from home due to the impossibility to come to work 4.[44]. Remote work is closely related to the knowledge of technology, and, before pandemic, it was strictly related to high-tech companies 4.[14]. Since the outbreak of Covid-19 virus, remote work was accompanied by accelerated technological education of the employees which depended on the motivation and predispositions of individuals, as well as the ownership of one's own computer for performing the work from home. In addition to this, the creation of virtual office space tests new relations such as: organization culture, communication and cooperation 4.[45]. Compared to the virtual work, office work increases the control of work and reduces potential risks of work activities 4.[46], and thus the responsibility of the employees. The employees have better support in work when in office, they are not isolated and they have better access to information 4.[47], while the virtualization of the workplace should be retained as the support to the employees. New generations of »digital aboriginals« have been increasingly directed towards the use of technology and this additionally prevents their social integration beyond Internet 4.[48]. Shrivastava and Singh 4.[49] emphasize the consequences of working virtual space, both in behaviour and in the organization itself, since the employees lose critical talent, intellectual and physical property, they stay in non-simulative working environment, they are under stress and they don't balance work and life obligations properly.

2.4. SUSTAINABILITY OF TELEWORKING

The number of people who worked from home increased radically during the pandemic 4.[14]. Teleworking was mostly implemented during the lockdown period, and the practice continued even after restrictions were lifted, albeit on a smaller scale. Remote work has been accompanying the development of digital technologies for ages, which has largely contributed to the changes in work organization 4.[43], both on local and international level, satellite offices or work from home due to the impossibility to come to work 4.[44].

The Covid -9 pandemic was accompanied by accelerated technological education of employees, and new relationships such as organizational culture, communication and cooperation. Employees are without colleague's support, access to information is poor, and they rely on their own computers and equipment, and an individual sense of responsibility. Working from home becomes unstimulating, critical talent is lost, and balancing proper work and life obligations is not possible 4.[49].

In May 2020, we conducted a survey with 34 combined questions. An anonymous questionnaire was conducted online on 202 respondents, mostly employed in the administrative sector (banks, ministries, schools), in the territory of Podgorica, the capital of Montenegro. The survey also contained a question that referred to highlighting the desired way of working after the pandemic. In less than a year since the start of the pandemic, the percentage of employees who want to return and do their work exclusively in offices has increased by 54%. The rest are willing to continue working in a combination, in the office and from home, while no one expressed a desire to work exclusively from home. The reasons for returning to the office are different and range from: noise levels in the home due to the overlap of family and work environments, blurring of boundaries between business and private obligations, functionally unsuitable work spaces, bad psychological impact due to additional stress due to sharing the work space with family members, quality of work performed, productivity, impossibility of consultation with colleagues, poor IT training, tension and the like.

These results are not in favor of the teleworking model of work in the post-pandemic period, which can be of key importance for directing the optimal working conditions after the pandemic, not only in the territory of Podgorica, but also more widely.

3. HYBRID WORKSPACES ENVIRONMENT: ARGUMENTS FOR ADAPTING ORGANIZATIONAL STRUCTURE

The working surfaces, as well as the number of employees at one working space had a great influence on the dynamics of business operations during Covid-19 pandemic, and they are one of the key parameters of this research. Taking into account the basic that anyone who had contact with infected persons must be in isolation, it can be concluded that although smaller spaces in which it was impossible to achieve physical distance prescribed by the measures, potentially were more favourable for the transmission of the disease, huge working spaces with larger number of employees had greater negative consequences, due to more frequent and forced isolation of the whole team, and therefore the work moved from the office space into the private one – work from home.

Todays' work is not necessarily bound to physically completed work space. Digitalization era encourages the idea that a workplace may become any space within which we deal with working assignments. Freedom and flexibility in the perception of the work space do not adhere to architectural principles and practices, since the beneficiaries frequently go into extremes, and thus almost each environment and each time have become adequate for work 4.[50]. In favor of this statement is the fact that in 2014, the Bureau of Labor Statistics recorded 14.4 million self-employed 4.[51]. Thus, in America, the number of self-employed increased for 80% in less than 10 years 4.[50]. Although this manner of work contributes to greater flexibility in the organization of a working time, greater autonomy and the sense of freedom, there is no doubt that this manner of work fosters the sense of isolation 4.[52] due to limited social engagements.

Employees are not willing to continue working only from home. Employers are challenged to bring employees back to the office, by resorting to new organizational schemes, in a more productive and stimulating work environment. In their book »Design for Sustainability« 4.[53] sustainability is an approach to architectural design, which offers a wide range of new design inputs, such as: environmental efficiency, responsible, holistic, contextual, restorative, visionary and synergy design, along with solving the problems such as comfort, aesthetics and costs. New standard in the design of offices is increasingly closer to the cellular type, since again the accent is put on »I« space against the »WE« space 4.[19], so the combination of these two principles may be regarded as optimal in pandemic conditions.

A common sense should be the guide for the return to the post Covid-19 office, and design should that premises. Some of the inputs should be:

- Lebowitz 4.[54] gave 10 usual ways big office could change in a post-covid world, such as: mudroom, baristas and community kitchen, collaborative corridors as dynamic and programmed spaces together with open collaboration spaces and virtual collab spaces (with a green virtual wall). Special focus is on the treatment of workstations that are more as elbow room and intimate scale. while the office becomes officle – not quite and cubicle as an cell office, but with the possibility to stop by and say hello, as well as the spaces with neighbourhood configuration (Figure 6);

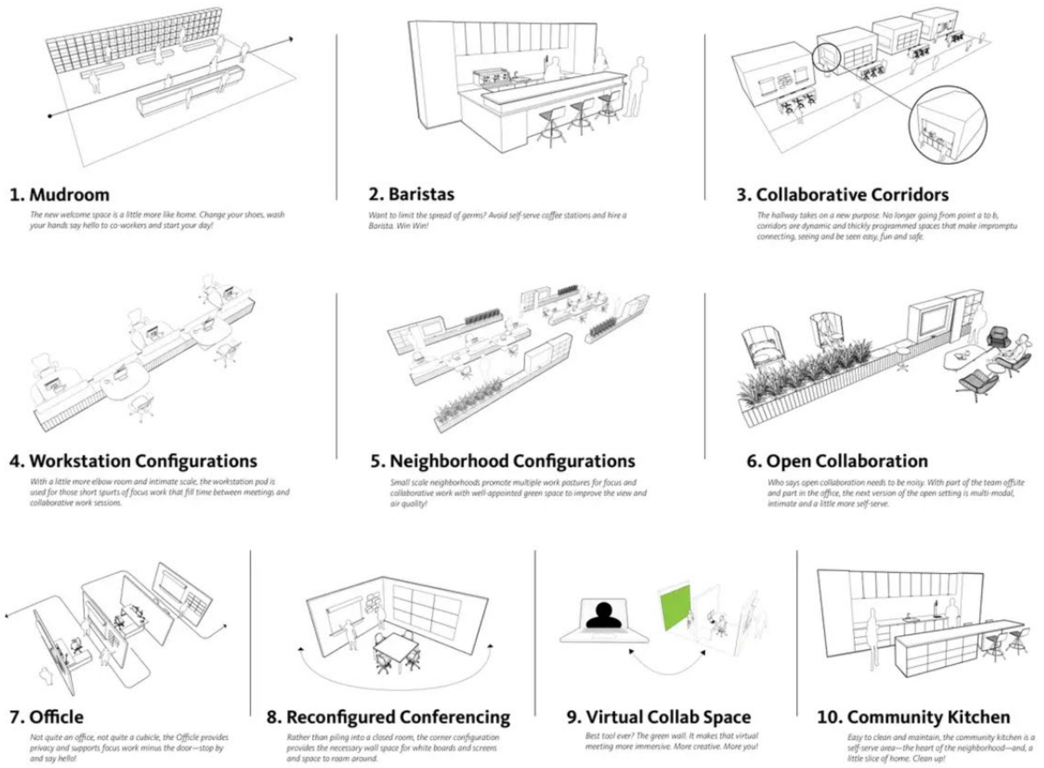


Figure 6. 10 usual ways big office could change by Lebowitz 4.[54]

- office should be done by the new layouts, that pay in attention safety, cognitive, emotional and physical aspects;
- Fixed vs. Fluid - open collaboration space. As social gardens the office should be a meeting space, but not too open. Work in office gives and opportunities for collaboration with colleagues. Open space encourages the feeling of belonging and connection with the collective, but it should also be more space for continued social distancing when needed 4.[55];
- biophilic design elements means it should bring in natural elements in the office (Figure 7). Offices go literally green. The assumptions are that employees after months of closure want an open space, so the presence of plants would increase lighting, a more pleasant atmosphere, the presence of natural colors and materials 4.[56]. It should enable connection with nature, setting up micro green micro points or open spaces with facilities for employees to stay;

Figure 7. Examples of hybrid nowadays offices 4.[57]

- Me vs. We- placement of "I", as well as “WE” space, where staff could be alone or relax, or organize meetings. The space should be acoustic, private, comfortable, built with every feature needed for successful video conferencing 4.[56]. It should also be: safe in materials (anti-virus solution), flexible (easy to install and lightweight), acoustic protected, ergonomic and functional adapted to different needs for work or rest. Office would be designed as a balance physical and virtual work. They include the Pop-Up Meeting space with small rooms and demountable walls 4.[58];

- miss office noise the acoustic design approach in the post pandemic scenario;
- offices should be flexible for different uses;
- Open vs. Enclosed - designing neighborhoods at work (Figure 8, Figure 9). New office should be easily changeable and have macro "locations", that makes indispensable for the employee with a home office etc. 4.[58] The work reality will change old patterns and behaviors, as well as people want their workplace to be more humanized which means the office needs to adapted to a new set of needs 4.[59]. Office should be "our neighborhoods where we live, learn and grow", that is also diverse, inclusive and resilient.

Figure 8. HushHybrid office call for one person and An office meeting pod seating 4 4.[58]

- it should also have "parks, plazas and cafes" 4.[59]. Office should not be assigned the same type of space, can be shared, multi-modal spaces, easy to switch from individual focus work to collaboration and socialization;
- Braiding Digital vs. Physical Experiences - is based on that are highly flexible and support a variety of types of work within one setting. It should be able for future changes. Technology and space should be in line and holistic.
- hybrid work should strive for engagement and ease 4.[59];
- assigned homes - welcoming section and office first impression (Figure 9). It gives home belonging feeling; you can change your clothes or shoes and be introduced to the upcoming obligations;
- office should be adaptive even in the scale of office furniture. It should be multifunctional, movable in order to increased collaboration between workgroups and designed for multi-generational.
- office should be smart in sense of technology. Hands-free technology reduces the spread of virus due touchless technology. Technological advances should keep pace with the development of offices and the demands of employees. Hybrid office design one step ahead technology progress and trends in companies that continuously evolves. It should follow ever-changing consumer expectations.

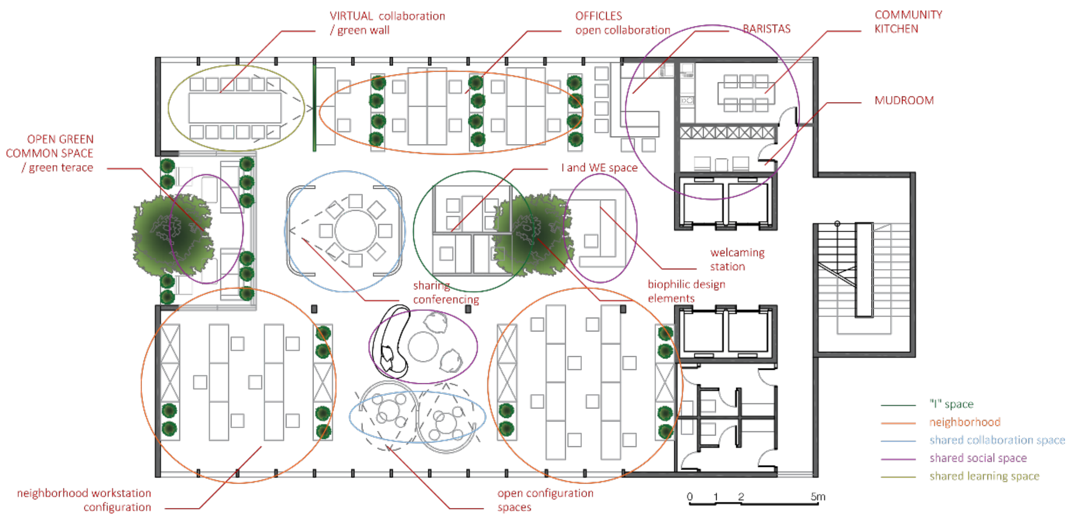


Figure 9. Hybrid workplaces - an example of the office transformation from 2.3.Figure 5. with macro "locations" with various contents needed during work and rest at work

4. DISCUSSION AND CONCLUSION

Covid-19 pandemic has had impacts on all segments of life, in which individuals were forced to change their regular way of living and work, due to the basic prevention measures based on physical distance. This has been predominantly reflected in the work space, which entails contacts with other people, and which has led to the change of traditional office models or in open systems – collective office. Under Covid-19 pandemic conditions, the work is not primarily related to physical and office framework anymore, but to the spaces that we regard as comfortable, functional working environment, authentic and specific for each individual. In this way, working space loses the limits of classical work space, and it has to be the space for rest, the space for creative activity, not rarely recreation and amusement, fully reorganized in a more radical and hindering sense [2].

Recently established co-working was created as the "third location" [51], which offers to the employees of related spheres of interest the opportunity to be nearby their residential spaces, but in an alternative environment which has better working attributes such as internet connection, technical support, information system security, assistance from other beneficiaries and socialization [3], [4]. This has also influenced partial modification of life spaces, while the beneficiaries were forced to partially adapt their life spaces to the working ones. It is exactly this type of departure from traditional cell offices, which consequently causes the transformation of life spaces, which is at the same time the focus of the research. The research is based exclusively on the adoption of attitudes and conclusions on office models during Covid-19 pandemic. The goal of the research is determination for optimum model of productive work space in post-pandemic period. It should be hybrid office type that respect safety, cognitive, emotional and physical aspects of users. It is also flexible in the term of space and furniture, with biophilic design elements. New office should be welcoming, designing in the manner of neighborhoods at work, assigned homes. It should be assigned as city with multi-modal spaces such as parks, plazas and cafes, that follows technology progress. It should respect "I" needs, as well as "WE" requirements.

This model has fully denied the concept of cellular offices, building a community for uncertain future. Under pandemic circumstances, their functional organization would have to be examined, as well as the possibility of aeration, the possibility of daylighting and the environment would have to be considered, as the redefining of management aspects in order to actively use mediation mechanisms via digital interaction [59].

On the basis of numerous collections and systematization of literature, this paper provides an overview of reference research in the context of the topic, which may be of importance for further research.

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19

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FROM CHAPEL TO CONVENT: UNVEILING TOLISA'S FRANCISCAN ARCHITECTURAL HERITAGE

Abstract

This article examines the establishment and architectural evolution of the Convent and Parish Church of the Assumption of Mary in Tolisa, Bosnia and Herzegovina, from its medieval origins to its status as a National Monument and important convent in Bosna Argentina. Along with the development process from the first chapel that led to the full-size convent, it traces its history through the Hungarian, Ottoman, and Austro-Hungarian periods, highlighting the pivotal role of Josip Vancaš in the church renovation, blending historicism with contemporary trends. The ensemble, emblematic of Franciscan legacy and cultural significance, attests to the endurance of faith amidst historical flux. This study offers insights into Tolisa's broader cultural milieu and architectural heritage through meticulous analysis of architectural elements and historical narratives.

Keywords: Tolisa, Franciscan architecture, church, convent, Josip Vancaš

ОД КАПЕЛЕ ДО САМОСТАНА: ФРАЊЕВАЧКО АРХИТЕКТОНСКО НАСЉЕЂЕ ТОЛИСЕ

Сажетак

Рад се бави истраживањем о успостави и архитектонском развоју самостана и жупе Узнесења Блажене Дјеве Марије у Толиси, Босна и Херцеговина, од њених средњовијековних почетака до њеног статуса као Националног споменика и значајног самостана у Босни Сребреној. Уз развојни процес од прве капеле која се развила до самостана у пуној размјери, рад прати историју кроз мађарски, османски и аустроугарски период. Посебно се истиче одлучујућа улогу Јосипа Вансаша у реконструкцији цркве, спајајући историцизам са савременим тековинама. Ансамбл објеката у Толиси је симбол фрањевачког насљеђа и културног значаја, те свједочи о издржљивости вјере усред историјских промјена. Кроз темељну анализу архитектонских елемената и историјских наратива, овај рад пружа увиде у шире културно окружење и архитектонско насљеђе Толисе.

Кључне ријечи: Толиса, фрањевачка архитектура, црква, самостан, Јосип Вацнаш

1. INTRODUCTION

Tolisa is situated in Posavina on the right bank of the Sava River, near Orašje in Bosnia and Herzegovina. It is connected by road to other surrounding places, including Brčko, Šamac, and Županja [1].

Tolisa was first mentioned in the Medieval era, during the time of Béla IV, King of Hungary, Croatia, and Duke of Styria, on July 20, 1244. In one of his Charters, he affirmed to the Bosnian Diocese, besides others, land Tolisa - *terra Tolycha* lat., received as a present from Matej Ninoslav, the Bosnian Ban at the time. During the time of Stephen II, Ban of Bosnia, this part of Posavina entered the Bosnian territory, where it remained until the XV century when it was returned to Hungary. After the Battle of Mohács in 1526, Posavina, like all other Hungarian territories, entered the Ottoman Empire.

Posavina existed formally as an Austrian territory briefly between the Treaty of Passarowitz in 1718 and the Treaty of Belgrade in 1739. Later, after 1878 and the Austro-Hungarian occupation, Posavina entered the territory of Bosnia and Herzegovina, where it has remained until today [2].

Tolisa is the seat of the Convent of the Assumption of Mary, which is part of the Bosna Argentina Franciscan province, the oldest province in the region. By the late 13th century, Bosnian Franciscans had acquired full clerical power among Roman Catholics in the area, leading to the establishment of the Bosnian Vicarate in 1340. In 1349, the Vicariate comprised two custodies, and over the next 40 years, it expanded to include seven custodies in 35 convents that covered Slavonia, Serbia, Croatia, Dalmatia, southern Hungary and Wallachia. In 1514, the Vicariate was split into *Bosna Argentina,* lat. (Bosna Srebrena) and *Bosna Croatia*, lat. (Bosna Hrvatska), which later became provinces in the Franciscan order – OFM, *Ordo fratrum minorum,* lat. Following the Ottoman conquests, many of the Bosnian Franciscan sites were destroyed and desecrated. Reconstruction and re-establishment of these sites only began during the Tanzimat era (1839-1876) and were completed with the arrival of the Austro-Hungarian authorities in 1878.

Located on the far northern border of the Bosnian province and the Bosnian territory under Ottoman rule, Tolisa played a crucial role in Christianization, education, and gathering of Roman Catholics, primarily Croats. This research paper examines the historical background and environment in which the Convent was established and developed up until the present day. The paper focuses on the architectural evaluation of the convent buildings and the church, the biggest Roman Catholic church in Bosnia and Herzegovina. The primary research sources used in this study are original projects found in the Convent's archive, a few published scientific studies, and thorough on-site field research. This research includes a critical evaluation, historical architectural analysis, narrative, and accompanying rich graphics.

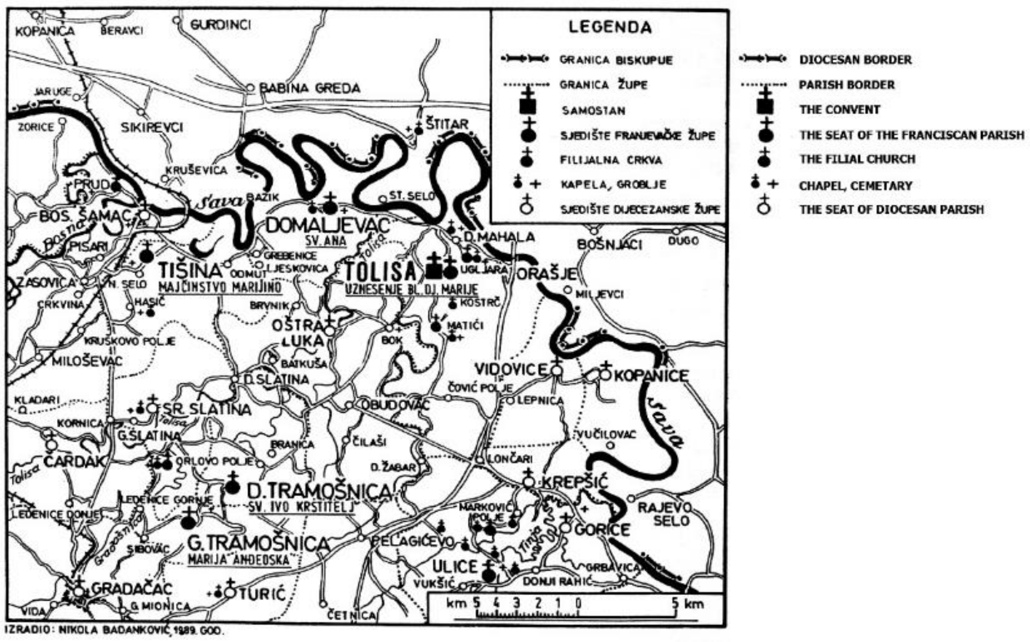

Figure 1. Convent area Tolisa with belonging parishes. Adapted map done by Nikola Badanković 1989 [1]

2. PARISH HOUSE, FIRST CHAPELS, AND THE CONVENT

The history of Christianity in Posavina is a topic that still needs to be fully understood. It is linked to the time when Posavina was part of the Roman province of Pannonia in the early centuries after Christ. During the 7th and 8th centuries, the Avars and Slavs who settled there were Christianized.

The Franciscans were present in Posavina earlier in history, with convents in Modriča, Skakava, Polje, and others. However, all of these were torn down in the 15th century during the Ottoman conquests. Afterwards, the region of Posavina was under continuous pressure, with many convents being demolished and many Catholics migrating to Slavonia, an area north of the Sava River.

In the 18th century, Tolisa was part of the Ravne parish, later becoming an independent chaplaincy in 1784. The first parish house in Tolisa was mentioned in Bishop Marijan Bogdanović's (1720-1772) chrism shortly after 1768 and served as a chapel. However, it was destroyed during the migrations of 1788-1792. The new parish house, where Friar Ilija Starčević (1794-1845), the famous founder of the first public elementary school in Bosnia and Herzegovina [3], lived, was constructed in 1792 by Friar Ambroža Vučković. The chapel was built in the same house and served its initial function until 1820.

Tolisa finally got the status of a parish in 1802, according to the decision of the Sacred Congregation and its confirmation by the Provincial Definitorium [4]. In 1819, Friar Ilija Starčević built the second parish house. In 1820, Friar Blaž Pejić built a separate chapel, which was later moved to Raščica, where it still stands today.

In Raščica, a new third parish house was built according to plans by Georg Einchorn from Osijek. Construction began in 1855 and was completed on July 18, 1856. Since it is not preserved, the analysis is founded on a few remaining paintings and descriptive archival records. The third parish house. Its main façade remained displaced for around 9 meters in front of the newly built church at the time. It was a modest mansion with ten living rooms, a big dining room, and auxiliary facilities, without any particular architectural values, given the historical and social context - as seen in Figure 8.

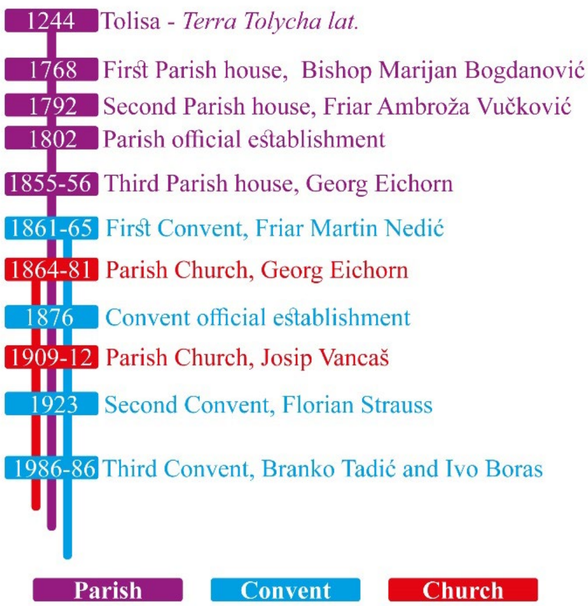

Figure 2. The historical timeline of Tolisa development, from the first mentioning to the construction of the third Convent building

3. THE CONVENT OF THE ASSUMPTION OF MARY

In 1861, Friar Martin Nedić (1810-1895) arrived in Tolisa and started the construction of a convent. However, there were some initial problems with the church's erection. The foundations of the first convent building were laid down in 1862 beside the parish house. Construction was completed in 1865, and in 1866, it was granted the status of a Franciscan residence. This status was later confirmed on March 3 1869, by the General Definitorium. In the meantime, Friar Martin Nedić sent an appeal to the Apostolic Vicar, Friar Paškal Vujičić (1826-1888), on August 23 1873, requesting the declaration of the residence in Tolisa as an official Convent. On September 24 1874, Provincial Superior Friar Mato Čondrić sent an official request for the same purpose, which was later accepted, even though earlier requests were made, such as the one dated March 3 1874. Finally, on January 12 1876, Tolisa was canonically established as a convent belonging to the hierarchy of OFM Bosna Argentina.

Figure 3. The Church and the Second Convent of the Assumption of Mary: view from the west; photograph taken in 1930 [5]

Over 60 years later, Dr Julijan Jelenić (1877-1931) proposed constructing a second convent building during the Convent Chapter.

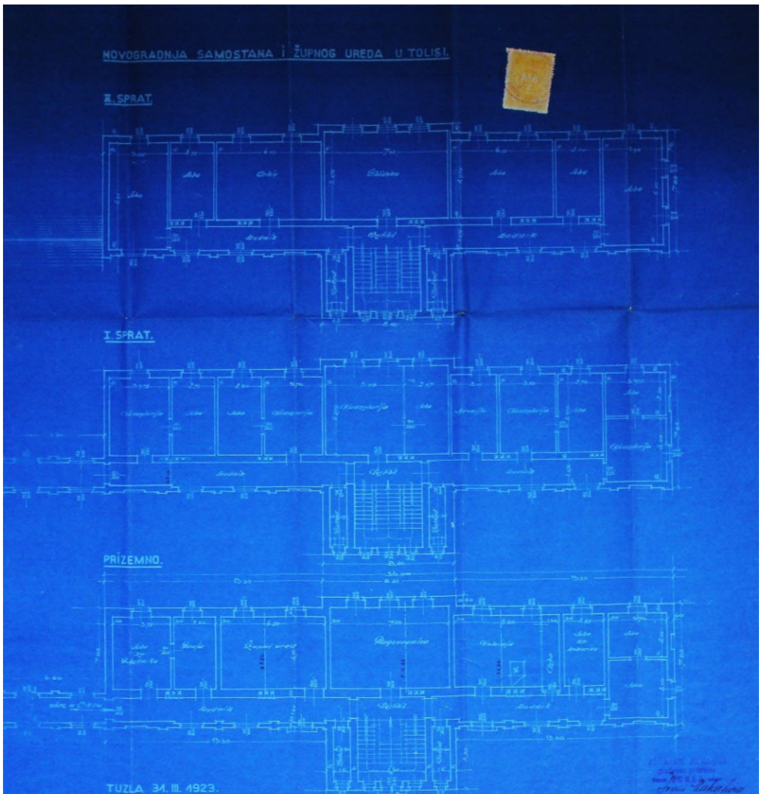

Figure 4. The Convent of the Assumption of Mary: floor plans of the ground floor and 1st and 2nd story, a segment of the project „New construction of the convent and parish office in Tolisa" done by architect Florian Strauss, dated 31st March 1923 [7]

The new building, which was slightly detached and aligned to the *Westwerk ger.*, was designed similarly to the first building. The project was created by Florian Strauss from Tuzla in March 1923, and construction works were carried out by Johan Bernhardt from Novi Sad, concluding on November 15, 1923 [6]. A small building housed the old electrical power plant between the church hall and the new convent building. This structure was later destroyed during one of the reconstructions, and the convent was extended in its place while maintaining the symmetrical design.

The convent was designed in the late Renaissance Revival style without undersized decorative elements. The main façade is symmetrical, with a large Avant corps emphasising the entrance. The pilasters are displaced along the façade, and the Avant Corps completes the design of a complex hipped roof covered with traditional clay tiles. Floor plans are structured according to typical designs, with a vertical communication core in the aforementioned Avant Corps linked to a long hallway. The hallway leads to rooms oriented towards the south-eastern garden. This same situation is found in all three above-ground storeys, while the cellar is located only in the central part of the building, within the width of the Avant-corps. Symmetrical design is also found on the garden façade, oriented towards the southeast, with the difference being that the Avant-corps is relatively shallow.

Considering the vast wooden resources nearby, the building's structural properties are outdated but understandable. All walls are made of traditional bricks, and all floors and roofs are made of massive wood.

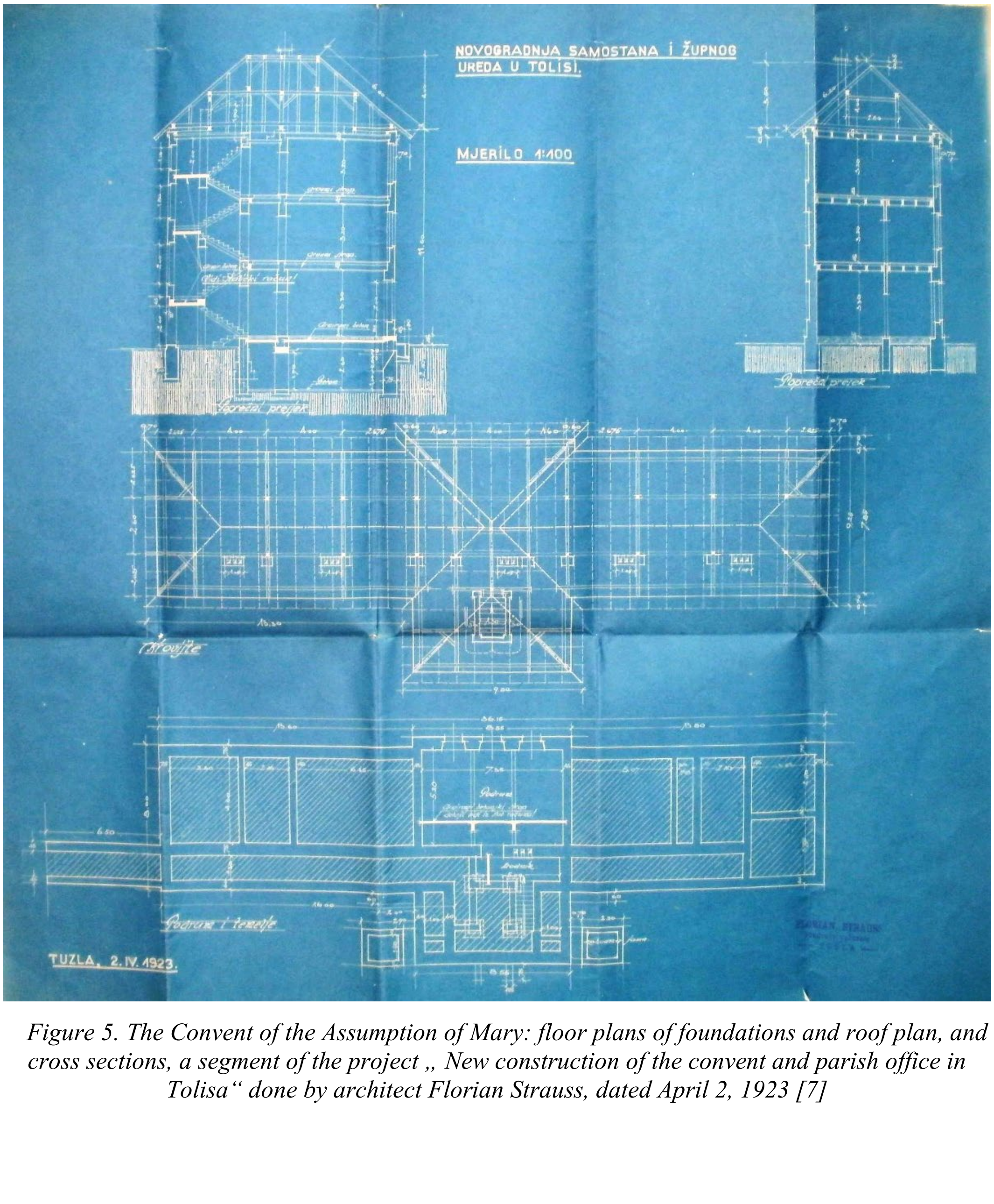

Figure 5. The Convent of the Assumption of Mary: floor plans of foundations and roof plan, and cross sections, a segment of the project „ New construction of the convent and parish office in Tolisa“ done by architect Florian Strauss, dated April 2, 1923 [7]

Figure 6. The Convent of the Assumption of Mary: elevation views from south-east and north-west: garden and entrance façade, a segment of the project „New construction of the convent and parish office in Tolisa" done by architect Florian Strauss, dated March 31, 1923 [7]

During the last reconstruction, the façade colours and elements in the foreground and background harmonised with the church's design, making them appear cohesive. Additionally, with the construction of the third convent, this old convent was repurposed, with the ground floor serving as a parish house and the first and second floors becoming home to the "Vrata Bosne - Door to Bosnia" museum, archive, and library. The primary project was conducted by architect Nada Džankić and civil engineer Željko Curić, following the previously accepted design.

As the convent expanded over time, the need for more space grew. The parish house was required because the convent was also the parish seat. The library's catalogue was enriched, as was the museum and archive. Therefore, in 1986, the construction of a new third convent began to provide a decent home for its initial function: friars' housing. Among several proposed projects, the work was assigned to architect Branko Tadić, with interior design done by architect Ivo Boras.

Unfortunately, moving to new facilities was prolonged until after the war due to war-caused circumstances [1] [6] [8].

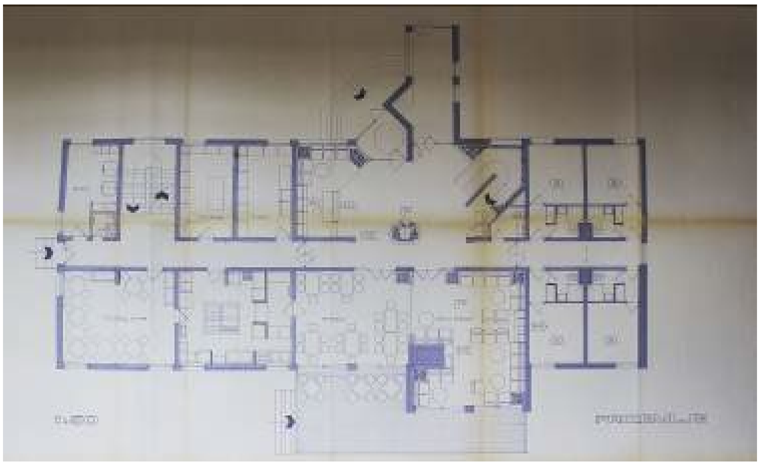

Figure 7. The Convent of the Assumption of Mary: ground floor plan of the third convent; a segment of the project „Residential building in Tolisa, a project of interior design" done by architect Ivo Boras, dated in August 1987 [9]

The main building volume is rectangular and is perpendicular to the old convent building on its south-western façade. The building comprises apartment rooms for friars, auxiliary service areas, as well as other rooms needed for regular life in a convent: chapel, speaking room, living room, dining room, etc. [10]
The building has a typical massive structural system with a cellar, ground floor, and two storeys. The façade is made of yellow bricks, while the roof is a traditional gable with wooden construction covered with clay tiles. Similar designs can be found in other Bosnian Franciscan Brestovsko, Visoko, and Rama facilities. The rectangular shape of the building is covered with a gabled roof, which extends with one of the ridges to the roof of a second convent. The architect tried to emphasise both horizontal and vertical outlines of the design. Horizontal stripes of façade bricks are underlined with dark brown lines at the level of floor construction, while vertical stripes of windows are an adjustment to the old building. The building is not a very expressive piece of architecture, especially when compared to the second convent and the church.

Figure 8. The Convent of the Assumption of Mary, Tolisa: second and third convent, view from the north; photograph taken in 2013

Some exciting projects have been done but have not been implemented in Tolisa. The inner courtyard does not exist in physical borders. Still, foundations and ground concrete outline are visible on the far southern side of what is supposed to be a cloister connected to the apse. After the initial extension project was done in the 1970s, another project proposal for a multi-purpose hall with sacred, cultural, social, and other activities of the parish members was made in 2001 by architect Ivan Štraus. However, the latter was not undertaken.

4. PARISH CHURCH OF THE ASSUMPTION OF MARY

The history of the parish church in Tolisa, which is the largest church in Bosnia [5] [11], dates back to the Provincial Chapter in 1855 held in Kraljeva Sutjeska, where it was decided to start the construction of a parish church in Tolisa. Despite the efforts of Bishop Marijan Šunjić (1798-1860), the Ottoman authorities did not allow the construction. Fortunately, after the arrival of Friar Martin Nedić in 1861, new attempts to build the church were recorded [6]. New obstacles followed but with the great help of Austro-Hungarian consul in Bosnia, Baron Stjepan Jovanović (1828-1885), a permit - firman, Ferman tur. - was finally signed in Istanbul in December 1863. Friar Martin received it on February 24 1864.
The construction works started on the feast day of the Assumption of Mary, July 11 1864. The foundation stone was set on July 17 1864, and Georg Eichorn, the author of the project for the parish house, led the construction [13]. However, it is less known that the actual model for this church was an old Jesuit church of Saint Michael in Osijek, Croatia, built between 1725 and 1766 [12] [14]. From that perspective, it is essential to emphasise that the similarity is linked to the approach to the *Westwerk*: the entrance façade oriented towards the northwest with characteristic bell towers, and not to the internal structural and architectural disposition. Moreover, the bell tower projects were done by two other architects: Dausch did the northern and Pietro Rimaldi did the southern tower, and they are unique in the whole Province [1] [2] [13].

Figure 9. The Parish Church and the first Convent of the Assumption of Mary, Tolisa, painting; view from the north [15]

Eichorn pioneered the project for the traditional basilica, with arches and oval vaults. This project gave an outline for the present church that emerged after the reconstruction. Although masses were held from December 5, 1873, construction works were only completed in August 1881 [13]. The church was constructed using simple clay bricks that were later plastered. A wooden structure covered with clay tiles was used for roofing. Only the bell towers were covered with sheets of metal tin.

Inside, the church has a simple, straightforward, linear communication between the congregation and the presbytery in the southeast apse. Five side altars or chapels are located in the side aisles, separated from the central nave with two rows of five solid square columns. The columns were connected with side walls belonging to the aisle with corresponding arches and pilasters. In addition, arches spanning over the central nave connected the columns, creating five arches that created four oval vaults. The apse and the entrance zone below the choir had flat ceilings.

Ivan Tordinac, an artist from Đakovo, Croatia, was responsible for designing furnishings and liturgical equipment at the Đakovo Cathedral of Saint Peter and Paul. He was also engaged in the design of equipment in Tolisa, where he created the main altar and one side altar, windows, confessionals, altar screen, and the choir. Ivan Rendić (1849-1932) made significant furnishings, including two side altars and *The Crucifixion*, which Bishop Josip Juraj Strossmayer gifted from Đakovo. These items were originally part of the old Cathedral in Đakovo. [8]

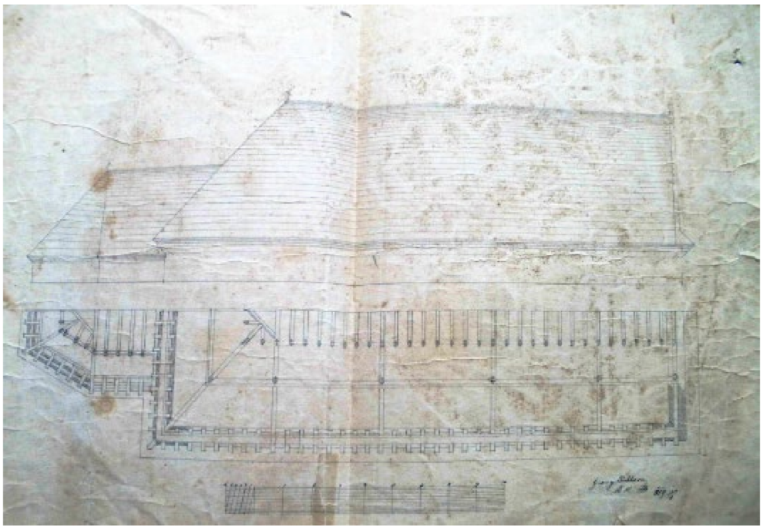

Figure 10. The Parish Church of the Assumption of Mary, Tolisa: Segment of the roof plan and elevation view from the north-east, part of the project done by Georg Eichorn [16]

Several parish priests and guardians were interchanged during the construction of a building. Friar Martin Nedić was initially in charge in 1873, but Friar Bono Nedić (1841-1903) later replaced him. From 1879 onwards, the first Guardian, Friar Mato Oršolić, was engaged in the construction works. [6]

The façades of the building were utterly devoid of decorations, similar to the current situation. Many defects, some of which were present since the initial construction and some of which occurred during regular use, were removed during a major reconstruction project. The decision to undertake this project was made in the spring of 1909 by the Guardian, Friar Grgo Došen. The responsibility of overseeing the project was assigned to architect Josip pl. Vancaš (1859-1932), at the time already established architect in Bosnia and Herzegovina with numerous engagements for Bosna Argentina. Vancaš visited Tolisa for the first time in July 1909 and completed the project in the spring of 1910, with some later alterations as defined in the first [17] [18] and second project for reconstruction.

Vancaš presented a radical proposal for the renovation of the interior of the convent and parish church in Tolisa. This proposal involved demolishing everything except the exterior walls. The columns with a vast square section of 190/190 cm were replaced with slim columns with a square section of 120/120 cm. The entire structure was covered with reinforced concrete arches and barrel vaults. This proposal was considered extreme, with a less radical renovation being made earlier. Construction works were entrusted to Johann Pimperl from Zavidovići, Bosnia, which began on February 21, 1911. After the reconstruction, the church was consecrated on the Feast of the Assumption in 1912, having been only blessed. [2] The costs of the construction were estimated to 119.000 Austrian krone.

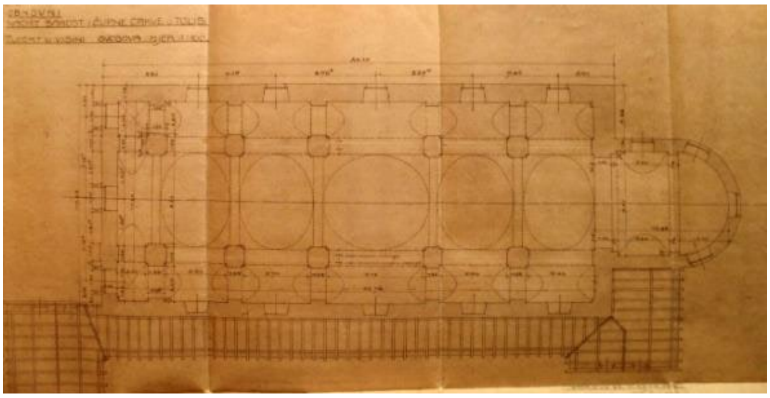

Figure 11. The Parish Church of the Assumption of Mary, Tolisa: floor plan in the vaults' height; a segment of the 1st project for reconstruction of the convent and parish church in Tolisa done by architect Josip pl. Vacaš, dated March 23, 1910 [18]

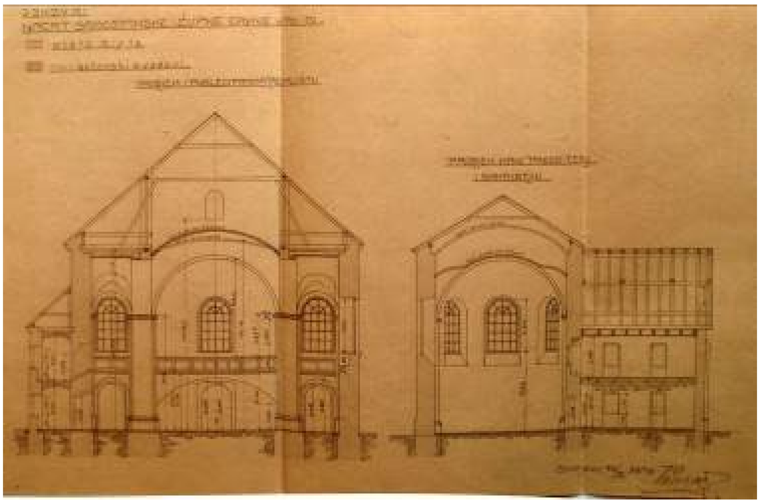

Figure 12. The Parish Church of the Assumption of Mary, Tolisa: section views through central nave viewing the choir, presbytery and sacristy viewing the apse; a segment of the project 1st project for reconstruction of the convent and parish church in Tolisa) done by architect Josip pl. Vacaš dated July 23, 1910 [18]

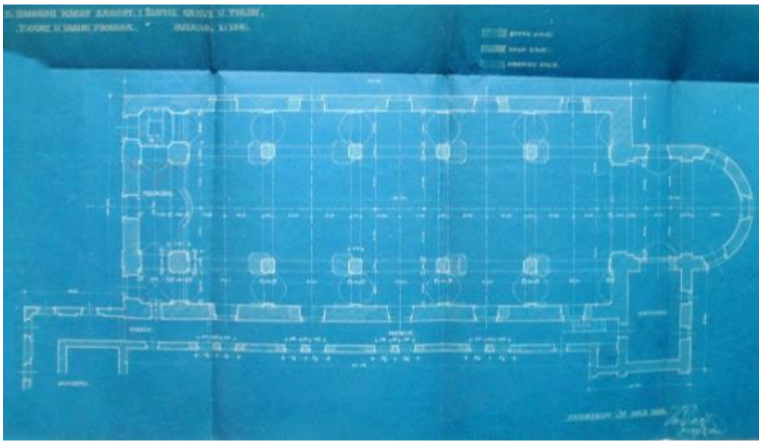

Figure 13. The Parish Church of the Assumption of Mary, Tolisa: floor plan in the window height; a segment of the 2nd project for convent and parish church reconstruction in Tolisa done by architect Josip pl. Vacaš dated July 21,1910 [19]

Figure 14. The Parish Church of the Assumption of Mary, Tolisa: section view through central nave viewing the north-eastern aisle and section views through central nave viewing the choir, presbytery and sacristy viewing the apse, and central nave viewing the apse; a segment of the project „II obnovni nacrt samostanske i župne crkve u Tolisi“ (2nd project for reconstruction of the convent and parish church in Tolisa) done by architect Josip pl. Vacaš dated July 21, 1910 [19]

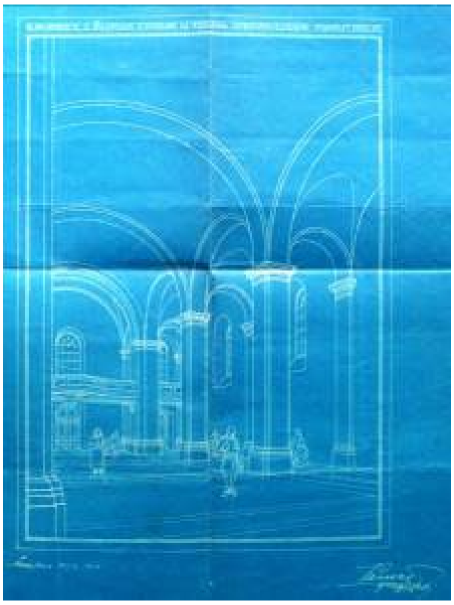

Figure 15. The Parish Church of the Assumption of Mary, Tolisa: interior view of the central nave, side aisle and chorus; a segment of the 2nd project for reconstruction of the convent and parish church in Tolisa done by architect Josip pl. Vacaš dated July 21, 1910 [19]

The church floor plan retained columns that hold the choir platform below the bell towers. The inner division between the central nave and side aisles is created by two rows of four columns and one additional column below the choir platform. There are five smaller groin vaults in the side aisles and five extensive groin vaults in the central nave; the roof structural system is above. The disposition of the altar and the choir is the same as in the first church, with the addition of the barrel vaults above each. Unique to Vancaš's projects, the floor is covered with small-format ceramic tiles imported from Hungary. Anton Huber painted the newly formed vaults and ceilings from Bruneck, Tirol. [6]

Figure 16. The Parish Church of the Assumption of Mary, Tolisa: interior view from chorus towards the main altar

From the outside, the *Westwerk* has two bell towers corresponding to the width of the side aisles and the outline of the central nave. There is very little decoration, with only impoverished stucco on the bell towers and around the windows. Blind horizontal cornices are on the levels corresponding to the choir, wall peaks, bell tower and façade joints. Hidden pilasters were used to create vertical divisions. The façades are coloured in a dual combination, with elements in the foreground in white and plains and the background in bright beige.

Figure 17. The Parish Church of the Assumption of Mary, Tolisa: interior view towards the choir

On the ground floor, three entrance doors are symmetrically displaced and aligned with windows on the choir platform. They are all completed with a simple arch. There is only one more window at the very top of the central corpus. The bell towers, with onion-shaped domes, are the only elements containing valuable decorations, retaining the original pre-reconstruction aesthetics. They are symmetrically designed with blind windows on all four sides, profiled corner pilasters, and crowning tympanums. Other exterior walls are also attractive. The sidewalls of the aisles are not symmetrical but structurally the same. Each is opened with five arched windows, analogous to inner vaults. However, on the façade, only the northeastern wall is visible, while the opposite is concealed with the small hallway leading to the sacristy, attached to the southern wall of the apse. The apse also holds similar windows; four of them are visible, and the fifth is a portal to the sacristy. The mentioned hallway has a direct entrance from the main façade. At the same time, the corresponding window is the point where total symmetry is lost and interrupted between the church and the convent building. Above it, on the first floor, there is another hallway linking the convent with the oratory, above the sacristy, and the choir platform above the entrance.

Figure 18. The Parish Church of the Assumption of Mary, Tolisa: view of the north-western entrance façade

Josip Vancaš considered this project as one of the most prominent sacred designs in Bosnia and Herzegovina. [21] The sacred architecture of Bosnia during the Austro-Hungarian rule (1878-1918) represented a complex blend of influences from various fields of art and contemporary trends. This was characteristic not only of Vancaš's production in occupied Bosnia but also of the work of other architects who aimed to combine revival historicism with the current trends in the late Ottoman period in Bosnia. The influence of late-Baroque decorated onion domes, typical of churches belonging to all confessions in the broader area of the Danube Basin under Austro-Hungarian rule, is undeniable. The church was severely damaged in a fire in 1917, particularly the furnishings of altars, windows, and wall paintings. The church underwent reconstruction between 1930 and 1935, and Josip Pellarini restored the paintings from Vinkovci, Croatia [6] [8].

Figure 19. The Convent and The Parish Church of the Assumption of Mary, Tolisa: view of the backyard from the south

Starting with the Guardian, Friar Pero Martinović, various reconstruction and maintenance works were carried out on the church. These included structural repairs, removal of wall moisture, reconstruction of the roof, installation of a new copper cover, and restoration of wall paintings. Friar Blaž Marković is credited with the stained glass decoration done by Vlatko Blažanović. Friar Marijan Živković thoroughly reconstructed the façades of the second convent and the church and landscape decoration around the complex. During the reconstruction period between 1981 and 1985, stone panels were mounted on the walls and columns inside, faking a plinth wall and representing a simple transition from impoverished façades to the surroundings. It is essential to mention the work of painters from Zagreb, Zlatko Modrić and Dubravko Gluhinić, who reconstructed Huber's wall paintings in 2005 and restored their initial designs, partly covered during the 1930-1935 reconstruction. [6]

Figure 20. The Parish Church of the Assumption of Mary, Tolisa: close-up view of the main altar done by Ivan Tordinac, reconstructed by Electo Maruzzi

The church holds many items with great artistic value, including statues and altars. One of the most notable pieces is the altar, created initially by Ivan Tordinac and later reconstructed by Friar Elekto Maruzzi from Zagreb. Another remarkable piece is *The Crucifixion*, created by Ivan Rendić. Tordinac also made a side altar, choir, all doors and windows, the altar fence and the confessionals. The church's organ is the oldest in Bosnia and Herzegovina. It was constructed by Caspar Fischer from Apatin, Serbia, in 1800 for the Saint Peter and Paul church in Osijek. When the church in Osijek was set for demolition, Tolisa's guardian, Friar Filip Oršolić, bought the organ for the church in Tolisa in 1890 [20]. Later on, two side altars were acquired as well. In 1896, the organ was reassembled by Ferdinand Heferer from Zagreb, Croatia. The *Via Crucis* stations, created by an unknown author, were installed in 1822. The bells date back to 1923 and 1927 [1] [6] [8].

Figure 21. The Convent and The Parish Church of the Assumption of Mary, Tolisa: complex, view from the north

5. CONCLUSION

The architectural ensemble comprising the Convent and the Parish Church of the Assumption of Mary in Tolisa encapsulates a rich tapestry of historical, religious, and artistic significance within the Posavina region. Across centuries marked by geopolitical upheaval and cultural evolution, this edifice has stood as a steadfast testament to the enduring presence of Franciscan stewardship and communal devotion.

Even though the oldest parts of the complex are not preserved anymore, three existing segments, each from three different eras and with a different story, are strong enough to narrate one exciting chronicle. Central to the narrative of this architectural history is the transformative vision of Josip Vancaš, whose innovative renovation proposals reshaped the church's interior design while respecting its intrinsic historical character. His fusion of revival historicism with contemporary architectural trends not only addressed the practical needs of the parish but also elevated the space into a beacon of artistic expression and spiritual contemplation.

Today, designated as the National Monument of Bosnia and Herzegovina [22], the Convent and the Parish Church of the Assumption of Mary, along with its movable heritage: paintings, archaeological artefacts, numismatic collection, collection of textile items, library, the firman for the church construction, and the organ, stand as custodians of tangible and intangible heritage, ensuring their preservation for posterity. As they continue to serve as focal points of worship and cultural exchange in Posavina, their architectural splendour and enduring significance underscore the timeless resonance of human ingenuity and communal endeavour in shaping the built environment.

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20

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QUANTITATIVE AND QUALITATIVE ANALYSIS OF URBAN GREEN AREAS USING NON-PARAMETRIC TESTS

Abstract

This paper analyzes the presence and quality of urban green areas in two local communities in the City of Banja Luka, namely: Lazarevo 1 and Lazarevo 2. The aim is to examine which categories and types of green areas are most represented in the study area and what is the quality of existing tree-lines. Two research questions were asked: whether all species are equally presented in the study area and whether the linden species present in this area get sick more often than other species. Part of the results was presented using descriptive statistics (frequency) methods, and to the other part non-parametric tests were applied, Pearson's χ^2-test using two basic forms: distribution shape test and χ^2 test of independence.

Keywords: urban green areas, non-parametric tests, Pearson's χ^2 test

КВАНТИТАТИВНЕ И КВАЛИТАТИВНЕ АНАЛИЗЕ УРБАНИХ ЗЕЛЕНИХ ПОВРШИНА ПРИМЈЕНОМ НЕПАРАМЕТАРСКИХ ТЕСТОВА

Сажетак

У овом раду анализирани су заступљеност и квалитет урбаних зелених површина у двије мјесне заједнице у Бањој Луци: Лазарево 1 и Лазарево 2. Циљ је да се испита које су категорије зелених површина најзаступљеније на овом подручју и какав је квалитет постојећих дрвореда. Постављена су два истраживачка питања: да ли су све врсте подједнако заступљене на подручју истраживања и да ли присутне врсте липе подлијежу болестима чешће од осталих врста. Дио резултата добијен је примјеном метода дескриптивне статистике (учесталости), а други дио добијен је примјеном непараметарских тестова, Пирсонов χ^2 тест и његова два основна облика: тест облика дистрибуције и χ^2 тест независности.

Кључне ријечи: урбане зелене површине, непараметарски тестови, Пирсонов χ^2 тест

1. INTRODUCTION

Over the past decades, rapid urbanization with consequent loss and degradation of green spaces has caused various environmental problems such as habitat fragmentation, biodiversity loss, air pollution, heat islands and heat waves, as well as negative impacts on human health and quality of urban life. In order to respond to this challenge and achieve urban sustainability, the concept of green infrastructure (GI) has been introduced. Sustainability and resilience of urban areas are closely linked to green spaces in urban areas [1]. Currently, landscapes are associated with several major challenges. Among them are dominant: climate change, high species extinction, ecosystem degradation, and the abolition of ecosystem services. There is a great deal of scientific research on the impact of human activities on these phenomena. In particular, land use can change not only the composition of landscapes and habitats, but also the function of ecosystems and their ecological potential, as well as the availability of natural resources [2]. Sustainable land use is key to protecting, recovering, and improving natural resources. Also, urban and landscape design can have a big impact on climate change. As a special element of urban and landscape design, urban open public spaces play an important role in reducing high temperatures, but also in overcoming the impact of climate change [3].

Cities around the world increasingly see urban greening (the use of urban green spaces) as an effective measure to mitigate the harmful effects of the effects of urban heat islands. Many studies have been done on this topic. In general, it is accepted that a larger amount of urban green areas gives a greater cooling effect. However, Masoudi and YokTan argue that this knowledge is inadequate to fully optimize the value of urban green spaces to mitigate the effects of urban heat islands, as the size, shape, and distribution of urban green spaces should also affect their ability to cool neighboring areas [4]. In other words, in addition to the amount of urban green space, their spatial pattern of location (neighborhood, settlement, city, region, etc.) is also important. The spatial pattern of urban green spaces refers to their spatial distribution and characteristics, and is generally described as having two independent components: configuration and composition. The configuration describes the spatial character and layout of urban green areas (for example, shape complexity, connectivity, and fragmentation), while the composition refers to measures of spatial characteristics that are not related to the layout of urban green areas (for example, diversity and abundance of different types). Different aspects of spatial composition and configuration can be quantified using mathematical constructions called landscape metrics. Landscape metrics are widely used in studies describing landscape patterns and their relationship to land use (cover changes), biodiversity distribution, ecological processes, and ecosystem functions [5].

Considering the quality and accessibility of urban green spaces has proven to be more important than considering only the amount of green space. Both planners and scientists have recognized that involving citizens through public participation and understanding their perceptions and preferences is an essential component of designing and managing inclusive and functional green spaces [6]. Here lies an important challenge: quality is subjective and can vary between different user groups [7]. Namely, green areas also provide social benefits, which are essential for the health and well-being of urban residents [8, 9]. Humans are social beings who need accessible green spaces where they can gather, socialize, walk, and relax. They will spend time in public space if they feel nice, comfortable and safe, and thus will provide mental restoration [10]. The quality characteristics of green areas are difficult to measure objectively [11]. There is a gap in knowledge about how to measure the quality of green spaces and whether they meet the needs of urban residents [12]. What constitutes good quality green space is usually unclear in planning processes. Planners have been criticized for relying on outdated, inconsistent, and low green space standards [13]. Various parametric methods, such as logistic regression, can be used to analyze data in studies about quality of life in urban areas. However, these methods have specific assumptions and predefined functions for describing the relationships between variables. Non-parametric models are used in the study of the quality of life of urban residents, in order to select the main variables that affect the quality of life, among the large amount of data collected [14].

Understanding how people perceive and appreciate different landscapes is essential for informing about landscape policies that reflect societal needs [15]. The importance of assessing the contribution of nature and the landscape to people's quality of life is increasingly recognized through frameworks such as ecosystem services and nature's contributions to people. The concept of ecosystem services (ES) is often used in the literature to represent the functions of green infrastructure. In this field, the multifunctionality of the ecosystem stands out, i.e., the capacity of green infrastructure to provide multiple ecosystem services [16].

Cities are major contributors to climate change, but at the same time, urban areas are also among the most vulnerable in the world. Many studies have been done that deal with the impact of urban public spaces on climate change. Thus, for example, authors in paper [17] analyze the potential for improving the comfort of open public spaces by introducing new elements of green infrastructure in order to meet the challenges of climate change. Special attention is paid to the analysis of the continuity of the green infrastructure network, analyzing the comfort of public space using clustered indicators that include greenery, urban equipment, water characteristics and urban morphology, and simulating microclimatic characteristics of the actual and proposed state of a particular public space (lower Dorćol in Belgrade), with the aim of presenting new elements of the process of designing open public space, which was developed at the Faculty of Forestry, University of Belgrade. They could be characterized as appropriate design tools, which will be used in response to challenges such as increased heat wave intensities, temperature thresholds, and the effects of urban heat islands. Urban greenery contributes to the urban environment as an individual element in a small space, but also at the city level as an element of the green infrastructure network. It offers a simple and precise design of the thermal comfort of an open public space. The simulation of climatic conditions on the segment of Jevrejska Street in Belgrade showed that by simply introducing tree lines and natural paving materials, adequate thermal settings for staying outdoors can be achieved. Research in the field of horticulture design and engineering, which will focus on issues of species selection and their characteristics and behavior in extreme weather conditions, has been recognized as important in the further process of this research [17].

Statistical methods, together with GIS and remote sensing data, can be used as an efficient and cost-effective option for analyzing urban growth and urban sprawl. The use of conventional methods of urban analysis is really difficult, time consuming, and expensive. Thus, for example, Al-Sharif et al. chose Tripoli, the capital of Libya, for their study. This study used Pearson's Chi-Square statistics and urban expansion intensity index (UEII) statistical models for quantitative analysis of urban sprawl in Tripoli [18].

The Chi-square statistic is a non-parametric (non-distributive) tool designed to analyze group differences when a dependent variable is measured at the nominal level. Like all non-parametric statistical methods, Chi-square is robust in terms of data distribution. In particular, it does not require equality of variables among research groups or homoscedasticity in the data. It enables the evaluation of both dichotomous independent variables and multiple group studies. Unlike many other non-parametric and some parametric statistics, the calculations required to calculate the Chi-square provide significant information about how each of the groups behaved in the study. This wealth of detail allows the researcher to understand the results and thus extract more detailed information from these statistics than from many others [19].

A similar methodology was used to research informal green spaces in a post-industrial city in Poland, Łódź [20]. Data were collected using orthophotos and a land use database. Then, interviews were conducted with local residents about their perception of undeveloped green areas, which are present in the immediate vicinity. The Chi-Square test was also used to analyze the relationship between the identified environmental services and the variables that characterize green areas. The results are presented using diagrams, after a tabular overview of all collected data.

Environmental heterogeneity affects biodiversity patterns such as species richness and community composition. Through the gradient of environmental heterogeneity, generated by different management treatments, Dornelas et al. (2009) analyzed weed communities in the United States. They used the statistical Pearson's Chi-Square test on the collected data. Their study showed that the distribution of the number of species is an informative indicator of environmental heterogeneity in modified landscapes. She suggests that creating heterogeneity of the environment, through different management treatments, throughout the landscape can be an effective way to promote biodiversity and reduce problematic species [21].

In the context of all the above in the experimental research, on the example of green areas in the urban area of the City of Banja Luka, the initial research questions will be examined using Pearson's Chi-Square test.

2. MATERIALS AND METHODS

The methodology of the research includes research through two phases: theoretical and experimental part. The first part of the paper (Introduction) presents the literature on the use of statistical methods in research on the quality of urban life, with special emphasis on the presence and quality of green spaces in cities and their impact on reducing the negative consequences of intensive urbanization, such as thermal islands. The method of content analysis was used. The literature review covers the time frame from 2005 to 2021 and includes publications, studies, books, scientific and research papers focusing on topics such as: green areas, urban environment and quality of life in it, statistical methods for large quantity analysis data and modern software technologies used in spatial data research, such as geographic information systems (GIS). The first part of the paper provides an overview of the literature and research on similar topics, explains how a large amount of data can be analyzed and how to find the relationship between variables. This section describes the field of research, the methodology used, and an overview of previous research.

The second part of the paper includes experimental research on the example of public green areas on the territory of two local communities, Lazarevo 1 and Lazarevo 2, in the wider urban area of the City of Banja Luka. The basic data classes that were analyzed can be divided into two groups, namely urban green areas and tree-lined trees. The first question that will be examined using the shape distribution test is: Are all types of green areas equally represented in the study area. The second question refers to the health condition of the trees and reads: Is small-leaved linden much more susceptible to diseases than European plane tree in the researched area? This question will also be examined using Pearson's χ^2-test, using contingency tables.

2.1. STUDY AREA

Banja Luka is known as a city of greenery - there are 22,000 trees planted in alleys, parks and settlements, which are obliged to maintain the City Administration. The city has 150 hectares of lawns, 40 kilometers of green fences, 31,000 pieces of ornamental shrubs and 5,000 pieces of roses, and a large number of seasonal flowers. The total area of landscaped park areas in the City of Banja Luka is 78,233 m^2 [22]. A complete exact analysis of the state of vegetation in Banja Luka has not been done, but there are several partial studies on the arrangement of certain urban areas and the protection of park-forests. A new approach to the analysis and observation of data related to urban greenery is given as a basis for future research in this field. Each category of greenery, according to its specifics, is maintained in different ways and by different methods. That is why the green areas of the city are systematized and classified by categories: parks and other smaller areas in the center; lanes along roads, greenery in settlements; tree lines and trees in block greenery; the greenery of the Kastel fortress; greenery memorials; Banj Brdo and picnic areas Trešnjik and Šibovi; weeds; flower beds; rose gardens; ornamental shrubs; hedges; surfaces that are cut in order to control ragweed according to the categorization defined in [23].

The pilot area investigated in this paper belongs to the urban part of the City of Banja Luka in two local communities: Lazarevo 1 and Lazarevo 2, and covers a total area of 11.25 km^2 [24]. The study area is shown in Figure 1.

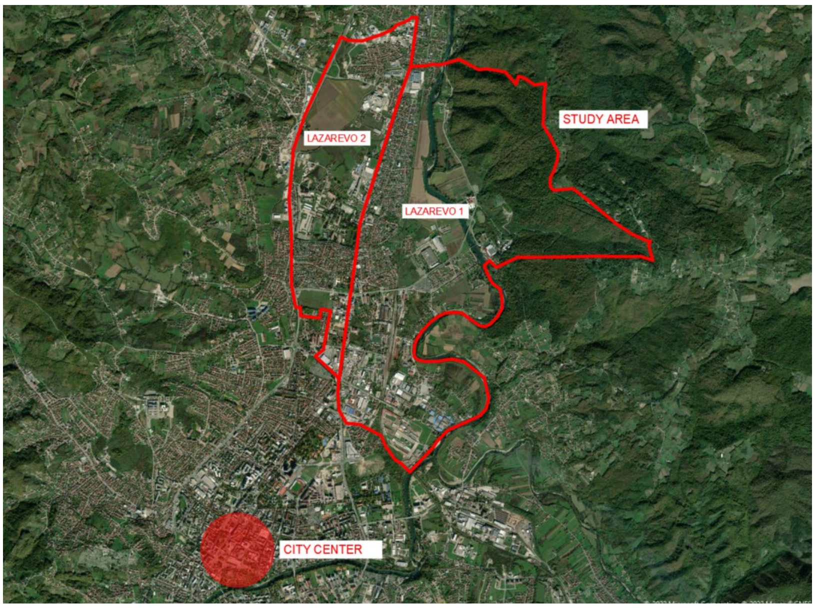

Figure 1. Study area location and boundaries

2.2. DATA COLLECTION AND ANALYSIS

The data analyzed in this paper has been collected during the development of the project entitled "Establishment of GIS database of urban green areas using AreaCAD-GIS platform" implemented by the company GeoINOVA – Informatički inženjering within the innovation challenge "Banja Luka - Future City". The first author was the project coordinator and participated in data collection and processing. Namely, data were collected for 5 groups of green areas in the pilot area Lazarevo 1 and Lazarevo 2; namely green areas, groups of trees, shrubs, hedges and trees. Due to the fact that green areas and tree-lines are the most represented in this area (other groups are insignificantly present), the subject of research in this paper will be only these two groups of data. Data on green areas has been collected from various sources (orthophotos and spatial planning documentation) and during field work. On this occasion, the following attributes are included: category, species, vitality rating, and area. The share of representation in the total area was obtained subsequently, by entering data into Excel spreadsheets. All data on trees (a total of 1328 individuals) were collected during fieldwork (September, 2020). These include: quantitative attributes (tree height, canopy width and trunk diameter) and qualitative attributes (species name, damage, disease, vitality rating, decorativeness rating, degree of protection, and additional description).

For data collection, the INOVA iGEO platform was used, on which the results were graphically presented (spatial arrangement of green areas with the possibility of viewing all attributes). The collected data is exported to shape format (.shp) which is further analyzed in Autodesk AutoCAD Map 3D software from where excel tables are created. Each descriptive attribute is assigned a code to speed up the process of entering data into the IBM SPSS (Statistical Package for the Social Sciences) statistical analysis software. The final phase included the creation of summary tables for green areas and trees from which various indicators were obtained. Distribution shape tests for green areas and contingency tables for trees were performed. Among the outputs, there are tables and graphs that will be presented in the experimental part of this paper. This examined the research questions asked, and the results were presented using formulas, tables and graphs.

3. RESULTS AND DISCUSSION

In order to reach the set goal, which refers to determining the representation of certain categories and types of green areas and analysis of the health status of trees in the study area, two research questions were asked:

- Are all types of green areas equally represented in the research area;
- Is small-leaved linden much more susceptible to diseases than European plane tree.

3.1. QUANTITY ANALYSIS OF GREEN AREAS

The study area (local communities Lazarevo 1 and Lazarevo 2) belongs to the wider urban area of the City of Banja Luka and covers a total area of 11.25 km^2 [24]. 28% of area belong to public green areas, with the largest share belonging to the Trapisti Park Forest (21.67%), and the rest are different types of green areas for public, limited and special purposes.

Of the total public green areas, the largest part belongs to green areas for public use, 89%. These are those areas whose scope of use is not limited by anything, in terms of working hours, entrance fees, etc: city parks, squares, boulevards, greenery of public buildings, tree lines, greenery along the coast, quays, squares, picnic areas, national parks, street greenery [23]. Limited green areas occupy 10%. These are areas that are in some way limited for use, whether it is the working hours of the building next to them or another factor: block greenery, greenery around schools, kindergartens, universities, hospitals, sports and recreational complexes, monuments, as well as private green areas [23]. Special purpose green areas occupy only 1%. These are protection zones and belts, cemeteries, roadside orchards, nurseries, botanical gardens [23]. This result is positive because the users (primarily local, and then the population from other settlements) have at their disposal permanent areas for active and passive rest.

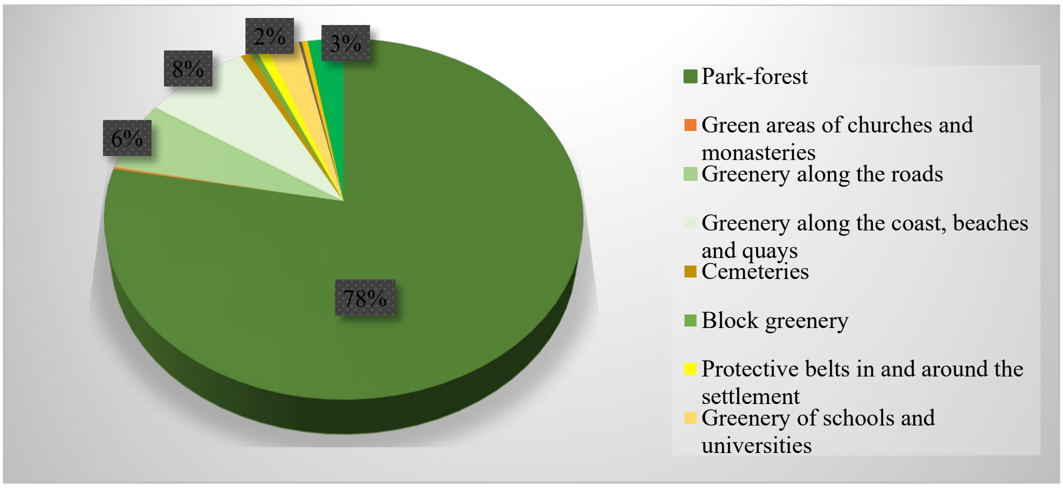

Figure 2. Percentage of individual types in the total green area

From all the above, it can be concluded that the present types of green areas are not equally represented in the study area, which was proven by the test of the form of distribution, which is shown below. A total of 109 green areas have been recorded in the study area, with 12 different types. This is shown in Table 1.

Table 1. Distribution of green areas by types

The area type	**8**	**34**	**16**	**6**	**22**	**12**	
Number	1	2	56	16	1	17	
$\frac{(m_i - np_i)^2}{np_i}$	7.19	5.52	242.33	5.27	7.19	6.90	
The area type	**7**	**13**	**14**	**19**	**4**	**23**	**Total**
Number	7	3	1	1	3	1	**109**
$\frac{(m_i - np_i)^2}{np_i}$	0.48	4.07	7.19	7.19	4.07	7.19	**304.61**

Types of green areas are marked with the following codes: 8 - Park-forest; 34 - Green areas of churches and monasteries; 16 - Greenery along the roads; 6 - Greenery along the river coast; 22 - Cemeteries; 12 - Block greenery; 7 - Protective belts in and around the settlement; 13 - Greenery of schools and universities; 14 - Greenery of kindergartens; 19 - Greenery of sport centers; 4 - Greenery in front of public buildings and 23 - Greenery around public administration buildings.
With a significance level of $\alpha = 0.05$, it was examined whether the number of present green areas differs significantly by types; i.e., whether all 12 recorded types can be considered equally represented. The set of events (types) is denoted by S_i, i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12. The null hypothesis assumes that they are equally represented, as observed in previous analyses:

$$H_0 : P(S_i) = p_i = \frac{1}{12},\ i = 1, \ldots, 12 \tag{1}$$

$$H_1 :\ P(S_i) \neq \frac{1}{12},\ \text{for at least one i} \tag{1.1}$$

Therefore, it is necessary to test the compliance of the sample with a discrete uniform distribution, where:

$$np_i = 109 \cdot \frac{1}{12} = 9{,}08,\ i = 1, \ldots, 12 \tag{2}$$

The number of individual types of green areas, i.e., the frequency of realization of the S_i event, is denoted by m_i, i = 1,. . . , 12. Within the realized sample, these values are as follows:

$$m_1=1,\ m_2=2,\ m_3=56,\ m_4=16,\ m_5=1,\ m_6=17,\ m_7=7,\ m_8=3,\ m_9=1,\ m_{10}=1,\ m_{11}=3 \text{ i } m_{12}=1 \tag{3}$$

The values of the χ^2-test for each of the events given in the previous table were obtained according to the formula:

$$\chi^2 = \frac{(m_i - np_i)^2}{np_i} = \frac{(m_i - 9{,}08)^2}{9{,}08} \tag{4}$$

$$\text{Than } \chi^2 = \sum_1^{12} \frac{(m_i - np_i)^2}{np_i} \tag{5}$$

When all 12 events are added up, the total value is obtained: $\chi^2_{12\text{-}1}$ = 304.61. From the table χ^2-distribution [25], the critical value of the test $\chi^2_{11;\,0.05}$ = 19.675, and the critical area is C = [19.675; + ∞]. Since 304.61 > 19.675, hypothesis H_0 is rejected and with a risk of 5% it can be argued that there is a significant difference in the distribution of green areas in the study area.

3.2. TREE-LINES QUALITY ANALYSIS

In the researched area, during field data collection, a total of 1328 trees were recorded, with 27 different species. All attributes, including the names of tree species, have been replaced by codes, for easier analysis and statistical presentation of data. The six most present species are marked with the following codes: 19 - Pedunculate oak (*Quercus robur*); 25 - Norway maple (*Acer platanoides*); 26 - European plane (*Platanus x acerifolia*); 31 - Large-leaved linden (*Tilia platyphyllos*); 39 - Small-leaved linden (*Tilia cordata*) and 41 - Silver linden (*Tilia tomentosa*) (Figure 3).

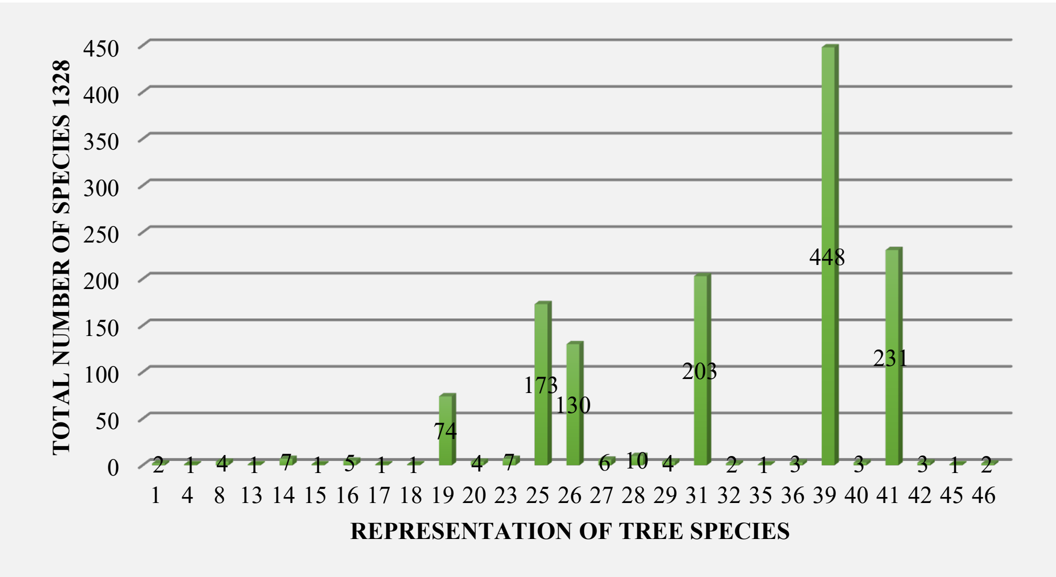

Figure 3. Representation of individual tree species in the total number of trees

As in the entire territory of the City of Banja Luka, so in the study area, the following species are most represented in tree lines: large-leaved, silver and small-leaved linden (882 trees), followed by Norway maple (173), European plane (130) and pedunculate oak (74). Their share in the total number of all trees is 95%, of which 3 species of linden occupy a percentage of 66%.

Among the attributes related to trees, there are also qualitative assessments of the general condition, both mechanical damage and phytopathological (fungal) or other types of diseases. Of the total number of trees, 297 trees (22%) were rated with the lowest vitality rating (1 - nearly dead tree to be removed). One part of the trees has certain damages/diseases, but there is a possibility of remediation, i.e., it is possible to apply phytosanitary measures to improve their health (10%). Of the total number of trees, healthy trees account for 68%.

Given the fact that small-leaved linden is the most numerous species and that during field work it was noticed that there are a large number of trees where the disease is present, especially in young trees, further analysis relates to health for all three species of linden present in study area: small-leaved, large-leaved and silver. Of the total number of trees (882), healthy trees account for 56%, diseased trees that need phytosanitary measures 14% and diseased trees that need replacement 30%. The number of linden species according to health status is shown in Table 2. Codes 0 and 1 imply healthy trees, code 2 diseased (those that need replacement) and code 3 also diseased, but by applying certain measures they can be preserved in tree-lines. The results are presented using the contingency tables.

Table 2: Number of linden species by health status

Species	0 - there is no additional description (healthy tree)	1 - young seedling (healthy tree)	2 - dry / diseased tree (replacement required)	3 - diseased tree (necessary phytosanitary measures)	Total
Large-leaved linden	12	147	18	26	203
Silver linden	144	17	29	41	231
Small-leaved linden	127	42	220	59	448
					882

From the Table 2, it can be concluded that the number of trees that need replacement predominates in small-leaved linden (220 trees, or 49%). Most of the diseased trees have phytopathological (fungal) disease, which was found during field work, in the form of small spots on the leaves of trees. For that reason, it was decided to analyze the number of these trees in more detail, so that further planning and replacement with new seedlings could be done. Also, the distribution of small-leaved linden trees according to health status shows that 59 diseased trees need phytosanitary measures or 13%, while 169 are healthy trees or 38% (young seedlings occupy 10% of healthy trees). A research question was asked: Is the small-leaved linden much more susceptible to diseases than the European plane? The first step was to use the method of descriptive statistics to do cross-tabulation, i.e., the table of contingency for these two species, taking into account only the assessment of vitality, i.e., their health status. The obtained results are shown in Table 3.

Table 3: Number of species of small-leaved linden and European plane tree according to health status

Tree species	Health status			
	Healthy trees	Diseased trees (necessary phytosanitary measures)	Sick / dry trees (replacement required)	Total
39 Small-leaved linden (*Tilia cordata*)	169	59	220	448
26 European plane (*Platanus x acerifolia*)	123	0	7	130
Total	292	59	227	578

With a risk of $\alpha = 0.02$, the χ^2 test of independence was used to test whether there is a significant difference in the types of linden and European plane seedlings, when it comes to their health condition. As attributive (descriptive) features X and Y are marked by tree species and health status, respectively. In this case, Hypothesis H_0 argues that there is a significant difference between these two features, ie. that features X and Y are independent. Table 3 also contains aggregate values, i.e., absolute frequencies of modality frequency of both characteristics:

$$n_{1.} = 448 \text{ i } n_{2.} = 130,\ n_{.1} = 292,\ n_{.2} = 59 \text{ i } n_{.3} = 227 \quad (5)$$

By applying equality, the expected number of pairs of all modalities is determined:

$$n_{11} = \frac{448 \cdot 292}{578} = 130{,}2;\ n_{21} = \frac{130 \cdot 292}{578} = 65{,}7;\ n_{12} = \frac{448 \cdot 59}{578} = 45{,}7;\ n_{22} = \frac{130 \cdot 59}{578} = 13{,}3;\ n_{13} = \frac{448 \cdot 227}{578} = 175{,}9;\ n_{23} = \frac{130 \cdot 227}{578} = 51{,}0 \quad (6)$$

Then the realized value of the statistical test was obtained, which reads:

$$\chi^2_{(2-1)(3-1)} = \frac{(169-130{,}2)^2}{130{,}2} + \frac{(59-45{,}7)^2}{45{,}7} + \frac{(220-175{,}9)^2}{175{,}9} + \frac{(123-65{,}7)^2}{65{,}7} + \frac{(0-13{,}3)^2}{13{,}3} + \frac{(7-51)^2}{51} = 127{,}72 \quad (7)$$

According to the tables used [25], the critical value of the test is $\chi^2_{(2-1)\,(3-1);\,0.02} = 7.824$. It follows that the critical area of the test is C = [7,824, + ∞]. Since the obtained result is 127.72 > 7.824, H_0 is accepted and with a risk of 2% it is claimed that there is a relationship between tree species and health status. A comparison of these two species is also shown in Figure 4.

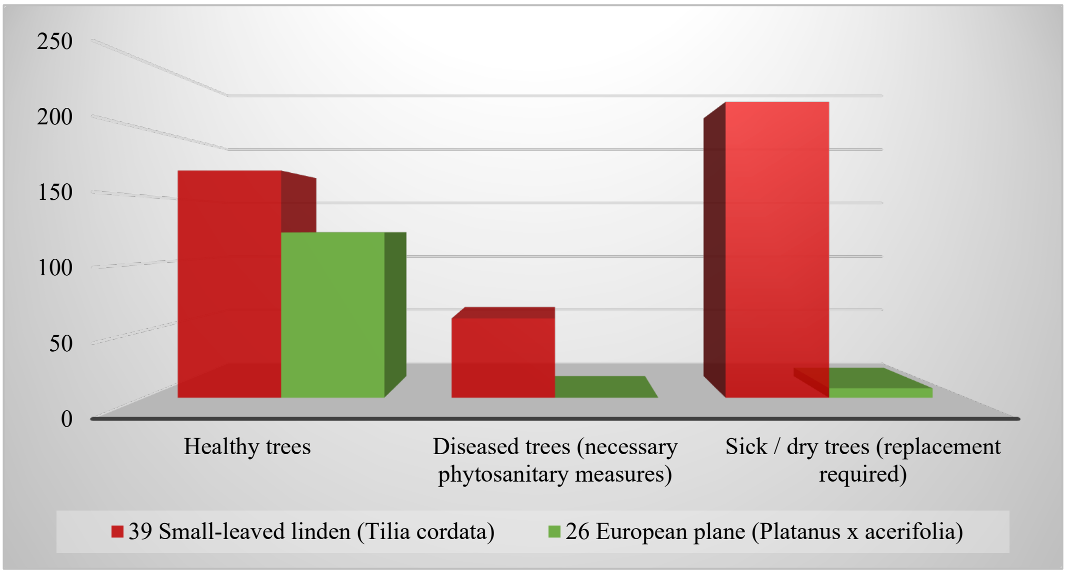

Figure 4. Comparison of the health condition of small-leaved linden and European plane

Based on all the above, it has been shown that the species of small-leaved linden tree gets sick more often than other species of trees. In this example, a comparison was made with the species of the European plane. Almost one half of the total number of this species (49%) have a certain type of disease and need replacement. Having in mind the health condition of plane trees and other species present in this area, recommendations can be given to the competent services of the City Administration of the City of Banja Luka for raising and maintaining green areas, to use them instead of linden, when building new tree-lines or do the reconstruction of existing ones.

4. CONCLUSIONS

This paper analyzes the representation and quality of urban green areas in two local communities of Banja Luka. Part of the results are presented using the methods of descriptive statistics (frequency), and for the second part, non-parametric tests, Pearson's χ^2-test using two basic forms: the test of the distribution form and the χ^2 test of independence were applied. When it comes to the quality of green areas, the health status of trees was examined, as the most sensitive category of all green areas. A research question was asked: Is the small-leaved linden (*Tilia cordata*) much more susceptible to diseases than the European plane (*Platanus x acerifolia*)? The obtained results are shown in table 3. Bearing in mind the health condition of plane trees and other species present in this area, recommendations can be made to the competent services of the City Administration of the Banja Luka for the establishment and maintenance of green areas. It was established that of all the species present, linden is more common than the others and much more susceptible to diseases than the European plane. For future activities in this area, it is recommended to use more permanent species, such as sycamore, oak, maple, etc., when filling existing rows of trees and building new ones. The stated concluding considerations as offered recommendations need to be supplemented. It is necessary to specify the limitations of the planning settings for the replacement of linden. The focus should be on the morphological characteristics of *Tilia cordata* and *Platanus x acerifolia*, which differ significantly, primarily in the domain of the crown and root system. Infrastructural profiles, street fronts as well as small urban gardens of single-family housing that dominate the location of Lazarevo 1 and 2 determine the interpolation of a certain dendrological type. Reconstructions of tree row in many locations cannot be replaced by trees with large habitus. RP (Regulatory Plan) Lazarevo

1 and 2, based on the projected number of inhabitants of 7,600 in the planning horizon, as well as planned areas under public greenery in chapter IX Environment, 1. Public green areas 1.1. Tree rows, 1.2. Park and 1.3. The green block determines the following settings. For planting material it is necessary to use:

Conifers: *Taxodium distichum, Metasequoia glyptostroboides, Abies concolor, Abies nordmanniana, Pinus strobus, Pinus wallichiana Picea omorika, Picea pungens, Cupressus arizonica, Cedrus atlantica, Cedrus libani*.

Deciduous trees: *Gingko biloba, Liriodendron tulipifera, Magnolia sp., Quercus robur, Quercus palustris, Quercus borealis, Fraxinus angustifolia, Ulmus laevis, Acer palmatum, Betula papyrifera, Sorbus torminalis and others, Sorbus torminalis*.

The selection of dendrological species from RP, intended for the landscape arrangement of the greenery system and the formation of tree rows can be used for recommendations, and of course it also includes the sycamore, for which research on the vital characteristics was determined in this paper. For example, in RP, a row of trees (*Liriodendron tulipifera*) with a length of 1,500 m is planned along the road parallel to the railway line Banja Luka – Slunja [26].

After conducting all phases of the research, several important conclusions were reached when it came to green areas. During the examination of the first research question, it was concluded that different types of green areas are not equally represented in the research area. There are a large number (and therefore a large occupied area) of green road belts, which cannot be classified as usable free areas, in terms of the using them by local population. On the other hand, the positive fact is the presence of the Trapisti Forest Park in this settlement, which occupies the largest part of the total green areas. Its preservation and arrangement are of great importance, not only for the local population, but also for users who come from other parts of the city of Banja Luka.

When it comes to the quality of green areas, the health condition of trees was examined, as the most sensitive categories of all green areas, because they are constantly influenced by negative factors: smoke, dust, exhaust fumes, salinization, construction works, wind and vandalism. It was stated that of all the present species, linden is more common than others, and it is recommended for future activities in this area to use more durable species, such as plane, oak, maple and the like, when filling existing tree-lines and building new ones.

The general conclusion reached during the research is that very little attention is paid to the analysis of greenery in the city of Banja Luka, especially when it comes to qualitative analysis, such as the health of tree-lines. Their role in the overall system of green areas of cities is to connect all existing areas into one functional unit, so that this system has multiple benefits for the urban environment. This is especially important at a time when more and more is being invested in preserving the environment, reducing global warming and sustainable development. As one of the most important categories in urban areas, green areas need to be constantly maintained, nurtured and increase their share in total areas, preceded by a detailed analysis of the current situation, so that further steps in this area can be planned.

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21
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RECLAIMING PUBLIC OPEN SPACE WITHIN LOCALIZATION OF SUSTAINABLE DEVELOPMENT GOAL 11: THE PERSPECTIVE OF THE CITY OF NIŠ, SERBIA

Abstract

Public space is a highlighted topic in the 2030 Agenda for Sustainable Development. The City of Niš has undertaken the process of Voluntary Local Review, and selected, among others, to report on the progress in achieving the Sustainable Development Goal 11, including the indicator related to public open space (POS). This paper explores the phenomenon of POS, with a particular focus on residential areas. Global practices are discussed to provide background on the issue, along with some particularities of Serbian context involving legislative and planning treatment of POS. Current state of POS is explored in the territory of the City of Niš, as well as exploitation and maintenance challenges. These findings are used to establish context-specific POS typology and discuss potential pathways towards inclusive, safe, resilient and sustainable local communities.

Keywords: public open space, typology, legislation, revitalization

РЕИНТЕГРИСАЊЕ ЈАВНОГ ОТВОРЕНОГ ПРОСТОРА У ОКВИРУ ЛОКАЛИЗАЦИЈЕ ЦИЉА ОДРЖИВОГ РАЗВОЈА 11: ПЕРСПЕКТИВА ГРАДА НИША, СРБИЈА

Сажетак

Јавни простор је истакнута тема у Агенди за одрживи развој 2030. Град Ниш је покренуо процес израде Добровољног локалног извјештаја и изабрао, између осталог, да извјештава о напретку у постизању Циља одрживог развоја 11, укључујући индикатор који је везан за јавни отворени простор (ЈОП). Овај рад истражује феномен ЈОП-а, са посебним фокусом на стамбена подручја. Разматране су глобалне праксе како би се стекао увид у знања о овом питању, заједно са неким специфичностима српског контекста које укључују законодавни и плански третман ЈОП-а. Истражује се тренутно стање ЈОП-а на територији града Ниша, као и изазови у експлоатацији и одржавању. Резултати се користе за дефинисање специфичне типологије ПОС-а и разматрање потенцијалних праваца ка инклузивним, сигурним, отпорним и одрживим локалним заједницама.

Кључне ријечи: јавни отворени простор, типологија, законодавство, ревитализација

1. INTRODUCTION

From the begging of the 1990's of the last century, and especially in the early transition period until the 2000's, the process of continuous degradation of existing public open space (from here on, POS) has been going on in Serbia, similar to other post-socialist cities [1], [2]. This period was also characterized by a complete absence of providing and furnishing new public spaces, within new developments. In turbulent times marked by the overall poverty, local administrations focused only on the necessary activities of maintaining the traffic and technical infrastructure, which were necessary for the functioning of cities.

Nowadays, 30 years later, the situation has not much improved. POS still does not have an important position in regulations, nor in strategic and urban plans, and its development potential is not recognized nor efficiently used in Serbian cities. Previous laws on the topic of planning, design and construction only determined boundaries between the so-called "public land" and "other land", without the obligation to establish norms for positioning, structuring, shaping and constructing POSs. The current Law on Planning and Construction recognizes "public use", "public interest" and "areas of public use", but not the terms "public space" nor "public open space". Additionally, the UN-Habitat definition of POS is not compatible with Serbian legislation, which often results in a variety of interpretations of the POS concept. This is a challenge that needs to be overcome, so that the data could be compared among urban settlements within the Republic of Serbia, and at the international level [3].

Intensive or uncontrolled urbanization in post-socialist development patterns in Niš led to urban decay, or even complete disappearance of POSs [4]. Some implications upon the urban landscape were obvious immediately after the first post-socialist residential developments were completed, such as infrastructure and parking overload, decrease in greenery and unattractive urban landscape, while others were grasped much later, like the negative effects of reducing POS on the environment and microclimate [5], involving air pollution, heat island effect, flooding risk, etc., or the implications on peoples' health due to the lack of shared spaces for outdoor activities and contact with nature. Current issues in maintaining and providing POS are particularly visible at the neighborhood level, in residential areas of the City of Niš.

In post-socialist cities such as Niš, POS is one of the key elements of urban structure for advancing the Sustainable Development Goals (SDGs) at the local level. Globally, United Nations member States work closely with local and regional governments on actively localizing the 2030 Agenda for Sustainable Development and the implementation of the SDGs that are outlined in this document. The 2030 Agenda encourages member States to perform regular and inclusive reviews of progress at the national and sub-national levels, and calls on major groups and other stakeholders, including local authorities, to report on their contribution to the implementation of the Agenda [6]. Consequently, local and regional governments are increasingly engaging in sub-national reviews of SDG implementation, also called Voluntary Local Reviews (VLRs), thereby strengthening the overall SDG implementation [7]. In July 2023, the City of Niš, Serbia has begun creating its first VLR with the support of the United Nations Human Settlements Program, within the project *Voluntary Local Reviews: Evidence for Greener, Resilient and Sustainable Urban Recovery in Eastern European and Central Asian Countries in Transition*. This also the first VLR in Serbia and the third in this region. Partners in the implementation of the project are: United Nations Human Settlements Program (UN-Habitat), United Nations Economic Commission for Europe (UNECE), United Nations Department for Economic and Social Affairs (UNDESA) and United Cities Local Governments (UCLG). Aside from Niš, the project also involves the following cities: Tbilisi (Georgia), Bishkek (Kyrgyzstan) and Dushanbe (Tajikistan). The VLR of the City of Niš is being developed untill the mid 2024, and is to be published and officially launched afterwards[1].

Within the process undertaking this voluntary local review, the City of Niš initially selected a number of SDGs, Targets and Indicators to be reviewed, in order to report on the progress in achieving the SDGs in its territory. Given the significance of POS for creating inclusive, safe, resilient and sustainable cities as a context-important topic for Niš, one of the selected indicators

[1] The Voluntary Local Review of the City of Niš is prepared by the Local Consultant Milena Dinić Branković, with the support of the Local-Regional Coordinator Tanja Obradović, the National Coordinator Siniša Trkulja, and the newly established Monitoring Department of the City of Niš. The VLR is under development as part of the UNDA Tranche 14 project implemented by the United Nations Human Settlements Programme, United Nations Economic Commission for Europe, United Nations Department of Economic and Social Affairs and United Cities and Local Governments.

involves *Indicator 11.7.1. Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities*.

It is the standpoint of this research that POSs are quite underused in the City of Niš, as well as in the entire country. This issue requires not only comprehensive review of POS treatment in legislative and planning framework, but also a shift in the perception of urban dwellers on POS as a valuable resource for the quality of urban living. In line with the framing issue, the main goals of this paper are: (1) to investigate the legislative and planning treatment of POS at the national and local level, and (2) to explore the current state (size, use, coverage, degree of publicity, morphology) and typologies of POS in the territory of the City of Niš. Additionally, the paper acknowledges local efforts of the City of Niš in advancing the SDG 11 that relates to public space, to show how far the City of Niš has come on the way towards inclusive, safe, resilient and sustainable local communities.

2. MATERIALS AND METHODS

This paper explores the phenomenon of POS, with a particular focus on POS in residential areas. For this purpose, the research uses review of relevant literature, legislative and planning documents, and empirical data obtained from various sources. Methodological framework is conceptualized on description, analysis and synthesis.

By exploring legislative documents at the national level, the shortcomings of POS treatment in legislation are identified, which are reflected in local planning documents, and consequently, in the provision and maintenance of POSs at the local level. These are further determined in the review of two standing planning documents of the City of Niš, and analysis of their implications: General Urban Plan of Niš 2010-2025 [8] and Plan of General Regulation of the City Municipality Medijana [9]. Analysis is firstly performed for POSs in the territory of the City of Niš, and further elaborated for POSs in residential areas within the City Municipality Medijana.

POS in residential areas is explored in more detail given its significant urban role, extensive surface area and underused potential in the City of Niš. The City Municipality Medijana was selected as a research polygon for the analysis of residential POS because it is the most urbanized of all City Municipalities, with compact urban form and extremely high population density of 7,768 inhabitants per hectare[2]. Additionally, in the City Municipality Medijana there are more than 100 registered plots of open space within multi-family housing areas. However, not all of the listed open spaces are indeed POSs in reality – even though they have potential, they do not have recreational use, are devastated and inadequately used, or their urban form does not foster access to the general public. Therefore, size, use, coverage, publicity level and morphological characteristics of urban blocks containing potential POSs in the City Municipality Medijana are investigated next, to determine their prospects to serve as public spaces and establish POS typology. In order to best reflect the context-suited typology of POSs, particular study sites for detailed POS analysis in the City Municipality Medijana were chosen to include POSs of various sizes, conceptualized within different urban forms, and with various functions of space. Current state and characteristics of POSs are determined on the basis of field observations, planning documents, satellite photo images and available data from Real Estate Cadastre.

The synthesis of study findings is than used to discuss the established challenges in legislative treatment, exploitation and maintenance of POS in the City of Niš, to overview the progress of the City in achieving the SDG 11 related to POS, and to explore potential pathways towards sustainable development of POS.

3. BACKGROUND

In order to understand the research context, background part of the paper explores the notions of *public space* and *open public space* in international context, in line with its significance for the overall quality of urban life. It further singles out some particularities of Serbian context related to the phenomenon of POS.

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2 This is significantly higher compared to the rest of the City territory (418 in/ha).

3.1. PUBLIC SPACE IN THE AGENDA 2030

Public space is a highlighted topic within the framework of the 2030 Agenda for Sustainable Development, which outlines 17 SDGs. Particularly, SDG 11 and its Target 7 focus on public space: "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities" [7]. The share of the built-up area of cities that is open space for public use is being monitored via Indicator 11.7.1. in order to assess the progress that cities are making towards achieving this Target. At the global level, 3 in 4 cities have less than 20% of their area dedicated public spaces and streets, which is much lower than the target of 45-50% [7].

The Global Public Space toolkit, which was developed by the UN-Habitat, defines Public Space as all places that are publicly owned or of public use, accessible and enjoyable by all, for free and without a profit motive [10]. Accessibility of public space as a concept implies unrestricted access to space for all user categories, regardless of their age, gender, ethnicity, socio-economic status or disability status [11]. Therefore, it should be perceived as a core component of sustainable urban development. In its widest sense, "public space" is defined as the meeting or gathering places that exist outside the home and workplace that are generally accessible by members of the public, and which foster resident interaction and opportunities for contact and proximity [11]. This definition implies a higher level of community interaction, and places a focus on public involvement rather than public ownership or stewardship. Such public space is categorized into streets, open spaces and public facilities. However, for the purpose of monitoring and reporting on indicator 11.7.1, public space is defined as all places of public use, accessible by all, and comprises open public space, which is in the focus of this research, and streets.

"Open public space" is any open piece of land that is undeveloped or land with no buildings (or other built structures) that is accessible to the public without charge, and provides recreational areas for residents and helps to enhance the beauty and environmental quality of neighborhoods [11]. According to the [12], open public space broadly includes parks, gardens, playgrounds, public beaches, riverbanks and waterfronts. These spaces are available to all without charge and are usually publicly owned and maintained.

In the global discourse on the topic of open public spaces, it is acknowledged that different cities have different types of these spaces, with variations in both size and typology suited to the local context. Two general classifications of open public space – by size and typology of the space – are presented here as relevant for this research.

Based on their *size and coverage area*, [12] establishes the following hierarchy of open public spaces:

- 1. Local/pocket open public spaces – these are small parklets that service the recreation needs of the immediate residential population within a walking distance or 400 meters (5-minute walk). Their average areas range from 0.03 to 0.04 hectares and are often used for recreation purposes. In some places, these may include small areas of nature space.
- 2. Neighborhood public open spaces – these are larger spaces which serve the recreational and social needs of a community. Their areas range from 0.04 and 0.4 hectares, and can easily be accessed within 400 meters walking distances from households. They can accommodate a variety of activities, such as recreation, sporting, and natural features conservation.
- 3. District/city open spaces or city open spaces – these spaces are mainly designed to provide for organized formal sport. They include substantial recreation areas and some nature spaces. They serve several neighborhoods with players and visitors traveling from surrounding districts. The size of the spaces ranges from 0.4 to 10 hectares, and are designed to serve populations within 800 meters (10-minute walking distance).
- 4. Regional open space/Larger city parks – these are substantial facilities for organized sport, play, social interaction, relaxation and enjoyment of nature. They serve one or more geographical or social regions and are likely to attract visitors from outside any one local government area. Their areas range between 10 and 50 hectares.
- 5. National/metropolitan open public spaces – these are large spaces whose areas range from 50 and 200 hectares. They support concurrent uses, and contain such services as recreational, sporting, and basic amenities.

Typology of open public space is established in line with the function of the space. According to the SDG Indicator Metadata Repository, various types of open public space include [11]: green public areas, riparian reserves, parks and urban forests, playground, square, plazas, waterfronts, sports field, community gardens, parklets and pocket parks.

3.2. LEGISLATIVE CONTEXT IN SERBIA

In Serbian legislation, public space is associated with “areas of public use”, implying streets, parks, squares and other publicly owned areas [13]. Therefore, “areas of public use” are limited only to spaces that are in public ownership. Other types of land, which also serve as POS, are not reviewed at all. This is the case with undeveloped land and green areas in multi-family residential zones that are often located on “other land” (non-public land).

The ambiguity concerning the regime of undeveloped land and green areas surrounding buildings in residential zones is particularly visible in inherited housing estates from the socialist past. In the Real Estate Cadastre of the Republic of Serbia, it is very common for a residential building to be located on a cadastral plot of the same size as that building, with no regard to the regime and use of the land in the immediate surroundings of the buildings [14]. Such treatment of undeveloped space causes many problems in exploitation, because it remains unclear who the land belongs to, who has the right to use it, and who is obliged to maintain the space. It may also occur that the cadastral plot intended for POS also contains multi-family residential buildings, because the process of parcellation has not been completed, i.e. the land under the structures has not been segregated for residential use in Real Estate Cadastre.

The matter is further complicated in residential urban blocks, where it is defined by Law that the land surrounding the buildings is “land that is in public use”, so that it could serve the buildings within that residential block [13]. It should be noted that this formulation of “land in public use” enables different forms of ownership. The Law particularly highlights that the land should be in public use for urban blocks that were designed in an open system of spatial organization. In urban blocks that were developed in an enclosed or semi-enclosed system of spatial organization pre-dating and during the socialist period, which are to be found mostly in central city zone, the land may also be in public or mixed ownership. However, in practice the spatial organization and the enclosed form of urban block suggest limited access to the general public, and implicate the shared use of the inner residential courtyards only by the residents of the buildings within that particular housing complex.

Existing legislative framework and modalities of land management do not provide sufficient basis for the implementation of POS as quality spaces accessible to all, into the practice of urban planning and design in Serbia. Given the vagueness of terminology in Serbia, for the purpose of this research the term Public Open Space (POS) will be used, referring to quality open space having recreational use and excluding streets. Such POS implies open space regardless of its ownership status, which is intended for public use and accessible to all users.

4. TOWARDS RECLAIMING POS IN THE CITY OF NIŠ

4.1. OVERVIEW ON POS

The surface area of POS in the City of Niš cannot be determined in line with international standards due to different methodologies and lack of consistent data. Some research was however performed at the national level, resulting in data that cannot be compared to other cities beyond Serbia[3]. Total surface of land allocated to streets alone or POS alone is not available.

According to the data from the Urban indicators database of UN-Habitat [15], the average share of the built-up area of the City of Niš that is open space for public use for all for the year 2020 is presented in Figure 1. The low share of POS of 3.7% (excluding streets) in the built-up area of Niš also implicates poor access to these spaces to a significant share of Niš population. The same source lists that only 57.2% of Niš population has access to POSs.

The City of Niš arranges and maintains POSs that are “areas of public use”. Apart from the street network, these are the following POSs: parks, forest parks, squares, pedestrian streets and quay along

[3] Based on a survey conducted in February 2023 performed by the Standing Conference of Towns and Municipalities, the share of POS in the construction area of Niš (plazas, squares, parks and other open spaces, including streets) is estimated at 25%. This value refers to POS in the construction area, which is developed or undeveloped urban land zoned for construction.

Nišava River. Total park area in Niš built-up area amounts to 49 hectares, and the largest city parks are Čair Park and the Park in Tvrđava. There are also two forest parks in the built-up area of the City: Bubanj Forest Park (40 hectares) in the urban area of Niš, and Koritnik Forest Park (40 hectares) in the urban area of Niška Banja. Other forest parks are located outside the built-up area. In the area of the General Urban Plan [8], which encompasses a much larger territory than the built-up area, the largest part of green areas consists of protective greenery and forests with forest land, while the share of parks and recreational areas that are available to citizens is quite small [16]. The share of green areas of only 1.2 m2 of greenery per inhabitant [17] indicates not only that green areas are insufficiently represented on the territory of the City, but also corroborates low representation of POSs that accommodate these green areas. There are also several city squares, and the largest is King Milan Square in central city zone. The two most important pedestrian streets, Obrenovićeva Street and Kazandžijsko Sokače, are located in the central zone.

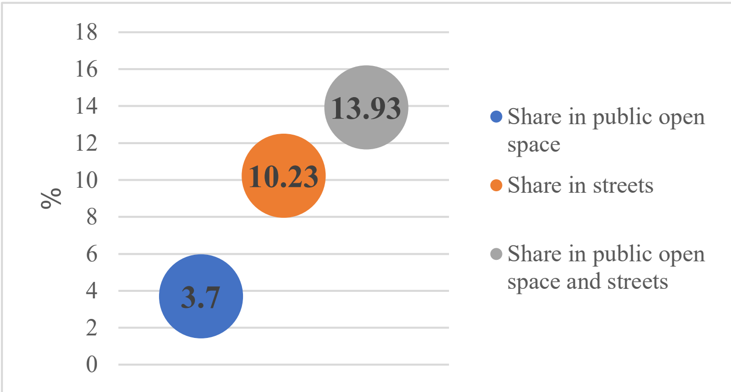

Figure 1. Average share of the built-up area of the City of Niš in 2020 that is open space for public use. Source: https://data.unhabitat.org/datasets/GUO-UN-Habitat::11-7-1-provision-and-access-to-open-spaces-in-cities-2020/explore

4.1.2. POS IN RESIDENTIAL AREAS IN THE CITY MUNICIPALITY MEDIJANA

POS that is located in residential zones of multi-family housing represents a crucial issue for the City of Niš nowadays, particularly regarding the legislative treatment, exploitation and management of these spaces. Post-socialist densification of a significant portion of urban fabric has placed POS under the spotlight, thereby becoming a polygon of interest for multiple stakeholders - local communities, planning professionals, developers and decision makers.

Problems in the functioning of POSs adjacent to multi-family housing in Niš were recognized by relevant institutions more than a decade ago, and the City of Niš started some activities in addressing this issue. The first attempt involved identifying POSs within official planning documents, which is illustrated in the case of the City Municipality Medijana (Figure 2). Also, this map presents other categories of public space aside from POS: streets and public facilities, thus illustrating the complexity of the topic of public space. Areas of public use in this figure involve both POS with recreational use and public facilities, such as hospitals, schools, public buildings etc.

The Plan adopted for the City Municipality Medijana in 2015 [9] acknowledged some of the spaces that are, according to the Law, “land in public use that serves the buildings within that residential block”. Unfortunately, and due the overall complexity of the phenomenon of public space and rather confusing terminology, in the Plan itself these areas were named “areas of public use that serve the buildings within that residential block”, which is conflicting with the Law. POS in the vicinity of multi-family buildings is not area of public use, because housing cannot be considered a public use, even though this land might be in public ownership. This led to additional confusion regarding POSs in residential areas, and conflicts with the residents exploiting these spaces. However, it can be assumed that the intent of the Plan was to identify the areas surrounding residential buildings that could serve the as POS, and which are necessary for the normal functioning of residential land use.

Regarding the land in public use that serves the buildings within that residential block, additional efforts by the City of Niš administration were made for the territory of City Municipality Medijana, beyond the classification illustrated in this Plan. With the initiative of the Chief Urban Planner in 2021, the City has begun the process of recording POSs in multi-family residential zones in its territory. So far, a comprehensive list of cadastral plots with open spaces in residential zones is completed for the City Municipality Medijana. This list only involves “land in public use that serves the buildings within that residential block", and excludes the street network and "areas of public use" (parks, squares, etc.).

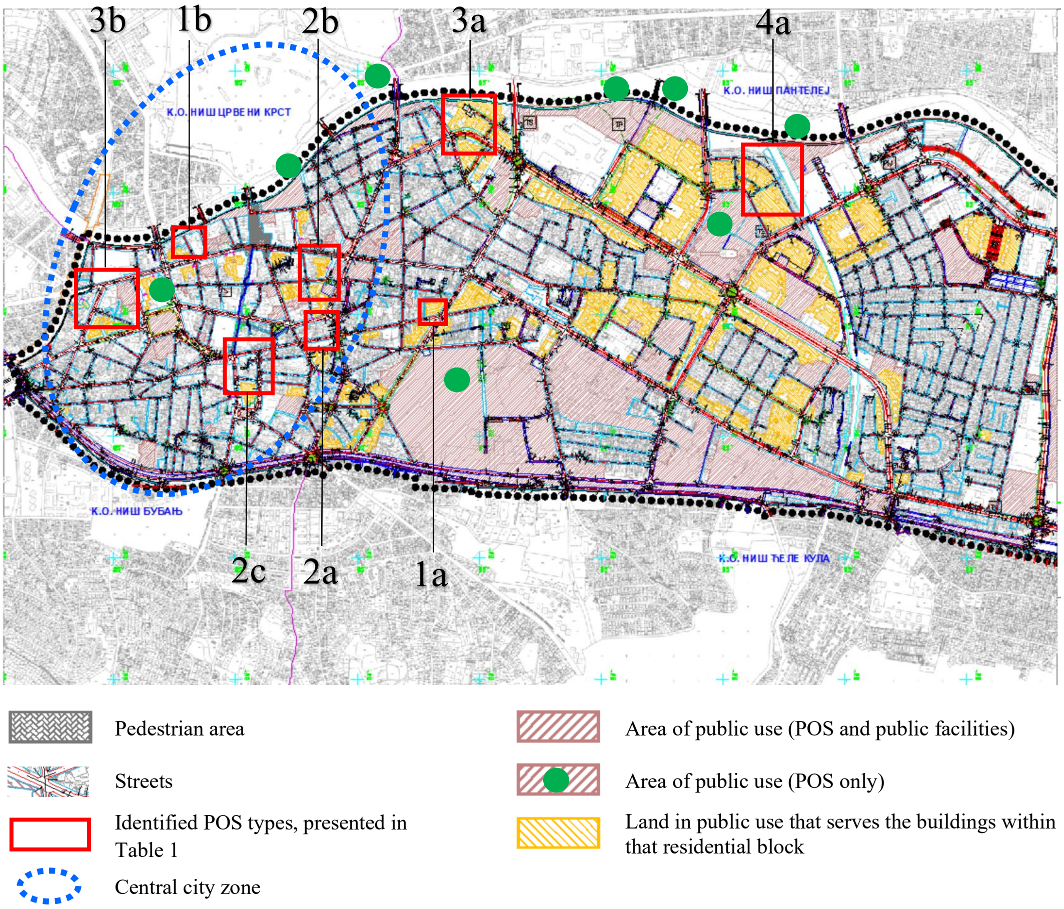

Figure 2. POSs within the Plan of General Regulation of the City Municipality Medijana, 2015 - Graphic: Traffic Solution and Areas of Public Use. Source: Own research based on the Plan, http://www.eservis.ni.rs/urbanistickiprojekti/

There are 124 such plots covering 76.85 hectares of land in the City Municipality Medijana[4]. The identified plots are of various sizes, with different urban forms, different character, various right of use and different share of green areas. Regarding the ownership, the plots are owned by the City or State, or have mixed ownership, and are located within different land uses. All analyzed plots designated for land in public use are actually undeveloped, except for the plot 2a where two residential buildings are also a part of the plot, because the process of parcellation is not yet completed.

Important features of the open spaces that are indeed POSs involve recreational and social use, easy access and public character. This is not case with all of the identified plots that are zoned as "land in public use that serves the buildings within that residential block". Given the fact that POS features are dependent on size, use, coverage, degree of publicity and form of space, it is necessary to evaluate spatial, functional and morphological characteristics of that residential block, and establish which of the open spaces have to potential to serve as public space, and to what extent.

Having in mind the overall general classifications of POS based on size and function of the space established by the UN-Habitat, a context-specific typology of residential POSs in the territory of City Municipality Medijana is conceptualized. This classification is based on the criteria that were identified as relevant for the urban fabric of the City of Niš, and involve size and coverage, urban form and function of residential POS. The classification is presented in Table 1.

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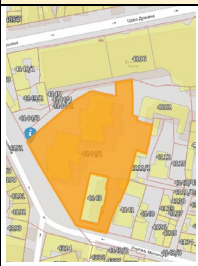
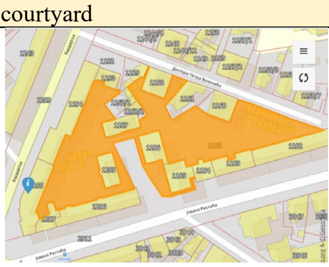
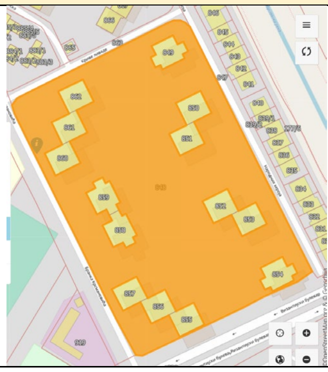
[4] Data obtained from the Office of the Chief Urban Planner of the City of Niš, 2022.

Table 1. Overview on indentified POS types in residential zones in City Municipality Medijana. Source: Own research based on data from the Office of the Chief Urban Planner

Type	**Type 1 - Local POS**		**Type 2 - Community POS**		
Urban form	a. POS in open system	b. Semi-enclosed residential courtyard	a. POS in open system	b. Semi-enclosed residential courtyard	c. Enclosed residential courtyard
Map					
Plot No	2917	1063	4144/1	840/3	4251
Plot size	1,830 m^2	1,690 m^2	3,809 m^2	4,342 m^2	3,205 m^2
Owner-ship	State	State	State, City	Mixed (State, City, Private)	State
Land use	Medium-density housing in urban area	Business-residential zone	High-density housing in urban area	Medium-density housing in urban area	High-density housing in urban area
POS function	Green public areas, parking	Green public areas, parking	Green public areas, parking, sitting area	Green public areas, parking, sport field	Green public areas, parking, sitting area, sport field

Type	**Type 3 – Neighborhood Unit POS**		**Type 4 - Residential Complex POS**
Urban form	a. POS in open system	b. Semi-enclosed residential courtyard	a. POS in open system
Map			
Plot No	1784	1163	848
Plot size	5,896 m_2	5,276 m^2	17,990 m^2
Owner-ship	State	City	City
Land use	High-density housing in urban area	Medium-density housing in urban area	Medium-density housing in urban area
POS function	Green public areas, parking, sitting area, sport filed, playground	Green public areas, parking, sitting area, sport filed, square	Green public areas, parking, sitting area, sport filed, playground

Size and coverage. Based on their individual sizes and catchment area, i.e. how far a user might travel to visit them, residential POS in the City Municipality Medijana can be classified into four categories: 1) Local POS, 2) Community POS, 3) Neighborhood Unit POS and 4) Residential Complex POS. Pocket open spaces are also present in the analyzed area, but were not mapped as a specific POS type. These local pocket parks are often a part of the existing larger plot, but can be identified as a distinctive spatial unit within that plot. Most often this refers to open space in-between the building and the street, but can also be found as distinctive and arranged "nooks" adjacent to the buildings, or may include small areas of green space.

Local POS is the open space in the immediate vicinity of the apartment (50-100 m; 2-minute walk), mostly used by a local group of residents of that particular building only, from a couple of hundred up to 1.000 residents. *Community POS* is a shared space where social interactions and recreational activities take place at the level of a smaller community or urban block (up to 2.000 residents), in close proximity to the apartment (150-200 m; 3-minute walk)[5]. *Neighborhood Unit POS* is intended for a wider group of users (5.000 -8.000 users), accommodates a variety of activities and is easily accessed within a short walking distance (400 m; 5-minute walk)[6]. *Residential Complex POS* is a space that includes significant recreation areas and lush nature space, serves several communities (up to 15.000 users) within a larger residential zone (600 m; 8-minute walk).

Even though some of the plots in Medijana territory are larger in size than 10.000 hectares, which is the case with the identified POS in an open system of spatial organization (marked 4a), these areas surrounding residential buildings cannot be considered city or regional open space. This is primarily due to their dominant land use (residential), but also their spatial organization and fragmentation of space into smaller units. Therefore, this POS type is classified as Residential Complex POS.

Urban form. Urban form and morphology of a neighborhood significantly affect the use and maintenance of POS. In the urban territory of City Municipality Medijana, three types of POS are identified that reflect the urban form: 1) POS in an open system of spatial organization, 2) Residential courtyards in a semi-closed system of spatial organization, and 3) Residential courtyards in an enclosed system of spatial organization (Table 1).

Residential courtyards in an enclosed system are well-defined by buildings, and the space is fully framed in the vertical sense. Such urban form suggests belonging to a group of residential units, while the open space is shared and intended for only a certain group of inhabitants. Enclosed residential courtyard has a limited flow, and may also have access control in some cases. Given that it is not intended for a wider user group, the common area is characterized by a more intimate character. Therefore, they are characteristic of the first two types – Local and Community POSs. Enclosed residential courtyards are mainly found in the densely built central city zones [18].

Semi-enclosed residential courtyards also have a lower level of publicity compared to the POS for the general public, but enable easier access than the enclosed courtyard. In the City of Niš territory, this type is mainly a result of development circumstances and urban transformations from a single-family to a multi-family housing pattern. Therefore, these POSs often lean on both multi-storey residential buildings and low-rise housing on individual plots. They are mostly located throughout the central city and its surrounding wider area. Given their character and scale, they are represented within Local and Community POSs, similar to POSs in the enclosed form. Notwithstanding, semi-enclosed courtyards might also characterize Neighborhood Unit POS as a format of larger scale.

Unlike the first two POS types, POS in an open system of spatial organization is a truly public space that is easily accessible to residents and all other users, without any access regulation. Such spaces are the dominant type of residential POSs in the City of Niš. They are mainly located in large housing estates from the socialist past throughout Niš urban area, but may also be found in the city center in a smaller format. This is the only type of urban form that characterizes large scale POS, i.e. the type Residential complex POS.

POS functions. The structure and functions of POS also have a significant impact on the use and maintenance of that space. The identified plots in City Municipality Medijana are located in areas with the following land uses: 1) medium-density housing in urban area, 2) high-density housing in urban area, 3) business-residential zone. These are all land uses that provide good grounds for the provision of POS, since they generate a large number of POSs users.

Regarding their structure of uses and functions they perform, it can be stated that the analyzed POSs in the territory of City Municipality Medijana are designed and equipped quite modestly. Local POSs have no amenities other than greenery, and their surface area has been significantly eroded with informal parking. The spontaneous usurpation of open space with vehicles represents a common issue in all POS types, but it is more evident at the smaller scale. At a local and community POS level, a significant portion of open space, predominantly green space, is lost for recreational use in favor of parking. These spaces are thus characterized by vast paved areas. Community POSs

[5] Similar to the "Neighbourhood open space" established in the UN-Habitat (2018) typology
[6] Similar to the "District open space" established in the UN-Habitat (2018) typology

might have an additional amenity such as sitting area or a sport field, but these are also insufficiently equipped in regard to their catchment area.

Neighborhood Unit POSs have more varied functions compared to the first two types, with some additional pedestrian areas for gathering and social interactions of users. Urban design of such areas is also poor, and the pavement and urban furniture are often devastated and neglected. Loss of greenery is also evident at the neighborhood unit scale. The POS form of this size requires introducing motorized traffic into the inner-block area in order to provide access to the buildings, thereby fragmenting POS and resulting in extensive occupation of open space by parking.

Residential complex POS has the largest green public areas due to its scale. Given that this POS type is conceptualized in an open system of spatial organization, POS is characterized by grandeur, high level of publicity and a high degree of physical and visual flow through space. Greenery, which was initially extensive and lush, is often poorly landscaped and maintained.

4.2. LOCAL INITIATIVES IN ADDRESSING POS ISSUES

4.2.1. COOPERATION OF THE CITY OF NIŠ AND THE FACULTY OF CIVIL ENGINEERING AND ARCHITECTURE OF NIŠ

One of the local efforts in reclaiming POS in the urban fabric of the City of Niš involve the cooperation of the City and the Faculty of Civil Engineering and Architecture of Niš[7]. Three joint actions on the remodeling of POSs in residential areas were realized in the past several years[8]. The first two were initiated by Chief Urban Planners (2018 and 2020), and the third by the local residents' association Zeleni zid (2021). In 2018 and 2021, the POSs chosen for remodeling were both located within large housing estates from the socialist period, which were designed in an open system of spatial organization. These involved urban blocks in Pasterova Street (2018) and in Knjaževačka Street (2021). In 2020, four locations were selected in the area of Niš central zone, involving residential courtyards in an enclosed or semi-closed system of spatial organization in Nade Tomić Street and Genrala Tranijea Street. Student projects resulted in inspiring proposals, which were presented to a wider audience in the exhibitions of works that were organized after project completion. Until today, these proposals remained only on paper due to lack of funding, and the implementation is still challenging.

4.1.1. Innovative actions underway – Implementation of the RePOS Project

The City of Niš has also endorsed the project entitled Reclaiming Public Open Space in Residential Areas: Shifting Planning Paradigms and Design Perspectives for a Resilient Urban Future (RePOS), with a Letter of support. RePOS project is financed by the Science Fund within the Prisma program, and started its implementation in January 2024. The project carrier is the Faculty of Civil Engineering and Architecture of the University of Niš, and the partner institution is the Faculty of Architecture of the University of Belgrade[9]. The project aims to re-introduce POS into residential areas of Serbian cities, through a novel integrated approach in urban planning and design. Project results will inspire updating of legislation and planning regulations, help local governments with decision-making, assist planners in guiding (re)development processes and benefit local communities by enhancing the quality of housing. The new POS concept generated by the Project will serve both as an "urban oasis" that brings prosperity and well-being to urban residents, and a "mitigation spot" that aids cities in coping with climate change challenges. RePOS is expected to result in the improved urban planning approach to (re)creation and scaling-up of the created model of POS in residential areas across Serbian cities.

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[7] The cooperation between the City and the Faculty was first established in 2000's, included different topics and continued throughout the years.

[8] The idea was carried out by engaging the students of the IX semester of integrated academic studies of the study program Architecture, within the elective course *Urban design and composition*. Under mentor supervision, the students performed the analysis of standing planning documents and existing state, identified user's needs by conducting a survey and interviewed key actors in the area (tenants, users, local administration), and finally proposed urban design for the explored sites.

[9] The RePOS project's Principal Investigator is Milena Dinić Branković, Associate Professor.

4.3. DISCUSSION: POS CHALLENGES AND POTENTIALS

POS in residential environment in the City of Niš do not fulfill their potential. In light of the analyzed plots of POSs, which are acknowledged in the Plan of General Regulation of the City Municipality Medijana [9], it can indeed be stated that a significant portion of this land has the character of POS (shared recreational spaces and green areas). Some plots or their parts are occupied by parking lots to a large extent, and consequently, these areas cannot not be associated with the term POS. They, however, have the potential to become quality POS on the grounds of their treatment in the planning document, their ownership status and their overall character.

Most of the challenges in providing quality POS in the City of Niš are actually related to the treatment of POS in legislation at the national level, and the failure to recognize the concept of "public open space". Particularly, undeveloped land and green areas in residential zones that are located on "other land" (non-public land) represent a major challenge for the City of Niš. Since they are not considered "areas of public use" by Law, they cannot be managed by other actors (city institutions, private companies), except for the inhabitants themselves. This is a crucial point for their quality, maintenance and usage. Unclear management regime of open spaces in residential environment, and the lack of precise instruction on both rights of use and duties involving this land and multiple stakeholders, all result in frequent disputes between the City and the residents.

The other important impediment for the sustainability of POSs concerns limited financial recourses. In the City of Niš, there are no stable sources of funding, nor sufficient human capacity for efficient organization of POSs and financing their arrangement and maintenance. Local self-governments in Serbia, including the City of Niš, mostly deal with the arrangement of public parks, squares and streets only, which are publicly owned, in line with the limitations of their budgets [14]. They do not have enough resources to invest in the arrangement of other spaces that do not represent areas of public use, but have the character of POS. It is therefore necessary to identify all public spaces in the City of Niš - both those that are in public ownership (areas of public use), and all other public spaces that are used by the everyone, regardless of sex, age or other limitations.

Analysis of other areas of multi-family housing within the Medijana territory, which was performed in the Office of the Chief Urban Planner of the City of Niš, revealed other potential POS sites. These residential open spaces have similar urban settings as the analyzed POS plots in the Plan of General Regulation of the City Municipality Medijana [9], but were not acknowledged by this Plan. Therefore, areas having the character of POS in City Municipality Medijana need further exploring, in order to be accurately defined. Equally important, data on POSs in other City Municipalities remains to be collected in the future, to establish a valid database of residential POSs in the City of Niš.

An additional problem for POSs in Niš is the low social and environmental awareness of citizens, who often do not accept responsibility for arranging, preserving and improving POSs in their living environment. This disregard for the extended living environment often results in neglected and devastated spaces in the immediate surroundings of residential buildings.

Although existing POSs in Niš are accessible to all regardless of age, gender, ethnicity or socio-economic status, not all population groups may feel comfortable in using them. Recent research performed by the Center for Girls investigated the safety of women in public places in Niš, within the project *SAFE: Empowering girls and women to feel safer in public places in Niš*, supported by UN Women [19]. The results show that as many as 51.9% of respondents feel moderately safe in public places in Niš, while only 6.6% of them feel completely safe. When asked in which public places they do not feel safe, the respondents singled out Tvrđava (52.7%), quay of Nišava River (47.7%) and the bus station (44.8%) as the most unsafe public places. Poor lighting is often identified as one of the main causes of discomfort and unsafety in POSs. This is often the result of insufficient maintenance of POS, particularly of the lack of financial resources.

The residential open spaces explored in this research could be revitalized to accommodate recreation and social interactions, and become quality POSs. POS types in an open system have the greatest potential to contribute to quality public spaces because of their conceptual layout and accessibility, regardless of their size. These spaces have high levels of publicity and may accommodate various activities to serve the neighborhood unit or a residential complex. POSs in a semi-enclosed system of spatial organization also provide good accessibility to users from a wider residential area. Aside from local community, semi-enclosed POSs of larger scale (over 4,000 m^2) may also serve the entire neighborhood unit and have a very public character. On the other hand, enclosed residential courtyards appear to be better suited to smaller user groups - the residents of particular buildings framing that open space. Therefore, these POSs often result in a shared space for residents only, with semi-public character, even though they do not restrict access to a wider audience. Some

enclosed courtyards may become Community POSs, serving the users beyond that urban block, but this requires larger plot area.
Regarding the progress in achieving the SDG 11 related to public space, the City of Niš has invested significant efforts in cooperating with the civil sector and academia, particularly regarding the treatment of POS in multi-family housing areas. In spite of institutional efforts in the last decade in the City of Niš to raise awareness on the significance of POSs, and enthusiastic projects created, not much has been done concerning POS revitalization in the field. Lack of financial resources and lack of effective planning instruments have delayed the actual implementation of revitalization projects.

5. CONCLUSION

Public space is a vital component of urban fabric that greatly contributes to the overall quality of urban life. Particularly, POSs in residential zones have an important role because they help to build a sense of community, mitigate adverse effects of natural hazards and create healthy and safe living environment. This paper explored the topical issue of POS, as key resource for sustainable local communities in the City of Niš.
In line with the first research aim, all the challenges identified in this study point towards the fact that the issue of POS must first be regulated at the national level by the fundamental law in urban planning, design and construction, as well as by accompanying regulations [14]. This is especially important for the identified open space in residential zones.
Regarding the second research aim, the results provided an overview on the current state of POSs in the territory of the City of Niš, and identified several potential types of POS in residential areas. It can be concluded that the City is still faced with many challenges in treatment, exploitation and maintenance of POSs. Therefore, POS revitalization should be the priority action for the immediate future. Revitalizing existing POSs in the City of Niš in order to become social and recreational focal points requires significant efforts on part of multiple stakeholders, including the local communities. This would also imply new allocation of duties and responsibilities amongst the stakeholders, additional sources of funding and new management solutions. POS typologies established in this research should help with this complex task. When allocating POSs throughout residential fabric, the planning documents could benefit from the established links between spatial, functional and morphological characteristics of residential urban blocks containing POSs.
Local initiatives presented in this research confirm that there is strong commitment of local authorities to address the issue of POSs in residential environments, but their options for action are limited. The possibilities at the local level for acting in current circumstances involve potential cooperation of the City with investors on the arrangement of POSs, by motivating them and obliging them to improve also the environment of newly constructed structures (through tax benefits, benefits in obtaining a building permit, square footage bonuses, etc.), and developing local regulations that would support such mechanisms.
Further POS studies should build on the established typology in order to create a comprehensive database of public spaces that could be used for upgrading POS treatment in legislation. Given the number and significance of residential open spaces within the system of POSs in the City of Niš, it is necessary to urgently develop POS revitalization model, which is expected to be accomplished through the RePOS Project. Finally, as a key process for advancing SDG implementation at local level, the VLR of the City of Niš has acknowledged the role of POS in developing inclusive, safe, resilient and sustainable local communities, thereby providing good grounds for a systemic and planned POS revitalization action.

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22

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RESEARCH BY DESIGN – FOSTERING STUDENTS' CREATIVITY BY IMPLEMENTATION OF WORKSHOPS IN ARCHITECTURAL EDUCATION

Abstract

Social, cultural, and economic aspects of contemporary architecture emerge in a variety of architectural and artistic works, together with theoretical and experimental research, which leads us to the rethinking of traditional teaching methods. This paper examines the possibilities of new formats for teaching architecture, which are relevant and attractive to students and could bring new approaches to education. This article describes the implementation of the "research by design" method of teaching architecture based on different multimedia projects. The new approach to teaching design should stimulate creative processes that could guide students to develop their creative skills by choosing their medium of expression following personal character and sensibility.

Keywords: architecture, design, research by design, teaching, higher education

ИСТРАЖИВАЊЕ КРОЗ ДИЗАЈН - САВРЕМЕНИ АРХИТЕКТОНСКИ СТИЛОВИ УЧЕЊА

Сажетак

Друштвени, културни и економски аспекти савремене архитектуре доводе до појаве мноштва архитектонских и умјетничких дјела, заједно са теоријским и експерименталним истраживањима, што нас доводи до преиспитивања традиционалних метода наставе. Овај рад испитује могућности нових формата за наставу архитектуре, који су релевантни и привлачни за студенте, а који би могли да донесу нове приступе у образовању у цјелини. На неколико примјера различитих пројеката, приказана је имплементација методе "истраживање кроз дизајн" засноване на различитим мултимедијалним пројектима у оквиру редовне наставе на основним студијама архитектуре. Нови приступ дизајну наставе требало би да стимулише креативне процесе који би могли да наводе студенте да развију своје креативне вјештине избором сопственог медијума изражавања у складу са личним карактером и сензибилитетом.

Кључне ријечи: архитектура, дизајн, истраживање кроз дизајн, настава, високо образовање

1. INTRODUCTION

Contemporary social context in which architects live and work demands a change of classical principles of education in architecture. The new social and cultural frames, as well as the fast technological development, represent the field that opens the possibilities for a broad spectrum of architectural practices, at the same time requiring different approaches in problem solving within architecture, and an examination of multi-layered character of the solutions. In these circumstances, teaching in the field of architecture is faced with dilemmas about the ways in which it is possible to establish new methods of work with students and introduce new formats of research in the domain of creative disciplines. Without a doubt, a special attention must be given to the simultaneous knowledge acquisition and development of original ideas through the teaching process in the courses where creativity is one of the most important elements for finding the solutions to the given problems. Numerous authors agree on the importance of the applied methods in the educational process in architecture, pointing out the significance of the education itself and stating different ways of stimulation of creativity in students [1, 2], along with the dilemma on the possibilities for changes that might be made to the discipline of design education and their effects within the higher education system [3].

Regardless of the curriculum of architectural studies, there is a common stance that in architectural education the main objective is to help students, especially first-year students, to improve their design ideas, creativity, perception of three dimensions and ways of expressing them [4]. However, the individual syllabuses provide teachers with possibility to select some specific formats in accordance with their own ideas, understandings, and work methods, which will support the students' development of creativity and thinking. Therefore, when defining the syllabus, one should take into consideration that "creative learning relies on experiential, often intuitive, contextualized judgements which are applied to complex, heuristic tasks- whether for internal or external verification" [5]. It is undoubtably that contemporary teaching of architecture and work with students should be conducted through a diversified and non-manipulative discourse on all levels of architectural work, and numerous educational and research processes. This approach is confirmed by the opinions of the authors who claimed that the change in design education should be addressed in the context of a newer paradigm based on the recent development of complexity theory. Such changes would include rethinking the epistemology of design, becoming more aware of the systematic processes of design, and incorporating multidisciplinary approaches to design projects and activities [3].

The advantage of this approach in teaching architecture is recognized at the Department of Architecture and Urbanism of the Faculty of Technical Sciences in Novi Sad, allowing working with students to be defined in accordance with current topics in the field and adaptable to modern teaching methods. Such modifications compared to the usual way of working with architecture students are covered by a global project common to the entire Department, which includes improvements in teaching as well as in the scientific and artistic segments of work. In this sense, the general objectives and outcomes of each specific course that is accredited within the study program could be precisely defined each year, followed by the methodological procedure chosen with an aim to achieve the desired learning outcomes. In this regard, each teacher can develop a workshop within the course in accordance with the syllabus. All the three students' workshops presented in this paper were part of the teaching process and represent the way in which students went through the learning process by exploring the given topic and then providing their own view of the problem, followed by several presentation steps and their own architectural representations throughout the semester and in the final exhibiting event. Each year, the process is adapted to the new generation and current global topics and trends in architecture, so that students also have a sense of belonging to contemporary architectural practice as well.

Thus, this article represents the way in which the new approach in teaching of design has been implemented, though a multimedia student projects at the first year of architectural and scene design studies. The method "research by design" represents a broader concept that involves both "research through practice" and "research about practice". Through this educational approach, students of architecture worked on developing their competences and creativity through a direct contact and cooperation with their peers. They were free to choose their own way of expression in accordance with their personal character and sensibility through an interdisciplinary approach to the spatial design.

2. CONTEMPORARY APPROACH IN TEACHING ARCHITECTURE – "RESEARCH BY DESIGN"

The introduction of new methods and formats in the tuition of architecture, presents the lecturers with a sensitive question of the approach to students and development of their creativity, which is a "tangible thing", easily identified and quantified [1]. Starting from the fact that contemporary architecture is not only the building practice, but also a creative process that interlaces theoretical and practical work, the research in this discipline is to provoke several dilemmas and solutions, which need to be articulated and applied. The various changes brought about by the 21st century determined a multimedia character of this discipline and influenced a reassessment of the existing educational processes. The approach to the teaching of architecture which will no longer be oriented exclusively towards the creativity itself that we are teaching or demonstrating, "but rather the ways in which the creative process or creation of works may be fostered through a range of acts, discussions, explorations and exposure to new ideas" [1, p. 153], stands for the contemporary context in which the curricula are developed. The acceptance of complexity theory in the education in architecture, should transform student projects from the simple problem solving one to "an open-ended process of discovery yielded by assuming the educational process as a whole with creatively emergent potentialities" [3, p. 178]. This enables an architectural education where learning is a continuous process in which knowledge is generated through a transformation of the experience [6].

Following the recommendations on the qualities of higher education given by the relevant institutions (European Association for Quality Assurance in Higher Education – EAQUA, European University Association - EUA) and the results of the research on learning styles in architecture [7], a method of "research by design" has been introduced, besides the classical methods of teaching in architecture, in the courses at the first year of undergraduate studies of architecture at the Faculty of Technical Sciences, University of Novi Sad. This new method has an important role in the work with students and includes any kind of inquiry in which the architectural design process opens the possibilities for new experiences, knowledge, practices, or products, generating a critical inquiry through the design work. This concept of teaching also encompasses a theoretical framework, which is necessary for the realization of tasks and reaching the aimed educational outcomes. The emphasis is on the active and experiential learning, cooperation, and interactive instruction. Starting from the socio-cultural demands of the architectural practice, this coursework provides students with a multidisciplinary approach and an insight into the possibilities of a non-traditional exploration within the architectural design.

This active exploration within the teaching process which is entirely empirical is increasingly becoming the subject of contemporary research and architectural and scientific criticism, which examine its relevance and scientific character, thus confirming the needs for contemporary design education to aim at "enabling students to identify their own areas of interest and to develop understanding and skills particular to design" [4]. The students explore and explain the problem through a dynamic interaction, thus gaining the knowledge through their own experience. Through this format of work, they are enabled to gain the knowledge both by theoretical research and learning, as well as through getting familiar with the architectural practice. The active learning is based on the students' personal experiences, through which they develop an understanding of the surroundings, and on the new knowledge, which provides a progress in their competences. The pedagogical benefits of active learning are based on its intellectual stimulation which maintains the motivation and the interest through the development of the many skills necessary for organization of activities, interaction, and communication with peers, with a continuous progress and a positive attitude towards the learning subject, while following the work together and discussing the actions and strategies [8].

"Research by design" is a contemporary and nontraditional form of teaching and working in architecture, which integrates the traditional and the new elements of contemporary architectural practice and entails the existence of a theoretical framework where the research takes place. Nontraditional research forms refer to the "art-based research or practice-based research, which must be comparable to the classical scientific methods" [9, p. 9]. If architecture is seen as an artistic discipline, it becomes clear that this type of empirical research "has a label of creativity which suggests that the research itself and the researcher have to perform creativity when defining the topic, research questions, analytical methods, etc." [10, p. 4].

The implementation of this method implies the organization of creative workshops, which are part of the teaching method, and point to the importance of the creative process for the result. Numerous experiences of learning in architecture confirm that the workshop provides a framework that enables ideas to be explored and pass freely between participants within the studio environment, as well as the possibilities for discussion about ideas. It is confirmed that this process rises from the exchange of tacit knowledge between workshop participants, student peers and tutors [11]. The workshops are based on the tradition of the architectural studio that is derived from the "atelier system of the education of architects at the École des Beaux-Arts in nineteenth-century France" [12, p. 349]. Students in architectural studios work in proximity and the environment is intensively socialized [3, p. 176].

This way of education has been conceptualized with the aim to stimulate the cognitive development (learning in its broad meaning), from gaining and acquisition of factual knowledge to the stimulation and development of higher intellectual processes (judgement, conclusion, problem solving, etc.). The importance of group work, where the students exchange the ideas, opinions, and answers to the posed tasks through the supportive evaluation and debate, is based also on the social aspect of developing creativity in design that involves seeking and giving peer feed-back, which is integral to the creative practice of designers.

3. THREE DIFFERENT WORKSHOPS – ONE TEACHING METHOD

For alteration of usual methods used in the process of teaching architecture, students were introduced to the "research by design" on the first-year course in the study programme of architecture. Al three workshops were organized within the course "Introduction to Architectural Design" at the first year of bachelor studies in Architecture. The aim of this course is to develop the ability to think, observe, understand, articulate, and represent space, as well as to enhance awareness of the complexity and multidisciplinarity of architecture as a discipline. Through various tasks, students are expected to broaden their perspective of architecture as a field and profession, and to familiarize themselves with the creative processes and potential outcomes of contemporary architectural practices. The course outcomes include the ability for individual and team creative exploration and expression, the capability for further and deeper study of architectural topics, and the application of acquired knowledge within other subjects. Throughout the course, students should become acquainted with the concept of architecture, the principles and forms of architectural creation, contemporary architectural practices, means and media of expression, elements of graphic, web, and stage design, as well as the relationships between architecture and events.

Each year, students within workshops were divided in smaller groups, to provide the unique and intense experience of the interactive work in the group, which holds significant didactic values and presents better learning outcomes than in the classic, ex cathedra tuition. The teacher's role was a mediator who establish the process of interaction between the students and enable them to conduct the research, realization, and presentation of their works, individually or in small groups, without influencing the final character of the student projects with his or her authority. He presented the task- project brief, which the students are to solve by applying the previously conceptualized steps and techniques within a given timeframe and spatial delimitation, to realize their ideas. The aim of such workshops was to stimulate the participants to challenge the traditional definitions of architecture, and to examine the contemporary practice from the aspects of perception and understanding of the space. The workshop activities start with a given thematic framework, which is transformed from an abstract image into a spatial model over time, through the research on formal structures, showing how the spirit of the times together with the atmosphere of the ambience and the moment, with personal narratives and experiences can be shaped into the three-dimensional material forms. Within each below shown workshop, the assigned topic initially involved researching a specific location in the city. Subsequently, the problem was analyzed and addressed through various forms of work during the course, and finally presented again at the site itself, which was the subject of contemplation.

In this work format, it is necessary that the participants perform flexibility, willingness to change and adaptability to each new idea and situation. The task for the teacher as the mediator of the entire process is to introduce the topic and the problem in a way that provokes the students' creative research and imaginative reaction. The principle of particularity of the topic, problem, location, timeframe, group structure, etc. can have a positive influence on both the process and the result, which does not necessarily have to be limited to the graphic and written form but should be founded on the sensory experiences. The values of such a work method are also confirmed by the pedagogical concepts of John Dewey, who stated that "learning is experiential, more a matter of exploration than of attainment" [3, p. 175].

3.1. "TOWARDS EU, BY THE BOULEVARD?' – RESEARCH PROJECT, WORSKOP AND THE EXIBITION

The concept of the students' project at the first year of architectural studies, at the course "Introduction to Architectural Design", came out of a consideration for a wider context marked by a continuous technological and technical advancement, characteristic for the beginning of the 21st century. The starting point of the project was the questioning of the traditional thinking that architectural practice encompasses solely design and building. At the same time, the processes, and ideas in the architectural practice on the global level were set as a challenge to the students of architecture, to question their ideas about the phenomenon, which was set by Aaron Betsky as a thematic framework of the 12th International Architecture Exhibition in Venice. He invited the authors from round the world to respond to the topic: "Out there: Architecture Beyond the Building", thus examining the everlasting question of whether architecture is merely the common practice of building or also a philosophy, way of thinking, an experiment, theory, or all these together - too complex a phenomenon to offer a single answer. The project "Towards EU, by the Boulevard?" was conceptualized as a multi-layered research work, derived from the need for a deeper exploration of the limits of architecture, in which, starting from the theoretical base, the innovative research processes are developed, while the results, presented as an exhibition in a public space, were exposed and accessible to the public. The aim of the project was to, by initiation and organization of a range of events, encourage the creative process in which every student, and the spectator, can develop their individual creative abilities in the appropriate spatio-temporal context, without presumptions on the outcome of the process.

The thematic framework of the research encompassed the students' research on the problems of space, society, and politics, hence the architecture. The socio-political reality represented the context in which the students examined the questions of Serbia's accession to the EU, the future shaped by that process and decisions, along with many other topics that the students set to themselves and their peers, which were present in their works, directly or indirectly. A careful selection of the spatial context for the project realization influenced the thematic deepening of the research, consequently contributing to the complexity of the responses to the given topic. For the most significant, final activity of the course work- the public exhibition, the freight train servicing hall "Kolnica" was selected, a part of the railway marshalling station in Novi Sad, designed in 1911, which belongs to the protected architectural heritage, with the aimed future purpose as cultural institution. The entire complex is located close to the newly built Boulevard of Europe, which was conceptualized as a physical connection of Novi Sad and the European Union.

The project of experimental character was conceptualized as a workshop in which different teaching methods were applied (method of experiential learning, cooperative method, problem-focused method), during a weeklong period. On the first day, all the students were divided into 29 groups with four to six members. This method of work could be named "programme within the programme" or "work within work", since besides enabling the work on a particular project, in this case a group spatial installation, it gives students the possibility to direct the entire exhibition, i.e. the concept of each group work influenced the flow and the form of the entire exhibition, where they developed the organizational skills alongside with the creative ones. The problem which prompted the authors to conceive the work in a different way is, in fact, an exploration and formation of a personal statement regarding the transitional period in which the country was at the moment, as well as the globalization and the processes in the context of the EU integrations.

Working on the project for a week, establishing the creative connections with the existing ambience and the surrounding space, using different technical and expressive means, within a few hours on the last day of workshop, the students realized several authentic spatial, interactive, light and auditive interventions, expressing them in different ways- by spatial installations, photos, videos, or texts. It can be concluded that the result of this project was a multi-layered, visually impressive work- provocative installations as a response to an even more provocative title. From suggestive and subtly ironic, to the comical ones, the individual works evoke the thoughts on the segment of a social and historic setting though their (non)architectonic character. Every installation examines, poses questions and provides the possible answers about the contemporary architecture, industrial heritage, and the uncertain future of the society we live in. All the works were created as an artistic practice in situ, which allowed for a closer contact with the location, the architectural form of the exhibition space, its history and future.

The individual student works, set in specific aesthetic and conceptual interrelations, were presented for the first time at the final exhibition, which was a work of art in itself. All the groups had a common spatial and thematic framework, from which they developed the different concepts as representations of the idealized future and reflections of the public opinion. The narratives and communication of the exhibition influenced the perception and experiencing both individual works and the entire exhibition. The works of the 29 teams- the utopian visions, installations, films, and performances- represent a multimedia collage, as a range of experiments, which in an informal way examine the new methods in architectural education. The diversity of students' attempts to provide the answers to the existing space and the questions on the directions in which we are moving (in a metaphoric sense), can be labeled as nontraditional and unconventional for the common architectural practice and education. At the end of the exhibition, the student installations were evaluated by a jury, consisted of professionals from different areas of architecture and arts.

Figure 1. The final activity of the work - the public exhibition in the"Kolnica", a part of the closed railway marshalling station in Novi Sad.

3.2. ABOUT SPACE (...) POINTS EXPRESSED IN THE LANGUAGE OF ARCHITECTURE - RESEARCH PROJECT, WORSKOP, VIDEO WORK AND THE EXIBITION

This workshop was organised within the course „Introduction to architectural design" at first year of architecture studies at the Faculty of Technical Sciences. During the study process in the semester, students went through five phases of the project. During the four months of work, using various media means: text, photography, performance, spatial model, and video, they explored the basic issues related to space, but also the language of architecture. With photographs, they marked the character of the spaces in Novi Sad, their presence in specially selected ambiences, the moments of a one-day workshop, their models as spatial answers to the task, as well as the exciting moments of the one-hour exhibition organized at the open space on Belgrade Quay in Novi Sad.

The first step was to explore the real spaces in Novi Sad in groups of 25 students, and the entire framework has been developed from the theme of the Venice Biennale topic called "Common Field". In the local framework of student work, the "common field" was defined in the context of the identity of the city consisting of the Danube, the riverbank, and the Danube Street. In relation to these elements, another 6 surrounding streets were defined, with views to the Danube River. All chosen streets were created at the beginning of the 18th century, and have different characteristics and morphology, following the development of Novi Sad until today. They represented totally different character compared to the Belgrade quay that was created in the middle of the 20th century.

The second step in the work process followed a detailed multi-layered survey of selected 6 streets. The task for students was to position their own identity of the group in which they worked (4-5 students) in real spatial frameworks that they defined and recognized as close to their own expression through the previous step. The means of expression was photography, so for each street there were 4 completely different ways, approaches, and representations of personal identification. The inclusion of the personal attitude in this step contributed to the deepening of the experience of space, and a better approach to the next step.

The third step was the central theme of the process and took place in the form of a workshop, where all students participated together, again divided into previously defined smaller groups. The task was related to the previously defined state on the space (the street they analysed) that they expressed through a spatial installation measuring 50x50x50 cm, using all available materials. It was not necessary to show the real space, but their thinking, attitude, idea, and experience about the chosen space. The way of presentation also represented the students' reaction towards certain aspects of the real space, which was clearly visible through the photographs of installations made at the end of the workshop.

Figure 2. The third phase in the project "About space" that took place at the Faculty of Technical Sciences in the form of a workshop with all students.

The fourth step was to show in the form of flyers the entire process of analysis and thinking that the student went through from the exploration of real space to their thinking about space, again working within small groups, using text and photography as a means, trying to show their own thinking process as clearly as possible. The final step in the process was a joint public exhibition on the Belgrade quay, opposite the Petrovaradin Fortress as the landmark of the city, with the aim of opening a potential dialogue with passers-by. Through the exhibition, a synthesis of space was realized, which was the starting point of all phases of work, students and their attitudes about space and the whole process as a single system of thinking, including the public as observers. By two media, the entire process of work was recorded and shown (as a video work and as a spatial installation of photographs), and then presented as part of the event "Eye of Architecture".

Figure 3. Joint public exhibition on the Belgrade quay, opposite the Petrovaradin Fortress.

3.3. SUBURBIUM - THE SUBCONSIOUS OF THE CITY, RESEARCH PROJECT AND THE EXIBITION

The research project related to the Lower town (*Suburbium*) of Petrovaradin fortress was also one in a series of projects developed within the regular teaching in the subject "Introduction to Architectural Design" at the first year of architecture studies. The main characteristic of this project, as well as previous ones, is that it had two phases. The first one involved the development of the teaching process by applying various educational formats designed to deepen the research of current topics of contemporary architectural practice. The second one involved defining of a possible type of presentation appropriate to the presentation of the achieved outcomes of the students' work, and then the final design of the complete event.

The teaching process for the project was carried out during the semester. Starting from the theme of the Venice Biennale of Architecture "Fundamentals", it was placed it to the oldest part of Novi Sad – The Lower town of the Petrovaradin fortress as the local context and the spatial framework for the development of ideas. After a detailed analysis of the available information and documents about the selected area, the final topic for the project was formulated. The work process proceeded in several stages. The first step involved the deployment of 120 students within 24 teams. After that, the process of initial acquaintance and research of the suburban area began, as well as the discovery of possible interpretations of the defined topic through a physical, historical, and sociological context. The next step involved defining a common position on the set topic, and then choosing the technical and expressive means that best illustrates the creative concept of each team. Using photography, models, catalogue, video, spatial and sound installation, and performance as a means of expression, students presented their impressions on the oldest part of the city, its history, but also possible directions of development.

The second step involved exploring the potential of certain types of events suitable for presenting the outcomes of the teaching process to the professionals and public. In this context, an exhibition of photographs in the form of an ambient installation in the house of Ban Jelačić in the suburbs of the Petrovaradin fortress was designed. The concept of the event implied a directed walk of visitors through the exhibition space enabling direct acquaintance and experience of the two spatial levels shown in the photos. The first level of real space was recorded in photographs that carry the sensibility of the author and his spontaneous feeling and initial way of perceiving the ambience. The second one refers to students' photographs of final works that have shown more deeply their thoughts and attitudes about the space and phenomenon of the suburbs of the Petrovaradin fortress. By bringing into direct physical connection photographs of these two levels, the observer, as well as students during the research process had the opportunity to briefly experience, but also understand many peculiarities of life in the complex and multi-layered space of the Lower town area of the Petrovaradin fortress. The ambient installation, as well as the exhibited works illustrated the view that the multimedia of architecture is implied today, as well as that creative forms of teaching of a research character can contribute to the formation of the architect as a creative personality within a wider social context. In addition to this specificity, the ephemeral character of the exhibition lasting two hours suggests changeability, which is one of the basic characteristics of space, and therefore architecture as a discipline today.

Figure 4. The exhibition "Subconscious of the city".

4. CONCLUSION

The interactive educational processes, creative workshops and research through the project were aimed at improving the traditional tuition by the introduction of new, contemporary contents, through a range of multimedia projects and visual research in the context of education in architecture. By this approach and the introduction of new teaching methods, the educational programme at the studies of architecture has been improved and updated, at the same time pointing to a wider field of action of architects and architecture. The results of all workshops were presented at public exhibitions, which were specially prepared by the teachers for the exhibition, specifically designing the whole way of presenting the process. The presentation of results of the students' research in a public space which is not only of a gallery type, allowed for the public to become familiar with the educational activities of the Department of Architecture and Urban Planning of the Faculty of Technical Sciences, University of Novi Sad, as a possibility of using a space which belongs to industrial heritage for the purposes of education, culture, and arts.

Within the framework of all abovementioned projects, it has been confirmed that architecture has a multidisciplinary character, and that the students of architecture can use "research by design" method for solving design problems through an experimental approach in their learning process during the first semester of the education. This approach can be altered each year with a new conceptual framework, with the aim of assisting students in acquisition of design competences, in both theoretical and practical terms. The results of this approach, regarding the improvement of the higher education, stimulate the ideas of the active student participation in the educational process, with an emphasis on learning though exploration, as in this way they create new experiences and gain new knowledge. Considering the entire creative process, we can conclude that the implementation of "research by design" in creative disciplines in the initial educational stage may provide students with a solid basis for the development of creative thinking and creative work. Besides, the outputs of students' research, formed in different and untypical formats, confirm that the extended field of action of architects is followed by the new means of expression and the architectural practices which are based on the development of personal potentials, revealed, and developed by the influence of research projects.

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23
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STEPGRAD
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THE PHENOMENON OF ATMOSPHERE IN ARCHITECTURE

Abstract

This paper explores the phenomenon of atmosphere in architecture, highlighting its increasing relevance in contemporary theory and practice. By analyzing various perspectives, it investigates how atmosphere is experienced and created in architectural space. The research aims to deepen the understanding of this phenomenon through theoretical analyses and practical approaches, with the intention of enhancing the methodology of architectural design. The combination of theoretical and qualitative methods allows for a diverse examination of atmosphere as a key aspect in the construction of architectural quality, contributing to both the theoretical and practical fields of architecture. These studies emphasize the significance of atmosphere as an integral part of architectural experience, offering new perspectives in the study and design of spaces.

Keywords: spatial-emotional phenomenon, sensory experience, atmosphere generators

ФЕНОМЕН АТМОСФЕРЕ У АРХИТЕКТУРИ

Сажетак

Овај рад истражује феномен атмосфере у архитектури, истичући његову све већу актуелност у савременој теорији и пракси. Анализирајући различите перспективе, истражује се како се атмосфера доживљава и ствара у архитектонском простору. Циљ истраживања је дубље разумијевање овог феномена кроз теоријске анализе и практичне приступе, с намјером унапријеђења методологије архитектонског пројектовања. Комбинација теоријских и квалитативних метода омогућава разноврсно сагледавање атмосфере као кључног аспекта у грађењу квалитета архитектуре, пружајући допринос како теоријском, тако и практичном пољу архитектуре. Ова истраживања наглашавају значај атмосфере као интегралног дијела архитектонског искуства, остварајући нове перспективе у проучавању и пројектовању простора.

Кључне ријечи: просторно-емоционална појава, чулно искуство, генератори атмосфере

1. INTRODUCTION

This study deals with the concept and phenomenon of atmosphere in architecture. It examines the characteristics of atmosphere in architecture, which is realized in the encounter between subjective experience and the immediate reality of architectural space. Atmosphere as a spatial phenomenon in architecture has become prominent in the last 30 years. The evidence of the current interest and pursuit of understanding and defining the phenomenon of atmosphere is visible both in the practices of contemporary architects and artists and in the growing literature addressing this issue, which constitutes the motivation for this research aimed at better understanding this current topic. As a result of the conference entitled "Atmospheres, Architecture, and Urban Space: New Conceptions of Management and the Social," held in Copenhagen in 2011, the book "Architectural Atmospheres: On the Experience and Politics of Architecture" [1] was published. The Dutch architecture journal OASE dedicated issue 91 in 2013 to this topic, titled "Building Atmosphere." [2]

In this study, the exploration of the phenomenon of atmosphere in architecture primarily relies on the contemporary research of three authors: the German philosopher Gernot Böhme, the architectural theorist and lecturer Juhani Pallasmaa, and the Swiss architect Peter Zumthor. Philosopher Böhme addresses the topic of atmosphere in a broader cultural sense, and of significant importance is his systematic translation of the concept of atmosphere into architectural discourse. The two architects who predominantly engage with the phenomenon of atmosphere in architecture, Pallasmaa and Zumthor, approach this issue from different research positions. Pallasmaa remains within theoretical frameworks, enhancing his long-standing phenomenological approach to architectural research with this concept. Zumthor, an architect-builder, primarily approaches the phenomenon of atmosphere through practice and through the analysis of his design approaches. However, it is evident that all three authors primarily utilize the concept of atmosphere to emphasize the general emotional impression associated with the entire building or some of its fragments.

The main goal of the research is to define the phenomenon of atmosphere in architecture as a spatial-emotional phenomenon through the analysis of key theoretical premises, as well as to consider how atmosphere is constructed in architectural practice. Additionally, the aim of the study is to point out possibilities for improving the methodology of architectural design in the context of constructing the phenomenon of atmosphere as a quality of architecture, as defined by Zumthor.

The research methodology in this study relies on theoretical and qualitative research. In the first part, the research is primarily positioned in the field of architectural theory. To explore the phenomenon of atmosphere in architecture, an overview is provided of the understanding of the atmosphere phenomenon, as a spatial-emotional phenomenon according to the interpretations of Gernot Böhme and Juhani Pallasmaa. In this way, a broader basis for interpreting concepts related to atmosphere is established, aiming to create a clearer picture for further examination of atmosphere generators in architecture. The second part of the study presents qualitative research, which is based on the analysis of examples of constructing the phenomenon of atmosphere in the work of Peter Zumthor, based on his design principles. In the concluding part of the study, a final discussion is formed based on the research findings, aiming to indicate the usefulness of establishing possibilities of principles and methods of constructing atmosphere, in order to expand the field of design strategies.

The results of the study relate to theoretical knowledge about the phenomenon of atmosphere in architecture and the possibility of practical application of knowledge in the field of architectural education and in the design practice. The methodological contribution pertains to expanding the possibilities of the methodology of studying architectural creation and design processes through the analysis of atmosphere as a spatial quality. The research represents a contribution to the methodology of architectural design by pointing out the importance of considering opinions and conceptualizations of atmosphere in architecture.

2. THEORETICAL FRAMEWORK

The primary intention of this section is to theoretically elucidate the phenomenon of atmosphere in architecture, its significance, and its role in shaping the experience of architecture and its qualities. Christian Borch, a professor of political sociology with an interest in architecture, notes: "One of the most significant recent trends is a turn towards (or perhaps a return to) atmospheric qualities in debates on architecture and urban space, as well as in practical architectural work." [3] The architectural theorist Mark Wigley, as early as 1998, in his essay "The Architecture of Atmosphere," [4] observed a lack of attention devoted to the phenomenon of atmosphere in architectural discourse. According to his observations, the concept of atmosphere is associated with something ephemeral and personal, something that is difficult to define and analyze, and even more challenging to create. Yet, he also emphasizes that it constitutes the essence of architecture.

A key figure in the field of atmosphere theory is the philosopher Gernot Böhme. In his framework, the theory of atmosphere becomes an aesthetic theory applicable in various domains, as discussed in the book "The Aesthetics of Atmospheres." [5] According to his theory, the phenomenon of atmosphere in architecture connects objective factors and spatial constellations with subjective bodily sensations and experiences of that space. In his view, atmospheres are quasi-objective, in the sense that we can be enveloped by an atmosphere, but they do not exist without the subject experiencing the atmosphere. Therefore, Böhme considers the phenomenon of atmosphere as a tuned space, or a space with a particular mood. Simply put, the phenomenon of atmosphere is something that is simultaneously spatial and emotional. He emphasizes two basic approaches to the theory of atmosphere: one can approach the atmosphere not only from the perspective of the aesthetics of perception but also from the perspective of the production of aesthetics. By providing comprehensive interpretations of atmosphere as a phenomenon in architecture, this philosopher has opened up possibilities for implementing this phenomenon in architectural practice, translating it from philosophical to architectural discourse. Of particular importance in this regard is his book "Atmospheric Architectures, The Aesthetics of Felt Spaces." [6]

The first to establish a relationship between the phenomenon of atmosphere and theories of perception was the German phenomenologist Herman Schmitz. In his theory, perception represents an affective and connecting participation, and atmosphere is interpreted as spatial carriers of mood and, as such, possesses motivational and emotional power. [6] Following in his footsteps, the philosopher Gernot Böhme, as mentioned, revitalizes the phenomenon of atmosphere in the context of architecture. Böhme, as stated in the introduction of the discussion, defines atmosphere as a space that contains mood and emotion because, according to his view, emotions are not only within us but can also be external, something that envelops us. From this perspective, space can be imbued with a certain emotion, and that is precisely how he defines the spatial character of atmosphere. Referring to Schmitz, Böhme calls the phenomenon of atmosphere an entity, a quasi-object; in other words, he sees that the phenomenon of atmosphere in architecture can be interpreted as a personal and emotional impression of space, but one that is based on and connected to the objective properties of space, such as composition, materials, spatial dimensions, material connection with the place or other objects, rhythms, lighting, etc. Thus, the concept of atmosphere is defined as a total experience, although it is determined by heterogeneous constitutive elements and many aspects. The introduction of the term atmosphere, as Böhme concludes, leads to a redefinition of the art of architecture in terms of creating space as bodily presence. [7]

Finnish architect and architectural theorist Pallasmaa has made a significant contribution to the theory and practice of architecture grounded in phenomenology. In his essay "Space, Place and Atmosphere: Peripheral Perception in Existential Experience," Pallasmaa defines the phenomenon of atmosphere as a spatial quality that provides and emphasizes sensory experience. [8] The experience of atmosphere as a quality of architecture, according to this definition, is an embodied experience. Pallasmaa builds his theory of atmosphere on two essential pillars. The first relates to emotional experience, which precedes intellectual understanding, stating: "We are mentally and emotionally affected by works of architecture and art before we understand them, or, in fact, we usually do not understand them at all." [9] The second pillar is based on the idea that our pre-intellectual encounter with architecture is directly linked to multisensory experience. Thus, Pallasmaa associates the intuitive and emotional realm with our subconscious, which is based on multisensory experience as a kind of pre-intellectual cognition.

Pallasmaa explains these characteristics by stating that humans are capable of instantly sensing the atmosphere of a space before analyzing details and intellectually mastering its elements, much like they are able to form a clear image, feeling, and retain a vivid memory of a particular atmosphere: "The judgment of environmental character is a complex fusion of countless factors that are immediately and synthetically grasped as an overall atmosphere, feeling, mood, or ambience." [8] This interpretation of the phenomenon of atmosphere in architecture is closely linked and grounded in the philosophical interpretation of perception by the renowned French phenomenologist Maurice Merleau-Ponty, as he elaborated in his famous work "Phenomenologie de la perception" [10] whose research serves as a basis for phenomenological investigations in architecture and the arts.

Pallasmaa utilizes the concept of atmosphere, among other things, as a critique of the dominant visual aestheticization or "architecture of the eye," introducing the notion of the embodied image: "But I think the notion of atmospheres is in balance with my understanding of the body image, or the embodied image, in its comprehensive, sudden grasping of the emotional and existential essence of a situation, whether social or architectural." [11] His critique is directed towards the contemporary state of dominant visual culture and modern life, which has become a world of images and simulacra. In response, his theory emphasizes the qualitative capacity of architectural multisensory and layered communication, which, predominantly focused on the visual, is neglected, resulting in, according to him, impoverishment of our existential existence in the world. [12]

Furthermore, he sees the essence of architectural experience in the character of verbs rather than nouns or adjectives, as architecture always implies and invites activity, which he connects with the term "lived image." Both terms, which overlap with each other, he developed in his earlier works, using them further as a metaphor to thematize the way architecture is experienced and as key terms to describe atmosphere as an emotional and multisensory experience. [13]

Since his seminal book "The Eyes of the Skin: Architecture and the Senses," [13] in which we recognize the influence of Merleau-Ponty and his theory of phenomenological perception, Pallasma suggests that tactility is the primary sense and that all senses are derived from it. As implied by the title itself, the sense of touch is prioritized, while all other senses, as Pallasma wishes to illustrate, are its unique extensions. Drawing on Merleau-Ponty's theory that our encounter with the world is through a thin membrane of skin and that all other senses are differentiations of this membrane, Pallasma insists on the concept of tactility not just as touch in the literal sense but in an existential sense, as a holistic experience emerging from all sensory modalities, as a haptic sense of being in a particular place at a particular moment, as the reality of existence. [14]

In terms of interwovenness and interdependence of subject and object, Pallasma states: "We behold, touch, listen and measure the world with our entire bodily existence, and the experiential world becomes organized and articulated around the center of the body. Our domicile is the refuge of our body, memory, and identity. We are in constant dialogue and interaction with the environment, to the degree that it is impossible to detach the image of the Self from its spatial and situational existence" [12:64]. Therefore, the question of atmosphere, according to him, is a question of existential spatial experience, as a qualitative value of architecture that fully engages human sensibility.

2.1. BUILDING ATMOSPHERE

In the previous chapter, an overview was provided of the understanding of the concept of atmosphere as a phenomenon in architecture. This laid a broader foundation for interpreting concepts related to atmosphere, aiming to create a clearer picture of the connection between the phenomenon of atmosphere and architecture. In this chapter, we will review the generators of atmosphere creation according to Böhme's interpretation, who systematically defined groups of generators as well as the characteristics of atmospheres. It starts from the fact that we create and determine the atmosphere just as it determines us. [6:119]. He elaborates on the space of atmosphere in architecture as a space of conscious physical presence that is linked to the sensibility of the user, or the user's personal experience. The relationship between conscious physical space and conscious physical sensibility is defined by the elements of atmosphere, or atmosphere generators [7:92-93].

The starting point is the perspective that atmosphere is designed and generated during the design phase in a way that establishes specific material conditions that will generate a particular atmosphere [6:161], which will be realized/experienced in the encounter between users and physical presence. Thus, behind the experiential quality of the architectural physical phenomenon lies intentionality, which, through generative forces, achieves the phenomenon of atmosphere. The emergence of experiencing atmosphere raises questions of architectural intention and conception, and in that sense, the architect's awareness of the possibilities of producing atmospheres is of great importance [14:95]. In other words, a specific atmosphere of space can be deliberately produced by certain elements of space, which can be defined as atmosphere generators.

In his theory, Böhme divided atmosphere generators in architecture into two main categories: material and immaterial generators. Material generators are tangible and relate to form, dimensions, spatial relationships, materials, including surrounding objects such as water and fire. On the other hand, immaterial generators are intangible and relate to light, color, sound, smell, and temperature, which alter the character of space with their characteristics. [6:3, 21, 22, 125]

In the process of design, architects should consider those atmosphere generators intentionally producing the desired atmosphere characteristics, starting from the integrity or the character of the atmosphere they aim to achieve in the space. In this sense, Böhme made a division of atmosphere characteristics based on the dominant atmosphere generator in the space, namely:

- The impression of movement, in a broader sense, is represented by the spatial structures of architectural form. These generators are perceived as suggestions of movement, motion, while in a broader context, such as the impact on the space of bodily presence, they can also be experienced as confinement/expansiveness, proximity/distance, volume, or load.
- Synesthesia as a characteristic refers to sensory qualities that can be experienced in the same way or can evoke the same mood by simultaneously activating different types of senses. When selecting sensory qualities of atmosphere generators that refer to synesthesia and establishing their order in the process of building atmosphere, the question arises: what mood does the architect want to create in a particular space, and precisely this specific type of mood represents one of the goals of building atmosphere.
- Social characteristics integrate suggestions of movement with synesthetic characteristics, often including conventional elements of semiotic nature. In other words, the third group of generators influences the first and second groups, that is, the experience of characteristics implying the mode of movement in space as well as the synesthetic properties of space. [6:91-93]

Depending on the character of the atmosphere to be generated, according to Böhme's interpretation, specific atmosphere generators are taken into account to achieve that character. Before the actual process of building atmosphere, it is important to identify the generators that imbue the space with the appropriate atmospheric properties.

3. ARCHITECTURAL PRACTICE: BUILDING ATMOSPHERE

In this section, we will examine the architectural practice of Swiss architect Peter Zumthor, who explores the phenomenon of atmosphere from design perspectives and through the analysis of his projects and approaches. In his book "Atmospheres: Architectural Environments. Surrounding Objects", Zumthor directly links the question of atmosphere with the quality of architecture, considering it as an aesthetic category. [15] As he explains, it is the initial and immediate experience of space, a phenomenon that emotionally affects humans, where emotional sensitivity is interpreted as a form of perception that acts very rapidly. The next focus of investigating atmosphere relates to the relationship between corporeality and the overall materialization of space, where bodily experience is considered through a synesthetic experience of space. In addition to the relationship between humans and space, he sees the concept of atmosphere also encompassing the relationship of objects with their surroundings into which they are placed, i.e., the way they are situated and become a constructive part of the environment. In line with these characteristics, Zumthor identifies twelve themes essential in his work for achieving architectural atmosphere.

More Precisely, Zumthor elaborates on each of the first nine themes, such as The Body of Architecture, Material compatibility, The Sound of a Space, The Temperature of a Space, Surrounding Objects, Between Composure and Seduction, Tension between Interior and Exterior, Levels of Intimacy, and The Light of Things, in each chapter individually as design approaches in his study. Additionally, he adds three more aspects that personally motivate him: Architecture as Surroundings, Coherence, and The Beautiful Form. [15:21-73]

The themes Material compatibility, The Sound of a Space, The Temperature of a Space, and The Light of Things are related to the materialization of objects and the properties of applied materials. Here, Zumthor examines material and haptic qualities, rhythm, and light, which are essential in his work for achieving architectural atmosphere, explaining them as guiding principles in his practice.

All the mentioned themes can be summarized briefly as follows:

1. **The Body of Architecture:** Architecture resembles bodies, composed of various elements that create a unified whole.
2. **Material Compatibility:** Materials interact, potentially complementing or contrasting each other, thus shaping the atmosphere.
3. Sound of Space: Spaces possess acoustics that can influence the atmosphere, affecting mood and dynamics.
4. **Space Temperature:** Temperature can impact space usage and its overall atmosphere.
5. **Surrounding Objects:** Objects within a space contribute to its atmosphere and serve specific purposes.
6. **Freedom of Movement:** Architecture should facilitate freedom of movement, enabling exploration and discovery.

7. **Tension between Interior and Exterior**: Interior and exterior spaces can merge seamlessly, without clear separation.
8. **Levels of Intimacy:** Various factors such as size, dimensions, and lighting influence the intimacy of a space.
9. **Light on Things:** Light and shadows significantly affect the atmosphere of a space.
10. **Architecture as Environment**: Architecture is influenced by the environment and, in turn, influences it.
11. **Coherence:** The success of architecture is measured by its effectiveness and functionality.
12. **Aesthetics:** The final form and atmosphere of architecture should evoke emotions.

Unlike Böhme, who provides general classifications of atmosphere generators and the character of atmospheres that arise depending on the combination and interdependence of generators, Zumthor approaches atmosphere-building from a design position and formulates a personal approach as a kind of manifesto of architectural quality, as outlined in this book. However, despite being set from a personal and authorial perspective, his thinking is of great significance for bridging theory and practice in the context of the phenomenon of atmosphere.

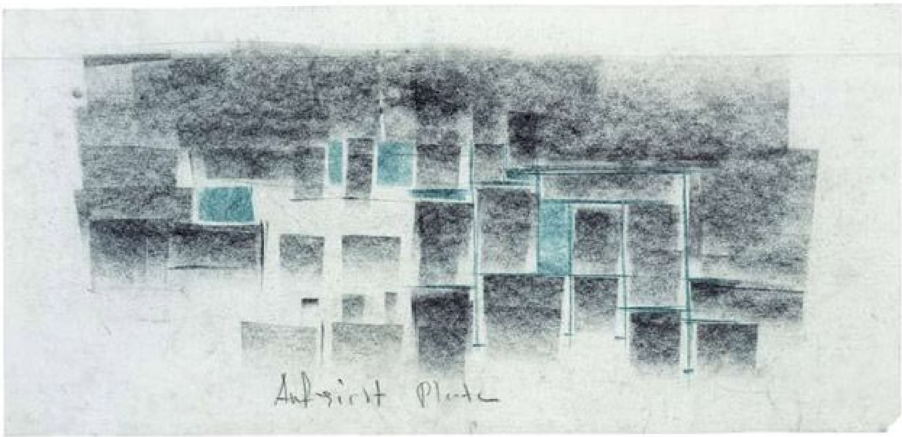

Figure 1. Drawing and Creating Atmosphere - For Zumthor, the phenomenon of atmosphere represents essential importance for constructing a concept, and this is recognized in the initial sketches. His drawings already possess atmosphere and an emotional form of perception that he aims to achieve. The character of Zumthor's drawings suggests an experience of space that involves multisensory perceptions, i.e., atmosphere and mood.

The following is an analysis of the applied goals of atmosphere building using the concrete example of the Therme Vals project by architect Peter Zumthor. Therme Vals, built in 1996 in Switzerland, stands as one of the most representative examples of architecture for considering atmosphere as a quality of architecture.

Architecture as Environment: Zumthor directly draws inspiration from the complex topography of the site where mountain silhouettes, forests, and rivers intersect - which inherently carries the recognizable atmosphere of the Alpine location. This informs the shaping of space and internal atmosphere. It pertains not only to the physical characteristics of the location but also to the sounds, scents, and temperature as intangible atmosphere generators, which infiltrate as elements into the concept of forming Therme Vals.

Figure 2. Architecture as Environment

Figure 3. The Body of Architecture

The Body of Architecture: The geometric forms of the Therme space evolve from the topography and geology of the site, where both vertical and horizontal volumes are carved from the mountainside, some of which are filled with water. [16] The aim was to blend the characteristics of the location with the constructed structure into a unified whole, but this does not exclusively refer to the physical characteristics of the location as stated.

Material compatibility;The Sound of a Space; The Temperature of a Space;The Light of Things: As Zumthor emphasizes, the primary generator of atmosphere is the material itself. Atmosphere is crafted stone by stone, along with other non-material generators such as light, sound, scent, and temperature, in shaping the space and material use. Inspiration for such an approach stems from the appearance of surfaces of natural materials predominant in the environment.

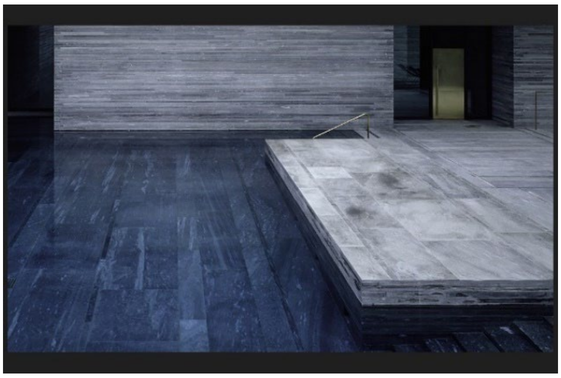

Figure 4. Material compatibility

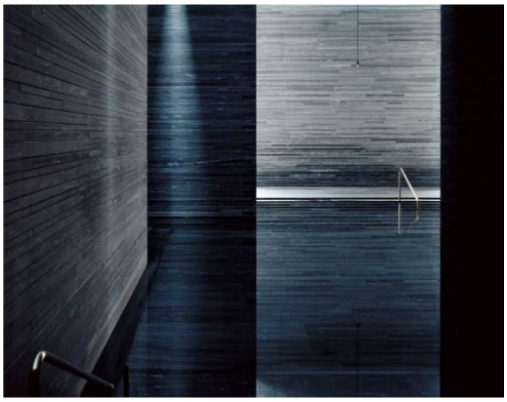

Figure 5. The Light of Things

Freedom of Movement: Visitors to the Therme Vals are not confined within rigid programmatic boundaries; rather, they are essentially allowed to roam freely, creating their own ritual and discovering various spatial sensations. Through the experience of movement, navigating through the interior of the pool, light, sound, and temperature take on different characters, thereby shaping the atmosphere experience to its fullest.

Tension between Interior and Exterior: The volumes of the interior and exterior spaces confront and blend into one unified whole. Their undefined boundary allows for the alternating melding of the interior and exterior space. The geometry of the form frames the sky and surrounding mountain peaks.

Figure 6. Tension between Interior and Exterior

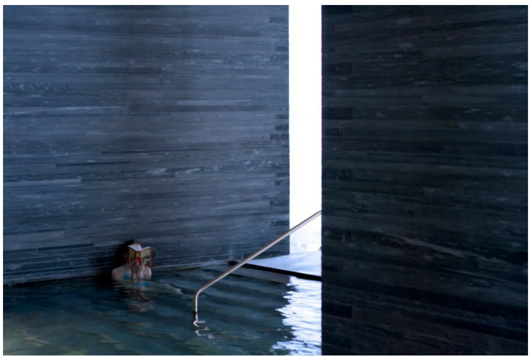

Figure 7. Levels of Intimacy

Levels of Intimacy: The bathing ritual framework is constructed using five-meter-high units that are beyond the scale of the human body, within which various levels of intimacy are formed, depending on the size of the units and the character of the lighting.

Starting from a clear image of spatial wholeness, Zumthor dedicates himself to each element of that space that contributes to the whole: from material processing, dynamics of openness and closure, light and shadow, to the relationship between landscape and architecture. The experience of a relaxing atmosphere is realized through the stimulation of bodily interactions with the space, producing a sense of free yet guided movement where feelings of anticipation and surprise arise. In this way, Zumthor constructs a strong image of the atmosphere that the object produces together with the environment as a visual and bodily experience, and the intensity of that image becomes an integral part of the user's experience and memory.

4. CONCLUSION

The findings presented in this study indicate the relevance and significance of the atmosphere phenomenon in contemporary architectural theory and practice. The theoretical framework of this work encompassed key interpretations that contextualize the atmosphere phenomenon in architecture by defining its elements, modes of perception, and questions through the construction of atmosphere. Through the analysis of various perspectives and approaches, it was explored how the atmosphere is experienced and constructed within architectural space. For the precise definition of the atmosphere phenomenon in architecture, it was crucial to analyze the ways in which it is experienced and perceived as a spatial-emotional phenomenon. In addition to examining the key theoretical concepts of atmosphere in architecture developed by Böhme and Pallasmaa, this work also considered the practical application of building atmosphere through the example of architect Zumthor's work, based on his design principles. The main aim of the research was a deeper understanding of this phenomenon through theoretical analyses and practical approaches, with the intention of enhancing the methodology of architectural design. This combination of theoretical and qualitative methods enabled the consideration of atmosphere as a significant aspect of architectural quality, contributing to both theoretical and practical fields. At the same time, the research emphasized the importance of atmosphere as an integral part of the architectural experience, opening new perspectives in the study and design of space. Through theoretical insights and the potential for practical application in education and architectural practice, this research provides a contribution to a better understanding of the importance of studying the phenomenon of atmosphere in architecture. The concrete application of the research findings relates to the possibilities of new research, approaches, and techniques for building atmosphere in architectural practice.

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24
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FOCUSING A CITY BRANDING STRATEGY ON A LUMINARY: A CASE STUDY OF TREBINJE AND JOVAN DUČIĆ

Abstract

Trebinje is a city with a rich cultural and historical heritage associated with influential historical figures who have played a role in its physical construction and contributed to its identity. Legends about these people are a part of the city's rich intangible cultural heritage and they can provide a solid basis for city branding.

This paper examines the possibilities of using a renowned person – more specifically, the poet, diplomat, art collector and patron Jovan Dučić – for branding Trebinje. The focus of the study is the tangible and intangible heritage associated with Jovan Dučić and covering all the crucial aspects of focusing the city branding strategy on a luminary.

Keywords: city branding, Jovan Dučić, Trebinje

КОРИШЋЕЊЕ ПОЗНАТИХ ЛИЧНОСТИ У СТРАТЕГИЈИ: БРЕНДИРАЊА ГРАДА – ПРИМЈЕР ЈОВАНА ДУЧИЋА У ТРЕБИЊУ

Сажетак

Требиње је град богатог културно историјског насљеђа који се повезује са значајним историјским личностима које су допринијеле како његовој физичкој изградњи, тако формирању његовог идентитета. Легенде о овим људима представљају дио богате нематеријалне културне баштине која може бити добра основа за брендирање града.

Овај рад се бави истраживањем могућности коришћења познате личности за брендирање града Требиња на примјеру пјесника Јована Дучића који је такође био дипломата, колекционар умјетничких дјела и добротвор. Истраживањем материјалног и нематеријалног насљеђа везаног за Дучићево име биће приказани сви битни аспекти коришћења познате личности у процесу брендирања мјеста.

Кључне ријечи: брендирање града, Јован Дучић, Требиње

1. INTRODUCTION

City branding has become popular over the last few decades, with increasingly more cities mobilising their resources to become more visible and recognisable in the stiff competition among cities. For that reason, many cities use various branding strategies for their development. Branding strategies may range from reputation-building advertising and promotion to policies aimed at attracting specific industries or target visitor/population groups to comprehensive urban governance strategies [1]. Cities compete in spatial and regional contexts because they can learn from one another and because of the similar tools of the target groups and similarities [1]. According to authors Lu and Ma, many studies focus on branding content, not on subtle city branding strategies. This is no simple task, as cities are complex phenomena that include geographic, economic, social, cultural, and many other elements [2]. As posited by Landry, city making is an art, not a formula.

Trebinje is a medium-sized city in Bosnia and Herzegovina. It is located very close to the Adriatic coast, so it has been exposed to Mediterranean influences, which are noticeable in its appearance. At the same time, it has a very rich history and culture, with traces of the past clearly visible in its physical structure. This city has already been recognised as a tourist destination, and with the great number of cultural events it hosts, it is known as a “city of culture”.

Also, Trebinje is known as Jovan Dučić’s birthplace. Dučić was a famous poet, diplomat and art collector who maintained ties with his native town all his life, despite living an exciting and busy life and working in the diplomatic service most of his life. Dučić as a figure has been pivotal to forging Trebinje’s identity as it is. Besides an outstanding poetic oeuvre, he left a rich art collection behind him, which he bequeathed to Trebinje and is now kept at the Museum of Herzegovina.

This paper deals with building a city brand around a famous person and their work and with using their influence for city promotion. It focuses on the city of Trebinje and the Trebinje-born famous poet Jovan Dučić to explore the widest range of aspects of using renowned person in the city branding process.

2. METHODOLOGY

Cultural tourism can be analyzed from economic, tourism, educational, organizational, cultural and other points of view, but the bottom line is that, if we are committed to this concept, we should think about how to put the cultural resources we manage into the function of development [3]. The one of most effective strategies in highlighting of the recognized values of the place is branding. A brand in tourism represents the creation of a destination where something can be experienced [4].

This paper presents a case study which seeks to examine a specific place associated with a public figure in order to discover any consistency and regularities that could be used in place branding, and also to specify all the positive and negative aspects of using a person for place branding.

With regard to branding strategies, three principal categories of city branding have been identified – those revolving around the built environment, famous people and historic events [5]. This paper focuses principally on the famous people category, with the other two ancillary categories, addressed to the extent they can be associated with the renowned person central to the branding process.

3. FOCUSING THE CITY BRANDING STRATEGY ON A RENOWNED PERSON

The theme of city branding strategy has inspired many studies, which have examined branding from different perspectives, such as brand image, identity, and personality [6]. The very notion of brand personality has provoked a debate among experts. According to Aaker and Joachimsthaler, the structure of brand identity includes four elements: brand as a product, brand as an organisation, brand as a person, and brand as a symbol [7].

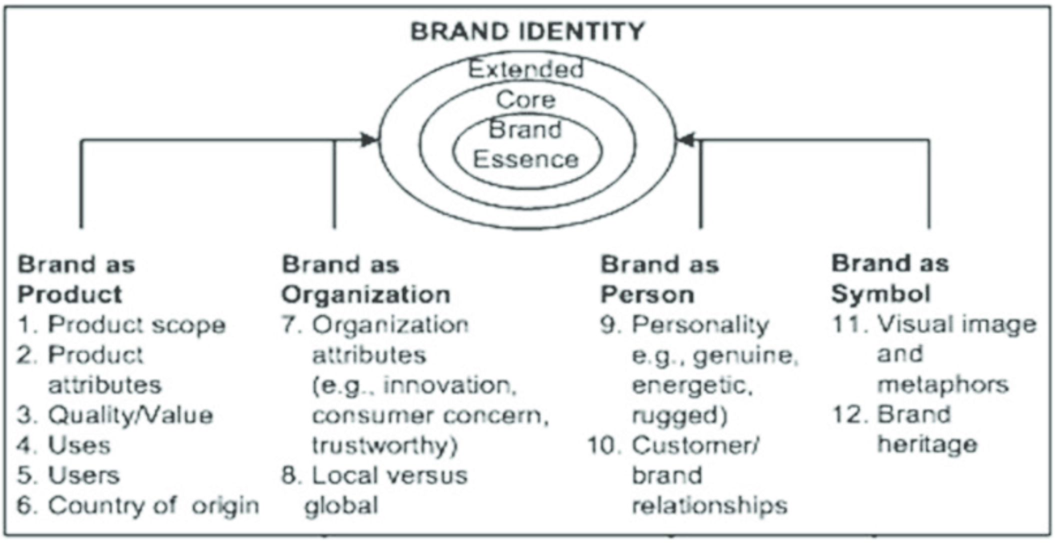

Figure 1. Brand identity [7]

A brand as a product adds value to a service, person or place; in contrast, Kapferer considers brands not to be products, but sources of products and meaning [8]. In today's literature, brand-related terminology that has general currency does not only refer to products that are goods or services. In that context, brands can be attributed personalities. Aaker specifies five brand dimensions, similar to the Big 5 model of human personality traits: sincerity, excitement, competence, sophistication and ruggedness [9]. They include honesty, integrity and trust; being up-to-date and inspiring; being reliable and responsible, as well as glamorous and charming; and lastly, being rugged and open. If these dimensions can be attributed to a well-known and accomplished person, that person can arguably become the brand of a place. This study examines the problem of cohering the biography of a person with place branding. Essentially, a biography can be retold in different ways in an effort to make a person appear unique [10]. According to author Stephen Brown, change is inherent to stories about a person's life and how their personality is understood. Hence, creative people and artists are said to express best the essence and character of the personality of a place [10]. The negative side of successful "city biographies" is when they become victims of their own success due to too many tourists, heavy traffic and congestion (Paris, London, Madrid, Rome, Jerusalem, Venice, etc.). The tourist industry is certainly quick to exploit culture. There are cities we associate with concrete artists or artworks; thus, we associate Dublin with Joyce, Verona with Romeo and Juliet, and Salzburg with Mozart. Also, artists can create visual biographies of places, such as in the films *Roman Holiday*, *Breakfast at Tiffany's* and *Notting Hill*.

3.2. TREBINJE AS A BRAND

As an old city where various influences and interests have intersected through its long and rich history, Trebinje's urban core changed in appearance and functions, and so did its importance for the greater surrounding area. Its urban structure, uniqueness, qualities and potential set Trebinje apart from other Herzegovinian towns and cities, giving it a competitive advantage for development [11].

The Trebinje Fort, as it looks today, was built in the early 18th century. During the 1683-1699 wars, the Turks were forced to construct a new town in Trebinje on the right bank of the River Trebišnjica. In Ottoman times, Trebinje was an important military stronghold and the seat of the local administration, and at that time, it got its distinct form, which has been preserved to this day. The modern city quarter developed under the influence of Austro-Hungarian and Mediterranean architectural traditions. In that matter, it is worthwhile to mention Trebinje's spiritual and cultural characteristics, i.e., the variety of cultural influences it has been under (Dubrovnik, Italy, Austro-Hungary, the Turks, etc.). After the First World War, Trebinje lost its strategic significance, and as a result, its urban development was retarded [12]. After the Second World War, it experienced fast urbanisation. All the changes in the city's long history have resulted in its establishing a multifaceted identity. Trebinje's long history has shaped its material and non-material culture, symbols and icons. In the last ten years, its growth has accelerated and it has become attractive for tourists, mostly because of its building heritage, its recognisable urban matrix, and its hedonic lifestyle.

The period between the two world wars is of particular importance for this research because it was at that time that the poet, diplomat and art collector Jovan Dučić, one of the greatest figures in Trebinje's recent history, lived and worked. Dučić's connection to his navive city is similar to irish novelist James Joyce [13]. He never broke the connection with his hometown and kept coming back to Trebinje However, unlike Joyce, Dučić displaces his hometown from everyday life, giving it an ontological dimension.

A native of Trebinje, Dučić left permanent marks on the city's public space, cultural history and identity. He is an icon and symbol of Trebinje, a luminary built in the very identity of the city.

Strategija razvoja turizma grada Trebinja 2020-2030 [27] places culture as the primary development potential and recognizes Dučić's heritage as a tourist resource of the city. The strategy even proposes the construction of the Jovan Dučić interpretation center. But it did not recognize the possibility of using Dučić's personality and creativity to create a recognizable city brand.

4. POET JOVAN DUČIĆ AS A BRAND

Jovan Dučić's literary oeuvre makes him one of the greatest and most influential Serbian poets and writers of the 20th century, as well as one of the finest essayists and travel writers [14]. Also known as the most pro-Western Serbian poet, in his time his poetry enjoyed the reputation of an unattainable ideal [15]. He was the key figure of the Serbian circle of writers and intellectuals based in Mostar.

While studying in Geneva and Paris, he became familiar with French poetry, which influenced his own understanding of the art. His writing developed from Parnassianism at the beginning of the 20th century to symbolism to versions of post-symbolism as represented by such great European poets as Valéry, Rilke and Pasternak [16]. While primarily known as a poet to the general public, Dučić was more prolific as a prosaist, which is a lesser-known fact. As a prosaist, he wrote different types of nonfiction, including travel writing, philosophical essays and maxims, literary critiques and essays, history, art criticism and opinion journalism. As a traveller, Dučić was fascinated with high mountains and continental Europe's metropolises, such as Paris and Geneva, and even more by those along the sunny Mediterranean. He felt the strongest affinity with the world of Greece, followed by Italy, Spain and Egypt.

The prose work he is best known for is *Cities and Chimeras*, a collection of ten travel stories written over a timespan of forty years. The book contains his impressions of the places he visited and stayed or lived in [15].

At the peak of his diplomatic career, he was the first ever officer to be appointed an ambassador in the history of Yugoslav diplomacy. He was accredited as an ambassador to Istanbul, Sofia, Rome, Athens, Madrid, Lisbon, Cairo, Geneva, Budapest and Bukurest [17]. He was in the diplomatic service of the Kingdom of Serbia, the Kingdom of the Serbs, Croats and Slovenes, and the Kingdom of Yugoslavia for over thirty years. It was as a diplomatic officer of the Kingdom of Yugoslavia that he became an accredited ambassador [17].

Having had such an exciting life and living at so many different places, it is no wonder Dučić started acquiring art. His role model was probably Count Sava Vladislavić Raguzinski, a great diplomat and art collector. Dučić claimed they were related and published a book about him while living in America.

Dučić's family was respected for being related to Archimandrite Nićifor Dučić, historian, member of the Serbian Royal Academy and president of the Serbian Learned Society.

Undisputably, all this inextricably tied Dučić to his birthplace. He tried to bring the spirit of modernity to Trebinje and sensitise it to European worldviews and values, thus shaping the city's material and non-material culture alike.

Figure 2. A portrait of the Serb luminary Jovan Dučić on a Post of Serbia stamp, 2021 [18]

Figure 3. Beta Vukanović's painting of Dučić's family house [14]

4.2. MATERIAL HERITAGE IN TREBINJE CONNECTED TO DUČIĆ

4.2.1. PUBLIC SPACE LEGACY

Since antiquity, architecture and art have enhanced cities' attractiveness and been the hallmarks of the culture associated with a specific period. The purpose of public art is to create material, virtual and imaginary space in which people can identify with a city [19]. In cities like Rome and Florence, art and architecture served the purpose of celebrating the cities themselves. Since the 19th century, the role of art has continuously been that of urban embellishment [20]. Casanovas holds the view that artworks in cities qualify the space and time in which they were created and define the relationship between people as individuals and their environment [20]. Art and architecture are a city's single most significant characteristics related to the historical period in which they originated as they indicate the level of cultural development of society. According to many authors, public art not only aestheticises urban space, but has an effect on several different levels and correlates with social policy. Any changes to social and cultural views considerably impact on architecture. That is why promoting culture through architecture and art is pivotal for establishing city identity.

Trebinje's urban development stagnated in the interbellum, with no major construction projects or changes to its urban fabric. Once a border city, its importance diminished in the Kingdom of Yugoslavia, a country organised as a big and complex political entity comprising parts of the former Dual Monarchy and Ottoman Empire. While the city also stagnated economically, this period is linked to the work of Jovan Dučić and his contribution to Trebinje's development. This contribution included Dučić's donations to plan and develop public spaces and install monuments, statues, stone ornaments and a public fountain. Dučić realised that by developing the city, the culture of its inhabitants would also develop and the city would become competitive and recognisable among the many historical places and cities around, primarily Dubrovnik, which is located in its immediate proximity. He drew sketches for many public art objects and structures. Njegoš's monument was designed by architect Brašovan and erected in 1934. The design of the Liberation Heroes monument, unveiled in 1938, was originally sketched by the poet himself. He particularly focused on the city park and its landscaping, bringing plants and saplings from all over the world. Thanks to his donations the city got a fountain with a statue of Cupid and two statues of lions were installed at the gates leading to the city park. Some of the gifts and stone ornaments were destroyed by the Croatian Ustasha in the Second World War, including an eagle sculpture on the Dubrovnik Gate, the statues of Hercules and Atlas at the entrance to the Old Town, and four statues and a fountain in the park in the vicinity of today's city administration building. All these gifts by Dučić may be thought of as "urban reminders", a term used by Marta Lewicka to denote people's memories of places – of architecture originating in different periods, peculiar public structures, historical monuments [21]. Besides having a practical function, historical cities have intangible social content that can be represented through symbols. It is in this way, through these "urban reminders" and symbols, that Jovan Dučić conveys something non-material – an idea, a quality, a sense of place. By "monumentalising" the city – a term coined by Monnet to denote the construction of beautiful and impressive buildings, statues, monuments, fountains, parks, facade renovation, etc. [22, 23] – Dučić gave it the sheen of a "city as an artwork". By creating what Cullen terms "focal points" [24] – vertical gathering symbols, Dučić established genuine socialisation and visual experience hubs. Trebinje's inhabitants have the privilege of enjoying city settings adorned with works of art, which, combined with the Mediterranean climate, easily leads to the creation of favourite places.

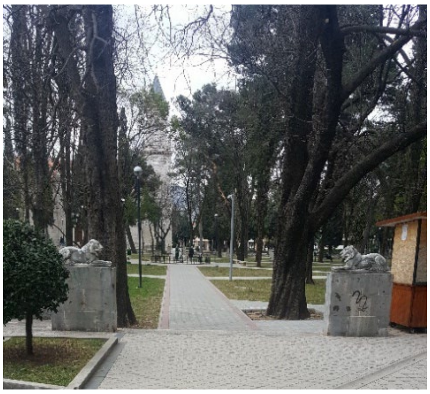

Figure 4. Lion statues at the entrance to the City Park [32]

Figure 5. A fountain with a sculpture in the City Park [32]

Figure 6. Liberation Heroes Memorial at Liberty Square [32]

Figure 7. A monument to Njegoš at the Plane-Tree Square (Flower Square) by sculptor Tomo Rosandić [32]

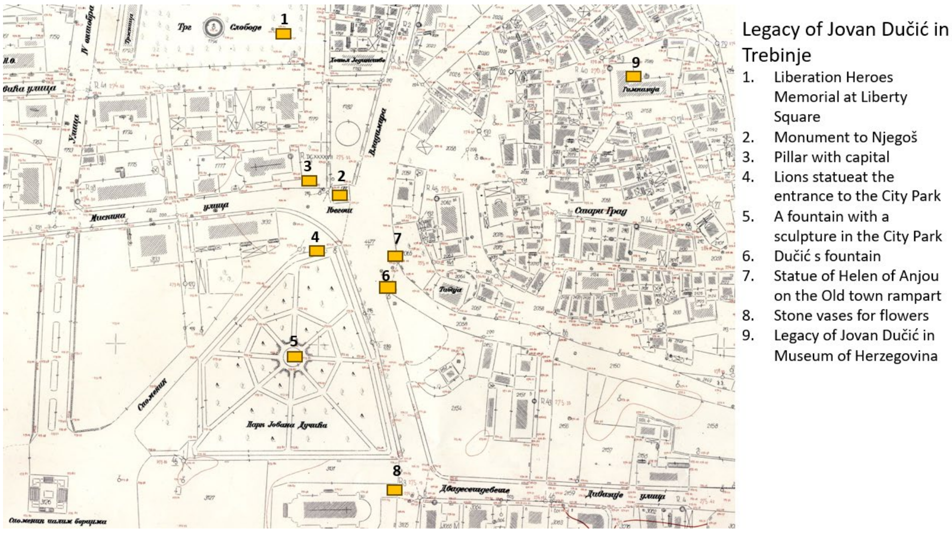

Figure 8. Material heritage legacy of Dučić in Trebinje [31]

4.2.2. DUČIĆ'S ART COLLECTION

Jovan Dučić's life in general and path as an artist unfolded steadily, surely and consistently from lows to highs, from his early modest days to his enthronement as the "king of all poets". Without many trials and tribulations, doubts or ordeals, it was the path of a man who was sure of himself and what the purpose of his public and private endeavours was – of both his diplomatic career and work as a poet [14]. This qualifies him as a person in several ways. He is known to the general public mainly as a poet and secondarily as a diplomat. It is little known, however, that Dučić was a great collector and patron of art. His patronage can best be seen at the Museum of Herzegovina in Trebinje. During his diplomatic mission in Italy, Dučić devotedly acquired artefacts and objects of art from the time of the Roman Empire. This valuable collection arrived in Trebinje in 15 iron-bound trunks in 1935. Some of the objects were used to decorate the city, and some were to have been used to start an archeological collection at the National Museum, as Dučić himself called it. However, the Second World War stopped him from implementing this idea. Unfortunately, the archaeological collection was placed in the Farming Collective Depot at the Ćelović House after the war. It was first inventoried in 1958 through the efforts of Ljubinka Kojić. A part of Dučić's bequest – his personal belongings, art paintings and library – were transported to Trebinje in 1960 [25].

The permanent exhibition of Jovan Dučić's bequest opened on Dučić's Day, on 7 April 1996. It consists of around seventy artefacts from Roman times, the art paintings remaining from the original collection and the poet's personal belongings.

The archeological collection consists of sarcophaguses, fragments of sculptures, column capitals and fragments of stone ornaments. The majority date back to the Roman Empire, with the exception of several mediaeval objects. The art collection comprises paintings by 16th- and 17th-century Spanish painters, paintings of Kosta Pitides, Daniel Mihalik and anonymous artists, as well as portraits of the Dučić family added to the collection after Dučić's death. The collection also includes a mosaic and two tapistries. The personal belongings in the collection are mostly those Dučić used on his diplomatic missions. Visitors can see his diplomatic uniform, parade sabres and decorations: Order of the Star of Romania, Grand Cross, 1st Class (Romania); Order of the White Lion, Class Commander (Czechoslovakia); Order of the Redeemer, 2nd Class (Greece); Order of the Crown of Italy, Star of the Grand Cordon (Italy); Order of Merit of the Kingdom of Hungary, Grand Cross (Hungary); Order of the Nile, Grand Officer (Egypt); Order of St Sava, 1st Class (Yugoslavia); Order of the Yugoslav Crown, 1st class (Yugoslavia); Order of Christ, 1st Class (Portugal) [26].

Figure 9. Legacy of Jovan Dučić in Museum of Herzegovina [33]

4.3. IMPORTANT EVENTS COMMEMORATING DUČIĆ

As previously stated, urban symbols express a city's urban identity. Nevertheless, it is not only material symbols that are important; intangible values, i.e., events and people, are equally significant. Given how competitive our world is on a global level, cities use cultural events for branding to assist them with urban development and attracting investment and tourists. Cities organise regular events which put them on the map (Cannes Film Festival; Berlinale; Rio Carnival; Milan Fashion Week; Novi Sad Exit, etc.). Events with a long tradition, such as public celebrations, have now essentially become cultural happenings. It is important to understand in what sense cultural activities and content are used because this requires a kind of "flexibility". Cities that foster their culture and hold and participate in cultural events maintain their vitality, enrich the lives of their inhabitants and attract visitors. Trebinje has a long tradition of hosting cultural events, and in the last few decades it has also included religious feasts (city processions marking religious holidays). In that context, numerous events are held, which are important for the city and region and also draw artists from other countries. According to Trebinje's Cultural Strategy, the city currently hosts cultural events connected with religious and public holidays [27].

Many historical figures are associated with Trebinje's history and its urban development; they include Queen Helen of Anjou, the Resulbegović family, the Baron Đuro Babić, Luka Ćelović, and the poet and diplomat Jovan Dučić as the most famous one. Legends featuring these luminaries are part of the city's intangible cultural heritage. These people are some of the city's symbols, or as some authors call them, "urban icons" [23, 28]. Some events held in Trebinje commemorating Dučić as an "urban icon" are examples of behavioural symbolism [28]. When Trebinje is mentioned today, poet Jovan Dučić is the first association."Trebinje – City of Culture", a project that belongs to the Euro-Mediterranean cultural tradition, is Jovan Dučić's legacy. This project rounds off the city's identity as a cultural and spiritual centre. These events are held under the title "Trebinje Summer Festivals" between April and October, and the city also stages "Dučić's Day" and "Dučić's Poetry Evenings". Trebinje's Cultural Strategy contains a proposal to build a venue to be called the Jovan Dučić Interpretation Centre, which would host thematic cultural events and present Dučić's rich legacy and life [27]. These festivals and events, understood as behavioural symbols and memory keepers, are spaces for interpreting and reinterpreting the city's past and future through art [28].

Dučić`s personality together with his literary oeuvre, art collection, church complex in Crkvina and very interesting personal biography certainly represents an extremely inspiring model for creating a brend. Already existing manifestation certainly contribute to this, which must be coordinated with future activities.

5. CITY IDENTITY AND CITY BRAND AS A PERSON: THE RELATIONSHIP

A great deal of research shows people identify with others if they are similar or share certain traits. People love visiting cities that luminaries or celebrities – e.g., poets, singers, etc. – come from or where popular events are organised [29]. The literature dealing with city branding clearly differentiates between city marketing and identity-guided city branding, with the latter seeking to choose values and narratives likely to influence people's perception of the city and make them connect with it [20, 31]. The process as such inherently leads to the selection of that which is considered "privileged" – the characteristics and people who are included in the brand, as opposed to those "unprivileged", which/who are left out [50]. When selecting a person to brand a city around, like any brand, this person must possess qualities the city's population can identify with. How is a brand as a person built?

Research shows that a brand as a person can provoke emotions and increase trust and loyalty [7]. Also, a person's impact can be such that they reinforce the other values and symbols under their direct influence. In the case of Trebinje, the value the urban places and settings connected with Dučić hold for the local population and visitors raises because of this association with the luminary. The valuable building heritage and public spaces that developed under the influence of different cultures which now contain the ornaments donated by Dučić become recognisable through their connection with the poet and their value increases. The figure of Jovan Dučić remains strong and stable as a brand and can be used for different marketing combinations.

When it comes to Trebinje and Dučić, a consideration of the relationship between the city brand and the city identity is in order. Identities are created spontaneously and they are the sum of various influences over a long period of time, whereas brands are the result of planned strategic activities. As such, a brand cannot jeopardise identity, but merely reinforce it.

6. CONCLUSION

Concerning the selection of luminaries for city branding, this paper shows that complex, multi-dimensional persons with rich biographies have great potential for a successful branding strategy.

As a poet, public figure, art collector and patron, Jovan Dučić helped to create Trebinje's urban symbols, shape its urban identity and make its cityscape recognisable. The value of Dučić's work lies in his efforts to bring the spirit of the world to his hometown, which is an excellent starting point for building a brand using a famous person as a resource.

If Dučić is promoted more extensively, this brand as a person could become the focus of planning. One option would be to trace a cultural path based on Dučić's life, from his birth through his schooling to all the "focal points" he created by presenting Trebinje with sculptures and other artefacts. Such a cultural path would benefit the community's collective memory and strengthen intergenerational dialogue and social interaction. The message his name would thus relay to the next generation would be to use their knowledge, fame and finances to build and strengthen their own community. The greatest value of Dučić's achievements is the pride the people of Trebinje take in them.

The branding strategy of Trebinje using the famous personality Jovan Dučić can be successfully created by coordinating already existing contents and activities and connecting them.

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25

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LOW-RISE HIGH-DENSITY HOUSING – POSSIBILITIES OF IMPLEMENTATION IN LOCAL CONTEXT, CASE OF NIŠ, SERBIA

Abstract

Low-rise, high-density housing (further LRHD housing) represents an alternative model for solving contemporary housing issues in urban areas. However this specific typological form is not recognized in local urban planning and legislative frameworks. The aim of this research is to explore the possibilities for development of LRHD housing within local frameworks through the assessment of urban parameters potentially achievable through the application of the pilot *Mix-Mesh* concept for LRHD housing and their comparative analysis with values defined by local planning regulations.

Keywords: low-rise high-density housing, modular design, sustainability

СТАНОВАЊЕ НИСКЕ СПРАТНОСТИ ВЕЛИКЕ ГУСТИНЕ – МОГУЋНОСТИ ПРИМЈЕНЕ У ЛОКАЛНИМ ОКВИРИМА, СЛУЧАЈ ГРАДА НИША, СРБИЈА

Сажетак

Становање ниске спратности велике густине (у наставку LRHD становање) представља алтернативни модел, који на ефикасан начин помаже у рјешавању савремених стамбених проблема у урбаним градским срединама. Нажалост, ова специфична типолошка форма није препозната у локалним урбанистичким оквирима. Циљ рада је да се истраже могућности развоја LRHD становања у локалним оквирима, кроз процјену урбанистичких параметара потенцијално остваривих примјеном пилот концепта LRHD становање, симболично названог *Mix-Mesh*, и њихову упоредну анализу са вриједностима дефинисаним локалном планском регулативом.

Кључне ријечи: становање ниске спратности велике густине, модуларно становање, одрживост

1. INTRODUCTION

The urbanization of cities has led to significant changes in the built urban fabric. The increased housing demands has triggered aggressive occupation of available spatial resources, resulting in the expansion of two diametrically opposed residential models – 1) single-family housing on the outskirts of the city, which caused the urban sprawl phenomenon and led to the deterioration of living quality due to inadequate infrastructure and service provision in these area and 2) high-rise, high-density multi-family construction, which initiated numerous social problems [1]-[3].

As an alternative solution, the modern approach in housing development turns to the application of low-rise, high-density housing models (further LRHD housing models), as a compromise solution that attempts to mitigate the differences between the aforementioned opposing housing models [4]-[7]. High-density housing justifies the infrastructure provision of the area, as well as the provision of service and amenity facilities, while the development of lower-rise structures, through the application of specific typological patterns, and by providing a wide range of open spaces, offers residents a comfort similar to that of single-family homes.

2. LOW-RISE HIGH-DENSITY HOUSING – DEFIITION AND ADVANTAGES

The roots of LRHD housing can be traced back to the 1960s and 1970s. Among the early achievements of this type, notable examples include: *Siedlung Halen* (1961, Bern, Switzerland), *Penn Landing Square* (1969, Philadelphia, US), and *Marcus Garvey Village* (1973, Brooklyn, New York, US) [1]. These residential developments set the foundations for LRHD housing, and established key design principles [8], which have undergone minor changes to this day.

Theoretical research [1][2][8][9], highlights the following main characteristics of LRHD housing:

- Housing density ranging from 350-550 inhabitants/ha,
- Maximum height of up to 5(6) above-ground floors,
- Compactness of physical structure and urban composition,
- High degree of individuality and privacy in housing – achieved through clear differentiation of private and public spaces, and utilization of appropriate physical elements at the ground level. Whenever possible, direct access to the units is provided from the ground level,
- Clear territorial differentiation of spaces – particularly favoring the allocation of part of the terrain to residential units, thereby privatizing a significant portion of the land,
- Wide range of open spaces,
- Integration of housing with accompanying functions, through the development of continuous built fabric.

2.1. BENEFITS OF LRHD HOUSING ON URBAN QUALITY

Decades-long practice in the implementation of LRHD housing confirms its efficiency in addressing numerous urban challenges of today [6][7][9]. Its application channels the common urban planning deficiencies associated with housing, fosters a sense of place, enhances the attractiveness and vitality of areas, and improves safety. Simultaneously, it enhances the sense of belonging, promotes the intensity of social interactions, and strengthens neighborly cohesion. Ultimately, it increases the value of land and real estate, all of which contribute to the sustainability of LRHD housing.

All the mentioned benefits influenced the wide acceptance of LRHD housing as a desirable model for the development of modern cities. Consequently, a large number of developed countries have implemented this type of housing in urban plans and issued recommendations related to its construction. Unfortunately, this type of housing is not represented in planning and urban practice in Serbia. Although there are some provisions in strategic documents that open the way for the implementation of this model, concrete realizations are still lacking. These circumstances initiated this research with the aim of creating a modular and flexible LRHD housing concept. On the one hand, such concept would follow the spatial requirements defined by local urban planning and architectural regulations, while on the other, it would be flexible enough to adapt to various location conditions. The possibility of its application in domestic circumstances is seen through the comparative analysis of achieved urban parameters applying *Mix-Mesh* concept and ones predefined by the regulation.

3. DESIGN METHODOLOGY FOR LRHD HOUSING

The methodology of designing LRHD housing has been the subject of numerous theoretical and practical studies. Although these studies are extensive and cover various aspects of the design process, for the purposes of this work, key architectural and urban elements have been marked out. These elements would serve as the backbone for the development of the LRHD housing model that could be implemented within local contexts.

In terms of typology (Figure 1) LRHD housing is characterized by the application of the following patterns:

- Linear or grid-type model of single-family housing, in the form of row houses and/or courtyard houses, with two or three above-ground floors [10][11].
- Transitional model, which in appearance and its advantages strongly resembles family housing, achieved through the multiplication of units by connecting, stacking, and overlapping them to form complex, "hybrid" residential type, with up to three above-ground floors [12].
- The "garden-apartment" model of multi-family housing, which can be developed in the form of a semi-closed or closed block, with private gardens on the terrain and up to 5 above-ground floors [12].

Figure 1. Examples of typologies applied in LRHD housing a) single-family row houses b)transitional model c) garden-apartment model

Regardless the typology, residential blocks are developed in accordance with pedestrian needs [9], prioritizing on-foot and cyclist traffic within the open block area. Vehicle traffic flows along the perimeter of the area, while within the LRHD areas themselves, if necessary, is organized in a form of integrated streets. Stationary traffic is located within underground garages or on the terrain, along street profiles or in separate parking areas along the perimeter of the area. The LRHD housing concept also features the introduction of a complex system of pedestrian paths (Figure 2), characterized by a three-level division into: primary, connecting and secondary paths. The width of primary paths ranges from 2.4 to 6.0 meters, depending on specific conditions, while the minimum width of other types of paths is 1.2 meters. This creates a safe and secure environment adapted to pedestrian and cyclist movement [9].

Figure 2. Examples of pedestrian friendly traffic in LRHD housing

One of the key characteristics of LRHD housing is the presence of significant private open spaces [2][9] which provide a suitable alternative to the yards of single-family houses. These spaces, in terms of their position, organization, and dimensions, should serve as an extension of the outdoor living area and support everyday activities such as dining, children's play, leisure activities, socializing with guests, and more [13][14][15]. LRHD typology is characterized by the prevalence of various forms of private open spaces (Figure 3) – from private gardens, created by adding part of the terrain to ground-floor units, to spacious balconies and loggias, to larger rooftop terraces on the top floors [2].

Figure 3. Examples of various forms of private open areas in LRHD housing

4. *MIX-MESH* DESIGN CONCEPT

The proposed modular concept, which could be used in the development of LRHD housing, is based on the design methodology outlined in the previous chapter. The basic module, with dimensions of 4.2x5.0 meters, has been selected as the most efficient due to its ability to accommodate various spatial arrangements: from parking (either underground or at ground level), through pedestrian and/or cycling paths, to the living rooms and double bedrooms, or grouping individual spatial functions within the given module (such as utilities and toilets, kitchen and dining area, two single bedrooms and etc.)

Varieties of spatial layouts, which arise from the possibility of different mixing combination of modules and their arrangement in a mesh-like form (symbolically reflected in the concept name *Mix-Mesh*) is reflected in a wide range of residential units (Figure 4): from studio apartments, through one-bedroom to multi-bedroom apartments (intended for larger households), with the possibility of organizing them within one or more floors.

One of the dominant characteristics accompanying LRHD housing, reflected in the development of significant private open spaces, represents the cornerstone in the development of the *Mix-Mesh* concept. All the units on the ground floor level are planned with their own piece of land in the form of private gardens. One part of these areas is planned with paving, while the rest is landscaped. Particularly high-quality solutions for multi-family housing are those where the ground-floor residential units, especially ones of larger structures, have direct access from the terrain and associated garden. In this way, a part of residential units in multi-family buildings acquire the characteristics of single-family town-houses. Private open areas in a form of balconies or loggias are added to units on higher floors. These areas in larger residential units are provided with planters, suitable for medium-sized greenery. Units on the top floors are set back from the facade plane, creating the opportunity for the development of larger private open spaces in the form of rooftop terraces.

All vehicular traffic is kept on the periphery of the block, while a network of 4.2/5.0 meters wide pedestrian footpaths are provided within the area.

Figure 4. Variation of housing units in Mix-Mesh concept

4.2. TYPOLOGICAL MODALITIES OF *MIX-MESH* CONCEPT

Regarding the manner of units' spatial organization, mutual combination and vertical assembling, residential blocks of different typologies and densities can be developed (Figure 5). Some of those possibilities will be presented in the continuation of the paper, along with achieved urban parameters regarding densities.

Residential block of single-family housing. In this case, up to six single-family residential units, larger in structures and suitable for multi-member households, are grouped together in the form of row houses. Each residential unit is accessed through a small front garden, 2.0m deep (with area of 8m²). All units have modest rear garden, with dimensions 5.0x4.2m (an area of 21m²). Units in such block can be two to three story high.

Residential block of multi-family apartment buildings. In this case, only multi-family apartment buildings are planned, with the number of floors depending on defined urban planning parameters. Depending on the specific conditions, corridor or gallery layouts can be applied. Significant private open areas, as the main feature of LRHD housing, are evident in this case as well. All residential units at ground level have private gardens with dimensions of 4.2x5.0m. This way, a large number of residential units acquire the characteristics of single-family houses. All units on higher floors have accompanying balconies or loggias. By withdrawing the façade levels on the top floor, significant roof terraces are developed, serving as alternatives to ground floor gardens.

Combined residential block. This urban form is a combination of single-family houses and multi-family apartment buildings. In this type of block, one part of the residential units is arranged in the form of row houses, while the other part is grouped within multi-family apartment building. Row houses typically have two to three floors, while the number of floors in multi-family apartment building can vary from three to five.

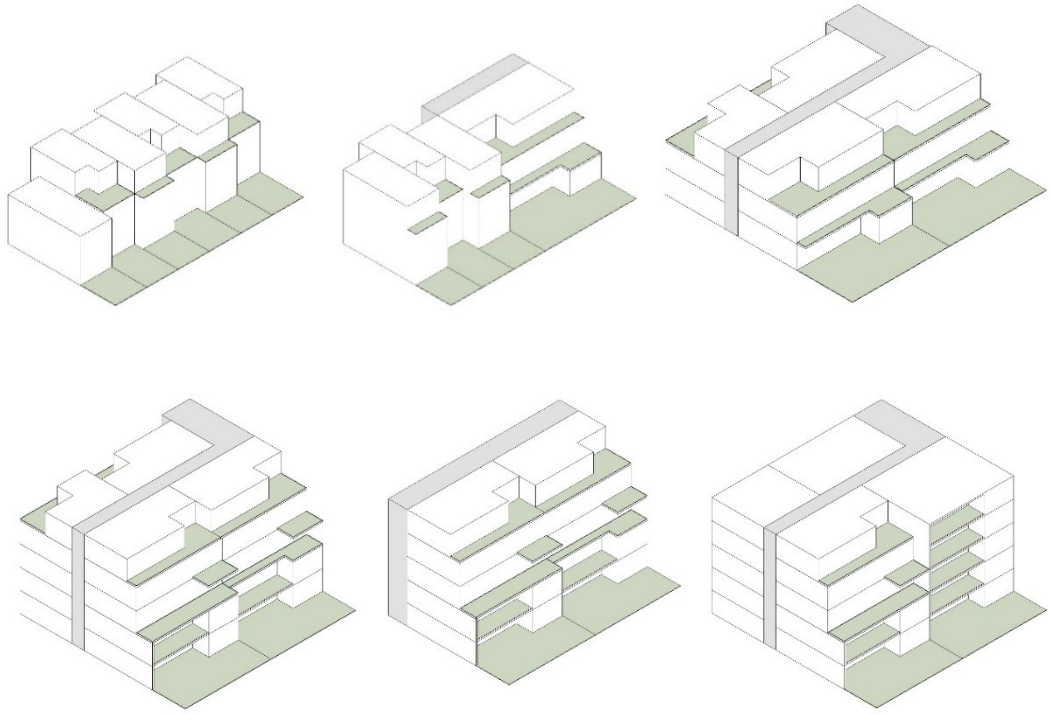

Figure 5. Different housing typologies in Mix-Mesh concept

5. EVALUATION OF THE POSSIBILITY OF APPLYING THE *MIX-MESH* CONCEPT WITHIN LOCAL CONTEXTS

As already mentioned, LRHD housing, especially aspects related to the organization of open spaces within this model, are unfamiliar in the planning and urban practice of the Republic of Serbia. Therefore, the possibility of applying this housing model within local framework can only be examined in accordance with prevailing planning regulation at the national and local levels.

5.1. LEGISLATIVE URBAN FRAMEWORK FOR THE RESIDENTIAL DEVELOPMENT- THE CITY OF NIŠ, SERBIA

In particular, in the city of Niš, residential areas are constructed according to the *General urban plan for city of Niš* (*GUP of Niš)* [16] and can be developed in a form of one of the following models: high-density housing, medium-density housing and low-density housing. Table 1. presents the urban parameters that define each of the mentioned models. It is important to note that urban areas within the *GUP of Niš*, which are nominally planned according to the housing densities, are not numerically defined (neither the number of housing units per hectare, nor number of inhabitants per hectare are provided for those areas). Since similar documents in the region define such housing densities with numerical values, as followed: low-density housing, up to 150 units/ha; medium-density housing, 150-250 units/ha; and high-density housing, over 250 units/ha (which aligns with the global interpretation of housing density) such values will be used for the further analysis [17].

Table 1. Urban planning parameters according to GUP of Niš, Serbia

Urban planning parameters	**Moderate density area**	**Medium density area**	**High density area**
Occupancy rate	50%	60%	70%
Construction rate	1,2	3,2	4,2
Building height	12m	21m	27m
Number of floors	P+2+Pk	P+4	P+6

5.2. URBAN PARAMETERS ACHIVED WITH DIFFERENT TYPOLOGICAL MODALITIES OF *MIX-MESH* CONCEPT

The feasibility evaluation of the of possibility of implementing the *Mix-Mesh* concept in local conditions will be conducted through a comparative analysis of urban parameters achieved by applying different typological patterns supported by the *Mix-Mesh* concept, and parameters predefined by urban planning regulations (GUP of Niš).

Single-family housing block of row houses, characterizes density of around 95 residential units per hectare. Considering that this involves family housing, achieved densities could range from 330 to 375 residents per hectare. This supports the lower density limit (350 residents per hectare) defined for the LRHD housing model. The spatial organization of row houses around pedestrian streets with a width of 4.2 meters allows occupancy rate of 40%, while the construction rate ranges from 1.0 (for combination of row houses with two and three above-ground floors) to 1.2 (only three floors single-family row houses). The variability in spatial organization of the residential units does not affect density in terms of the number of residential units per hectare but can influence an increase in the number of residents per hectare.

Combined housing model, in which approximately one half of the block is arranged in a form of single-family row houses, while the other half is in form of multi-family apartment buildings (with three to five above-ground floors). Given the large number of modalities in terms of applied typologies (row houses of different floor levels, and different typologies and height of multifamily apartment buildings, as well as the possibility of their variable proportion), the density of the area may vary from case to case. In the case of combining row houses and multi-family buildings of corridor type, with three above-ground floors (with setbacks of facade planes on the top floors to form larger roof terraces) and a distance between multi-family buildings of 15 meters (combined model type 1, Table 2), it is possible to achieve a density of around 130 residential units per hectare, or around 355-415 residents per hectare. In this case, the achieved occupancy rate is approximately 50%, while the construction rate is around 1.5. In the case of combining row housing and multi-family apartment buildings of corridor type, with five above-ground floors (with setbacks of facade planes on the top floors to form larger roof terraces) (combined model type 2, Table 2), it is possible to achieve a density of 150 residential units per hectare, or around 375-480 residents per hectare. In this case as well, the achieved site coverage ratio is around 50%, while the floor area ratio is around 1.7.

Multi-family housing model provides even more dense blocks. In the case of developing a semi-enclosed apartment block, with corridor-type buildings (with setback on the top floors) an occupancy rate of 47% can be achieved. Depending on the buildings height, the construction rate ranges from 1.8, in the case of three above-ground floors (multi-family housing model type 1, Table 2) to 2.4, in the case of five above-ground floors (multi-family housing model type 2, Table 2). Housing density in such cases would range from 144 to 215 residential units per hectare, or 430-650 residents per hectare.

Table 2. Urban parameters in various modalities of Mix-Mesh concept

Achieved urban parameters	**Single-family housing** Row houses	**Combined housing, type 1** Row houses + Multi-family houisng (P+2+Pk)	**Combined housing, type 2** Row houses + Multi-family housing (P+4)	**Multi-family housing, type 1** Multi-family housing (P+2+Pk)	**Multi-family housing, type 2** Multi-family housing (P+4)
Occupancy rate	40%	50%	50%	47%	47%
Construction rate	1.0 - 1.2	1.5	1.7	1.8	2.3
Density	95	130	150	170	215
Density	330-375	335-415	375-480	425-595	540-750
Number of floors	P+1 and P+2	P+1/P+2and P+2+Pk	P+1/P+2 and P+4	P+2+PK	P+4

5.3. DISCUSION OF THE RESULTS

Through a comparative analysis of the values achieved by applying different typologies within the *Mix-Mesh* concept and those defined by the *GUP of Niš*, it is possible to assess the real potential of implementing the LRHD housing model in local contexts.

A detailed analysis of urban parameters regarding building heights and occupancy rates suggests that single-family housing model, in the form of row houses, could be implemented within **urban areas with moderate housing densities**. The combined model type 1 and multi-family housing model type 1 could also find their place within urban areas with moderate densities, with a floor area ratio up to 1.2 (of possible 1.5 or 1.7). In order to maximize the potential of LRHD housing, it is necessary to modernize planning regulations and enrich them by introducing and defining this LRHD model as a distinct residential typological pattern. Adjustment of urban parameters would be entirely understandable and would not compromise the housing quality, considering that this type of housing is enriched with significant open spaces.

The combined model type 2 and multi-family housing model type 2 could be developed within **urban areas with medium densities**. In this case, there are no limits regarding building heights or constriction rates, as planning parameters allow for much denser construction within these areas.

What is evident is that each analyzed modality of the *Mix-Mesh* concept implies high densities (350 units per hectare or greater). However, through a comparative analysis of urban parameters (primarily building heights and occupancy rates the proposed conceptual solutions correspond to urban areas with medium or moderate densities. Although this fact does not limit the possibility of applying the defined LRHD model in any way, it suggests that in reality on-site situation regarding density, in all of the urban areas in the city of Nis, are far higher than nominal (which is up to 150 residents per hectare for moderate densities or 150-250 residents per hectare for medium densities). Such on-site situation casts a shadow on the perspective of LRHD model development within local contexts.

6. CONCLUSION

The LRHD model represents an alternative housing approach aimed at preventing issues arising from uncontrolled urban sprawl and the development of high-rise, high-density housing. Since density itself does not pose a barrier to quality living and is inevitable in the development of modern cities, enriching housing regulations by introducing LRHD housing as distinguish residential model, along with a set of measures customized for this typological pattern would have a positive impact on residential quality.

Specifically, in the case of the city of Niš, examining the feasibility of implementing the LRHD model has concluded that implementation could occur through: 1) forming larger residential blocks on the outskirts of the city, with increased housing density accompanied by the introduction of significant communal and green areas; and 2) developing smaller residential blocks within build urban fabric, in areas defined for medium density housing, thus promoting the compactness of urban fabric and enriching the area with missing amenities.

Application of LRHD housing would not only address urban housing needs but also enhance the overall livability and sustainability of the city.

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26
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PRESENT CONTEXT OF INFORMAL ROMANI SETTLEMENTS IN BELGRADE AS EXORDIUM FOR THEIR REGENERATION: ONE CONTEXT BUT SIX THEMES OF A SUSTAINABLE FUTURE

Abstract

The intent of this paper is to present how several characteristics of the functional organization of Roma community present the essence of forming spatial structures in settlements that by correct understanding and reinterpreting have the potential to successfully trace the steps of future planning and designing decisions in the revitalization process of existing informal settlements. In further development of the paper concrete physical patterns of settlements and houses will be demonstrated, systematized and classified into a useful base of program principles, for which research has proven to be inevitable and important to be considered in every responsible process of settlement regeneration.

Keywords: romani settlements, Romanipen, regeneration, La Biennale di Venezia 2023

РОМСКА НАСЕЉА У БЕОГРАДУ КАО УВОД У ЊИХОВУ РЕГЕНЕРАЦИЈУ: ЈЕДАН КОНТЕКСТ И ШЕСТ ТЕМА ЗА ОДРЖИВУ БУДУЋНОСТ

Сажетак

Намјера рада је да покаже како одређене функционалне карактеристике ромске заједнице представљају есенцију фомирања просторних структура које правилним разумијевањем и интерпретацијом имају потенцијал да формирају будуће кораке у планерским и пројектантским одлукама чији је циљ ревитализација тих насеља. У развоју рада указаће се на конкретне мустре насеља и кућа, које као се као систематизована база програмских начела неизбјежно морају узети у обзир у сваком одговорном процесу обнове насеља.

Кључне ријечи: ромска насеља, Romanipen, регенерација, , La Biennale di Venezia 2023

1. INTRODUCTION

To regenerate means to restore something to a better state. Regeneration is how we can restore the soil, the water, the flora, the fauna, the livelihoods, the health of the Earth and most of all, the way human beings relate to nature, to power, to civilization and to progress by designing an equal and balanced nature-inspired system.

By valuing and bringing forth indigenous knowledge and selectively applying advances of our technological age, regenerative approaches seek to reverse the degradation of the planet's natural systems and design human-driven systems that co-evolve with natural systems to generate mutual benefits, improve life for all on this planet and create resilience for the future.

Regenerative development, which draws inspiration from the self-healing and self-organizing capacities of natural living systems, aims for an integrated, whole-systems approach to the design and construction of human settlements and practices and development, is increasingly seen as a successful model for achieving this end.

Even though the establishment of such principles is theoretically vast, in practice it primarily deals with the local level, as every community has different social, economic and environmental needs whose parameters remain unique in constant change. In the case of the Roma population, the subject of housing is additionally made even more complex due to the subtext of appreciating the different; such subtext becomes a certain imperative because the current documentation dealing with the integration of the Romani is based on the theoretical model of integration. This means that all projects regarding the Roma population including housing projects need to emphasize the preservation of the ethnic and cultural identity of that community.

Through the overlapping of the two functions of housing – the physical and the social – the meaning of the term territorialization is also broadened. Therefore, the places claimed by the Roma cultural group aren't only spatial facts, but also cultural, social, economic and ecological, and as such, as explained by Ferguson, make possible the understanding and analysis of what different cultural groups create in space [1]. The understanding of regenerative settlements is thus changed from green units, which might be the primary association to a social enhancement in a much broader sense.

Romani studies and sociological research find that the Roma microenvironments represent the most reliable form of protection of the cultural identity of the Romani; and even though it changed dynamically, it preserved the social and cultural behavioral patterns – the Romanipen – which still hold a key role in the everyday life of the Roma people [2, 3]. What actually qualifies the informal Roma settlements as spaces of significance is the fact that the Romani themselves shaped them and formed them based on the needs of everyday life, and without the involvement of professionals. According to Eagleton, the lifestyle of every cultural group holds a complex set of cultural values, traditions, habits and beliefs [4], the Romanipen (Romani identity system) being exactly that for the Roma people.

In that sense, several concepts of physical structure were noticed in various slum-type informal Roma settlements analyzed by the author of this paper from 2011 in Belgrade (Serbia) and as a result of those earlier studies, they are singled out and explained and can be considered as culturally adjusted environments.

In further, more detailed and focused research, which will be presented in this paper, the intention is to demonstrate that within these patterns, which can already be considered as culturally adapted environments, there are significant potentials that need to be given special attention in the domain of settlements development towards the general process of regeneration. This simultaneously reconciles strategic duality - achieving improvements that are affirmative for the broader society and acceptable within the framework of the Roma cultural context.

Directly observed culturally adapted formations within the broader context of the settlement include yard group and its immediate neighborhood.

Therefore, the first step of the research involved field studies through observation. The reality of the observer consists in the stimuli produced within as he observes the space and its use. In order for these stimuli to remain recorded, and to be able to be communicated later, they need to be memorized in an organized structure that is an extensive representation of the perceived world and in which the stimuli are related to each other, stored together as information.

Further methodological development of the study involves the classification and systematization of knowledge established through direct observation in the field and the identification of the characteristics of physical structures as regenerative potential in referent types of Roma settlements and houses. This set of information will form the relational database.

The third step involved comparing the results with the concepts of sustainable development presented at The Laboratory of the Future at the Venice Architecture Biennale in 2023 to demonstrate that the obtained and extracted results have both the strength and direction for further action on the path of regeneration.

2. FIELD RESEARCH: OBSERVATION AND DATA RECORDING

The methodology was created in such a way as to provoke one to dive deeper into the micro in a realistic (existing) scenography of the existing context, using the intuitive deeper basis of being when observing the potential of the space for regeneration.

The concept of this methodology is based on Kant's guidelines that if we treat the space that surrounds us as a handy empirical world, it is possible to decipher the deeper meaning, the one that is felt, that is received by experiencing, not by reason, but by the power of the archetypal mind. By including personal perception, we want to achieve the deconstruction of iconic rules that primarily relate to the meaning that regeneration themes imply in a general sense.

A specific space, with a special focus on isolated segments, was intensively observed every day, at different times of the day for 7 days, during which all the changes occurring within the yard groups and their immediate environment were recorded.

Diagrams were chosen to record all observations. They have the potential to illuminate, round off, mark the important, without it being explicit and conceptual. Each occurrence is assigned a universal identifier in the form of small circles. (Figure 1)

2.1. METHODOLOGICAL TOOLS FOR OBSERVATION AND RECORDING

The screen is the selected space that will be observed during this research, where concrete objects reside and which is infinitely rich in information. He is never really known, because we only have a mediated approach to him, through the perception of the observer. Thus, we emphasize that what is important for the observer is not the world in itself, but the perception that the observer has of it. It exists only for the observer and only during his perception. The screen can be imagined as a frame placed on a given part of the space. The screen is as big as it needs to be, but its boundaries must be clearly and logically defined. The screen includes all actors (both animate and inanimate nature) and their events and changes. It is drawn as a circle with the largest diameter.

The configurations of the screen are all the values perceived by the observer; all the values provided to us by the senses. The screen contains different groups of such patterns that can be classified into categories:

Territory is the field of action of various phenomena, not all of which need to be physically present, but they must be spatially defined. Territories can also have their own field of action, which depends on the mobility of its users (agents). Territorial membranes can be completely impermeable, semipermeable or permeable. They can freely transmit influences or allow only some of them to pass and transmit influences in one or more directions.

For example, we can single out several types of territory: house, street, garden, but also solar panel...

We also mark the territories with small circles, but with three. One small circle marks the physical presence of the territory, the second circle indicates the type of membrane and is drawn as a concentric circle slightly outside the circumference of its territory, and the third circle is the territory's field of action.

Institutions. Institutions are rules of behavior imposed by certain institutional impositions. A classic system that works from the top down and acts as a community concern. It can be treated as an element of organization that affects a certain control of the behavior of agents in an attempt to control the space (fences, parking, sign, prohibition...).

They are marked by a circle of colored surfaces, the shade of which varies according to the strength of their power of action (lighter is weaker, darker is more powerful). The diameter of the circle varies depending on the breadth of influence that the institutions have on the observed space.

Agents. Agents are people within the space, perhaps the most important factor, they are the ones who create all of the changes in the screen. Their behaviors can be predictable and unpredictable and it requires further research. Special attention needs to be paid to the relation between the agents and the institutions and the relation between agents and territories, as well as their mobility ways. How do the agents move? What do they use to move? What are the distances in question?

They are marked by circles with the smallest circumference.

Desires and wishes. Desires and wishes are also dynamic elements of the screen. They are tendencies on a specific topic (regenerative potential here). They are produced exclusively by agents and they can be individual, in the form of intention or under the influence of an institution. Holistic themes in the form of experiential and interpretive qualities of human thought aspirations, feelings, actions are very important and applicable in regenerative processes. Special attention should be paid to them. They can be perceived as gestures by pure observation, and they can also be obtained through dialogue with agents.

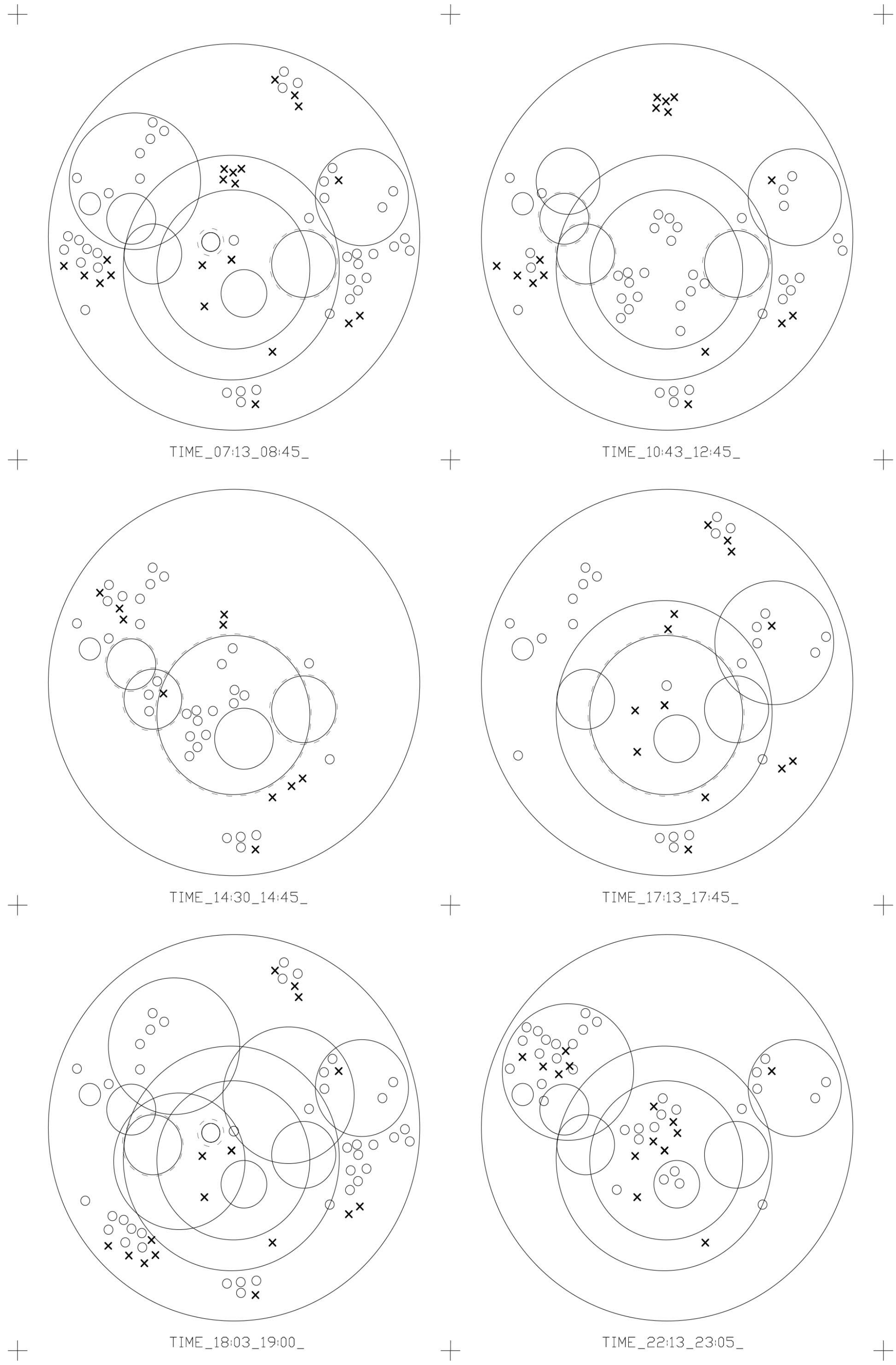

Figure 1. Diagrammatic representation of research

3. RESULTS: CLASSIFICATION AND SYSTEMATIZATION OF KNOWLEDGE

As already mentioned, Romani lifestyle is based on the extended family household, ostensibly established on the family residence, but it cannot be recognized as a single-family house. The residence consists of several units which are spatially interdependent and socially organized as a whole – the yard group. Representing the core unit of the settlement, it is based on a collective Romani lifestyle of expanded family. It is usually a semi-atrium formation where the built and non-built spaces are clearly defined and separated. The built space is made up of a few housing units, usually four to five and a few additional utility units.

By researching the behavior and analyzing the functioning of yard groups of buildings and their integral elements of the built structure, the following potentials for regeneration were determined using the aforementioned methodology.

Reuse of elements that materialize the house. The basic structure of dilapidated houses - barracks is made of wooden planks or beams. The materialization of the basic structure is achieved by cladding boards, doors, windows, wooden boards, nylon, sheet metal or cardboard. All elements of materialization were found on some kind of waste and reused. (Figure 2)

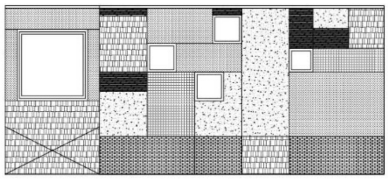

Figure 2. Materialization of a house

Floor of the house. In all analyzed barracks, the floor of the house is made of ground, and cardboard or Styrofoam is often laid over the ground. (Figure 3)

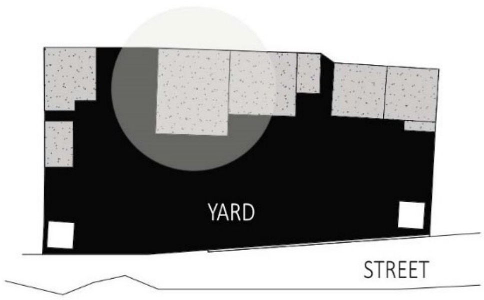

Figure 3. Prevalence of earthen floors

The size of the house. A Romani barrack for an average of 5 family members, which is the case in over 60% of the houses in the observed scope, is about $30m^2$, or about $54m^3$. The height of the shack is up to 2m due to better heating of the space in winter. (Figure 4)

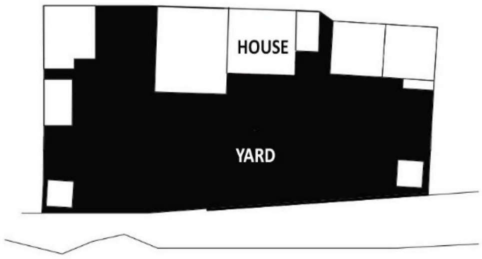

Figure 4. Ratio of house to yard area

Fences. A fence in the usual sense, which marks and encloses a group of buildings across the entire surface, is rarely present in slums. Almost as a rule, only one part of it, a few meters long, is placed, which marks the surface that defines the boundary of the courtyard group in relation to the street. Fences between houses within the courtyard group are almost always absent. Therefore, the common yard belongs equally to all houses within the yard group. (Figure 5)

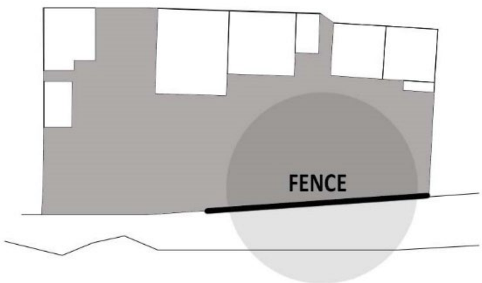

Figure 5. Position of the fence

The ratio of built and unbuilt space. In the slums, great attention is paid to the "occupation" of open space. Romani daily life is quite oriented towards the open space. The yard is a place to help each other in daily tasks. The spirit of community that is achieved there is a resource on several grounds. The yard represents the most visible place of connection within which knowledge and skills are shared and enables mutual assistance in the fight with everyday challenges - from babysitting, food preparation to house building services and help with their rehabilitation. The ratio of built and unbuilt space is 3:10. (Figure 6)

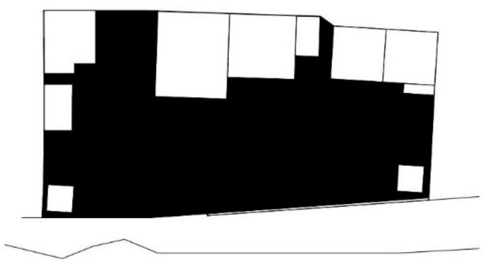

Figure 6. Ratio of built and unbuilt space

Field toilets. Due to the way slums are created, the shacks have no access to water supply or sewage. Within the yard group, the most common sanitary area is the field toilet. (Figure 7)

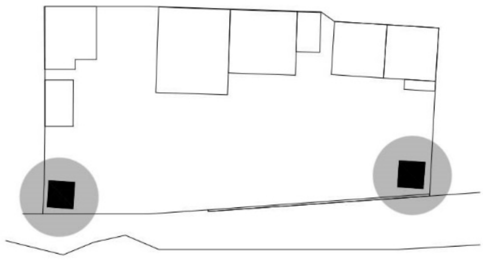

Figure 7. Position of field toilets

4. AND THEN, WHERE ARE THE AGENTS OF CHANGE?

The sets of data obtained by this methodology are very diverse because they shed light on micro-level functioning in a special way. The micro level is a pure world of signals, it contains numerous indications for future actions, which are often unexpected. This interpretation of information, which is full of value, creates a wealth of possible choices. It narrows when the label becomes the meaning, that is, the definitive choice for inclusion in further steps. In this one urban contest, six topics were opened for further discussions about the possible steps that the Roma microenvironment carries in itself, and they concern regeneration. In order to directly indicate their meaning and potential that is worth thinking about, they were demonstrated through six recognized exhibition concepts of the recently concluded Biennale of Architecture and which, each in their own way, excellently indicated the thematization of possible choices. At this moment, exhibitions like this are especially important for this topic, because their impact is felt far beyond the physical walls and spaces in which they are located.

So, what can be considered as important when you are ‘an agent of change’?

Reuse of secondary raw materials. This topic of contemporary architectural practice and the social context in general, by which the Roma are forced to handle reflexively due to their social position, is considered one of the important topics in the regeneration process because it makes an important contribution to the maintenance of the urban fabric and towards developing a more cautious approach to urban renewal and the conservation of communities. The setting of the German pavilion is precisely the installation that was dedicated to the issues of care, rehabilitation and maintenance of the built stock. The entire setting of the German Pavilion was made from the rest of the settings of the previous Art Biennale also held in Venice in 2022. The architects wanted to point out the large amounts of waste material in order to promote the theme of material reuse as a socially responsible architectural principle. The concept also aims to shed light on contemporary debates over the existing building stock and the social practice of maintaining urban fabric. [5]

Floors made from soil and the relation of built and unbuilt spaces. What does soil and contact with the ground mean for us? The exhibition in Brazilian pavilion had focus on earth as the center of discussion, both as a poetic and a concrete element in the exhibition space. The curatorial team has proposed covering the entire pavilion with soil. This allowed the public to have direct contact with Terra. Earth as soil, fertilizer, floor and territory. But also, the earth in its global and cosmic sense, as a planet and common home of all life, human and non-human. Earth as memory, and also as the future, looking at the past and heritage to expand the field of architecture in the face of the most pressing contemporary urban, territorial and environmental issues. The architects actually wanted to use examples of socio-spatial practices of Indigenous and Afro-Brazilian knowledge about land and territory and their true relation towards the ground in order to enhance the importance of presence other narratives through architecture, landscapes, and neglected heritage within the architecture canon. [6]

The size of the house. How many "m^2" are actually enough for us? Two excellent themes dealing with housing situations in cities were set by the creators of the Estonian and Singapore pavilions. The Estonian pavilion, with its setting, explores the contradiction between the use and the exchange value of living space. A regular occurrence in modern cities is reflected in the two opposites of the relationship between people and real estate. Housing is no longer only aimed at acquiring a place for a sense of stability as one's own intimate space or a place of family history, but has become an investment; the primary purpose is to have more and more apartments, which affects their increasing demand, which conditions the increase in the price of real estate or rent. City centers abound with such investments where life itself has become redundant. The accumulation of houses that have owners but no tenants' points to the problem of the absence of restrictions on the square footage that an individual may own as an owner. [7]

The Singapore pavilion examines the other extreme in its specific segments: what do people think - when they really have enough? Visitors were asked to answer six questions that highlight the intangible characteristics of the city to encourage reflection on the traits that can elevate the urban environment. Visitors were choosing the ideal combination of characteristics to evoke their ideal habitat by navigating through various creative renderings, weighing their choices, and registering these values at the pavilion. This is a test methodology for future practice creators to know what measures must be taken to calibrate different entities, environments and dreams with the question of the sufficiency of architectural space. [8]

Absence of fences, joint neighborhood, sense of community. The installation of the Swiss Pavilion, titled "Neighbors," was a project focused on the spatial and structural proximity between the Swiss Pavilion and its Venezuelan neighbor. Artist Karin Sander and art historian Philip Ursprung point out the proximity of the Switzerland and Venezuela pavilions. Of all the pavilions in Giardini, they are the closest, separated by a wall. By temporarily removing the fence between these two pavilions, the authors pointed out several important things through the story of two sycamore trees that influenced the shape and proximity of both pavilions. First, the fence, that is, the wall, is above all a political act. In a broader sense, overcoming the conventional limits that we impose even in such a small space, what nature can tell us. Two sycamore trees grew side by side, one belonging to the Venezuela pavilion and the other to the Switzerland pavilion. When the Swiss sycamore had to be cut down, the Venezuelan one branched out even more, shading both yards. To whom then does the shade belong, if the tree belongs to one? And can the elements be more intelligently organized when fencing is not forced and when the connection between neighbors is more immediate and on multiple levels? The point is that with the joint action of the neighborhood, significant and more favorable solutions can be obtained that can have an impact on a wider social sense. [9]

Field toilets. The exhibition of the Finnish representation at the biennale critically evaluates the sanitary infrastructure in the context of the global freshwater shortage that has become a reality in Europe. Sanitary infrastructure is also linked to the possibility of renewing the cycle of nutrients in food production.

As a solution for places with low population density, the exhibition presents the modern dry toilet, Huussi, which is still a typical sanitary solution in remote locations and cottages in Finland. Questioning the undisputed position of the current water-based sanitation system, the exhibition aims to inspire architects to start looking for alternative solutions, also on an urban scale, to better serve the world we live in today. [10]

5. CONCLUSION

When it comes to climate change, most people do not know what they should do or believes that things that can be done are not enough, in regards to such a meaningful and omnipresent subject. However, believing that regeneration is something that life has always done, and we are also life, the thesis is that on the micro level exist conscious or unconscious gestures that still move the fight against climate change and this paper tries to shed a light on that, as a potential for future steps in regenerative strategies.

Lesli Luoco noticed that it is often said that culture is the sum total of the stories we tell ourselves, about ourselves. Whilst it is true, what is missing in the statement is any acknowledgement of who the 'we' in question is. In architecture particularly, the dominant voice has historically been a singular, exclusive voice, whose reach and power ignores huge swathes of humanity — financially, creatively, conceptually — as though we have been listening and speaking in one tongue only. The 'story' of architecture is therefore incomplete Not wrong, but incomplete [11]. Pointing out the importance of micro level is important because it encourages the common man that he is already on his way to make his contribution and that big deeds are not needed, but that even small gestures are big and have their significant share.

In particular case the fact that informal Romani settlements were created spontaneously in unbuilt parts of Belgrade, with no expert influence, and that they were formed by the Roma themselves, using their own knowledges and skills based on needs of everyday functioning of the community and the individual has inestimable value. It is important to show that they are not exclusively places of social damnation but rather a valuable source of information about the lifestyle within which we can recognize and understand potential for each intervention to be adequate as well. Acknowledging the character of the physical structure of a culturally adjusted environment with integrated principles of regeneration has a dual effect: it pushes architecture towards a smarter, more sustainable future; and, it achieves the fulfillment of certain spatial needs which enable the development of a cultural identity, meaning the enabling of adequate conditions for a lifestyle acceptable to the Roma population.

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27
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THE SIGNIFICANCE OF THE DEVELOPMENT AND IMPROVEMENT OF MULTIPURPOSE SPACES AS CENTERS IN RURAL AREAS OF SERBIA

Abstract

The research examines the possibility of improving the spatial and functional capacities of centers in rural areas of the Republic of Serbia. The basic question raised in the paper refers to the specific definition of the center, more precisely the criteria that define it in the contemporary context. That is, how rural areas and settlements can be integrated into contemporary development trends. The initiation of multipurpose spaces is analyzed as a development model that can contribute to the social and economic sustainability of the settlement. The relevance of the study is based on the analysis of examples, i.e. the analysis of positive and negative sides of different types of spatial entities that represent centers in rural areas.

Keywords: multipurpose spaces, rural centers, rural development, rural areas

ЗНАЧАЈ РАЗВОЈА И УНАПРЕЂЕЊА ВИШЕНАМЈЕНСКИХ ПРОСТОРА КАО ЦЕНТАРА У РУРАЛНИМ ПОДРУЧЈИМА СРБИЈЕ

Сажетак

Истраживање испитује могућност унапређења просторних и функционалних капацитета центара у руралним подручјима Републике Србије. Основно питање које се поставља у раду односи се на конкретну дефиницију центра, тачније критеријума који га дефинишу у савременом контексту. Односно како рурална подручја и насеља интегрисати у савремене развојне токове. Иницирање вишенамјенских простора анализира се као развојни модел који може допринијети социјалној и привредној одрживости насеља. Релевантност студије се заснива на анализи примјера, односно анализи позитивних и негативних страна различитих типова објеката који као појавни облици представљају центре у руралним подручјима.

Кључне ријечи: вишенаменски простори, сеоски центри, рурални развој, рурална подручја

1. INTRODUCTION

The complexity of the social, economic, cultural and other determinants of different settlements in the Republic of Serbia largely makes it impossible to find a common solution that should be followed in the situation of arrangement and revitalization of rural centers. Accordingly, the subject research largely indicates to the former socialist practice of arranging village centers through the construction of cooperative homes as objects of an economic and cultural character, but also to the appearance of a different practice in the modern context which, following the development of tourism as one of the important carriers of rural development, initiates the placement of new contents such as wineries which in contemporary architectural practice have greatly surpassed the category of production facilities and have become important multi-functional spaces. This question is particularly interesting considering the former socialist context of Serbia, where wineries mostly represented production facilities that were not accessible to the general public and which, apart from their basic purpose, had no other contents.

Methodologically, the research presents an analysis of the current practice of spatial and functional arranging of rural centers in Serbia, suggesting the possibility of introducing some new approaches in this field. The paper essentially indicates a paradigm shift in the understanding of the meaning of rural centers (regardless of whether they are spaces of a private or public property) where the introduction of a different interpretation of the definitions of rural centers in this sense should trigger some new thinking on this topic.

Changes in the way of life, technological development as well as other changes in society have greatly influenced numerous issues regarding the development of rural areas. There is a need to devise innovative approaches to the revitalization of existing ones and to devise new contents that should serve the purpose of economic and cultural improvement of the quality of life in the rural areas. The issue of the development of rural areas has become a comprehensive issue of the development of a specific state and society [1]. Affirmation of rural centers in the contemporary context has actually become a question of the general development of the settlements which in fact ensures the social and economic sustainability of the entire surrounding area.

The importance of individual settlements will largely influence the fact whether they will remain neglected in the future or will be integrated into the wider context of the development of a specific community [2]. The selection of settlements will mainly depend on the number of inhabitants, spatial-geographical, social, touristic and other factors as parameters that will indicate certain potentials of their sustainability. Diversification of the rural economy, as a legitimate reflection of changes in the social sphere, in its various combinations will affect certain changes in the rural area, which will be reflected by the planning of some new contents.

However, the planning and definition of multi-purpose spaces and contents will not be of decisive importance for the survival of a settlement. The reason for this is certainly the impossibility of forcing someone to stay if he does not want to live and work in the countryside. Mechanisms for such a thing do not exist in practice. On the other hand, the point of the entire philosophy of rural development should be based on providing elementary living conditions to the population that chooses to live in the countryside. First of all, health and social protection, and then other conditions worthy of the civilizational development of the 21st century (infrastructural, cultural-educational, service contents, etc.). Otherwise, modern strategic approaches and rural development plans remain in the category of demagogic claims.

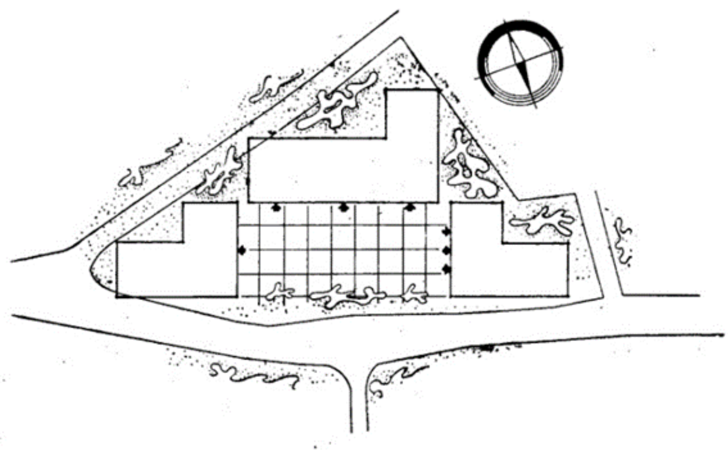
Starting from the assumption that the initiation of multi-purpose spaces within individual buildings or groupings of them can promote the improvement of the quality of life in rural areas, the research examines some possibilities of future spatial-functional arrangement and affirmation of village centers. Combining different approaches in the understanding and interpretation of the definition of a village center, that is, the analysis of their meaning as the center of public and social life. By showing the positive and negative sides, the contribution of the research moves within the limits of attributing new/different development models in the matter of defining future rural centers.

2. CONTRIBUTION TO THE AFFIRMATION OF RURAL CENTERS

An insufficient number of researches refer to eventual possibilities of improvement of the existing rural centers. The deterioration of rural settlements in the modern context is most often associated with the concept of "depopulation" of rural areas. A large number of studies point out the phenomenon of leaving the countryside and moving to the cities, which puts the emphasis on the consequences and not the real causes of their stagnation. However, one of the reasons for leaving the villages is certainly the inadequate conditions and quality of life in them [3]. It is a practice that has long been present in all European countries.

The question of the quality of life in rural areas is an issue that deserves more and more attention today. That is, whether the population in rural areas should receive the same treatment in terms of providing services as in urban areas. This refers above all to the provision of basic services of public life such as buying and selling, but also the availability of the internet and other modern information-technology services [4]. Precisely for the reason that by improving services in the countryside, they encourage their integration into the modern trends of society, ensuring the social and economic sustainability of the settlement.

The architectural-urban definition of village centers can be categorized into two groups based on their spatial-physical and functional characteristics. The category of spatial-physical village centers includes spaces most often positioned at the intersection of the main roads in the settlement (Figure 1) or along one of them as a dominant direction (linear type of center). Within such spaces, individual buildings with different purposes are usually grouped, such as a church, school, cooperative center (center of culture), catering facilities, and the like [5].



Ситуација.

Figure 1. Arrangement of the village center. (J. Krunić, ed. Zadružni domovi: Zbirka projekata masovne izgradnje na teritoriji uže Srbije, Autonomne Pokrajine Vojvodine i Autonomne Pokrajine Kosovsko Metohijske oblasti u 1948. godini. Beograd, Srbija: Zadružna knjiga, 1948. p.83.)

The concept of the center as a functionally cohesive element of the settlement, on the other hand, represents a different approach to defining centers that spatially and physically do not have to occupy a central position in the settlement. In the earlier period of the development of rural settlements in the Republic of Serbia, there was a tendency for the spatial-geographical position of the settlement to influence the formation of a common center for several rural settlements, which would somehow rationalize the possibility of using numerous contents [6]. However, that idea never fully took off in practice, except for individual cases. The reasons for this were numerous, but among the most important were certainly the disintegration of the Yugoslav state in the 90s and the economic stagnation of its republics.

The contemporary development of rural areas, on the other hand, has moved the village centers from the previous framework and as such, thanks to their function and contents, they have become individual spaces physically displaced from the core of the settlement. Thanks to their multipurpose character, they have acquired the character of places that target a diverse user profile. In this sense, it is important to integrate such spatial units into a network of centers that can function in synchronization at the wider level of the specific area.

The centralization of public purpose content in rural areas, regardless of modern development trends, is still an ideal and profitable model for the provision of various services in one place. Especially

bearing in mind the configuration of rural settlements which, for example, analyzing the context of the Republic of Serbia, mostly belong to the categories of broken or semi-broken settlements [7].
However, improving the quality of services in rural areas, following the example of those in urban areas, should not remain the main task of rural development. [8]. There is a great demand for new, more advanced models in the provision of services that will reduce the depopulation process, aware of the fact that if there are no adequate living conditions in the specific area, there is no possibility of sustainability of the local community.
A huge credit for changing the paradigm of planning and defining rural centers unequivocally goes to tourism as a globally accepted model for the development of rural areas. Their strategic development was generated by using the so-called tourist potential, which, in addition to the promotion and protection of natural and cultural heritage, largely influences the improvement of the competitiveness of various areas, which indirectly encourages the improvement of the contents in the settlement [9]. Certainly, this contributes to the economic improvement of the local population's position, but the question arises whether and to what extent it can also contribute to the improvement of some other needs of the local population. By comprehensively integrating various contents as a response to frequent changes in society that are more pronounced today than it was in some earlier periods.
The improvement and development of rural centers, in line with the trend of tourism, should be seen in a wider context. The existence of certain cultural-historical or natural values can be used to define the programmatic content of newly designed or adapted buildings. Focus special attention on the arrangement of open spaces and spaces in their surroundings, which can play a significant role as gathering places and daily activities in the countryside. To the extent that they go beyond the basic tourist and hospitality purpose.

3. FORMER MULTI-PURPOSE SPACES WITHIN RURAL CENTERS

The development of rural centers and public facilities within them have always indicated the degree of economic development of a particular settlement as a whole. The existence of commercial services, crafts or other facilities significantly improved the quality of life of the local population [10]. The first multi-purpose public buildings in the countryside in the Republic of Serbia were cooperative homes (Figure 2). Massively built after the Second World War, they were typical buildings defined on the basis of the criteria of size and economic potential of the settlement. What is interesting to point out is that homes, regardless of the different interpretations and the importance of their construction, had a large share in the planning of rural settlements [11]. They were mostly centrally located in the settlement in the immediate vicinity of the main roads. The access plateau in front of the this buildings represented a space in the form of a landscaped area (square) where, when the weather conditions allowed, various events and festivities in the settlement were held.

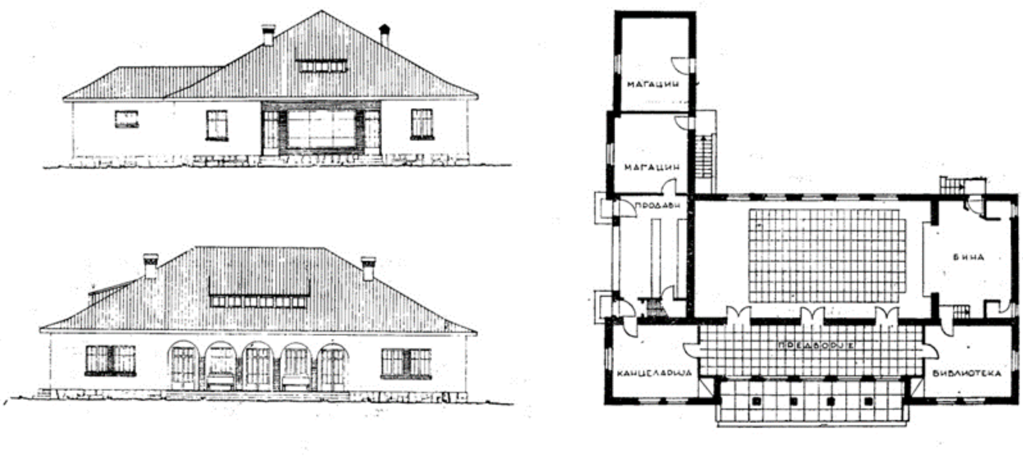


Figure 2. Cooperative home type 1, architect Dimitrije Marinković. (J. Krunić, ed. Zadružni domovi: Zbirka projekata masovne izgradnje na teritoriji uže Srbije, Autonomne Pokrajine Vojvodine i Autonomne Pokrajine Kosovsko Metohijske oblasti u 1948. godini. Beograd, Srbija: Zadružna knjiga, 1948. p.3.)

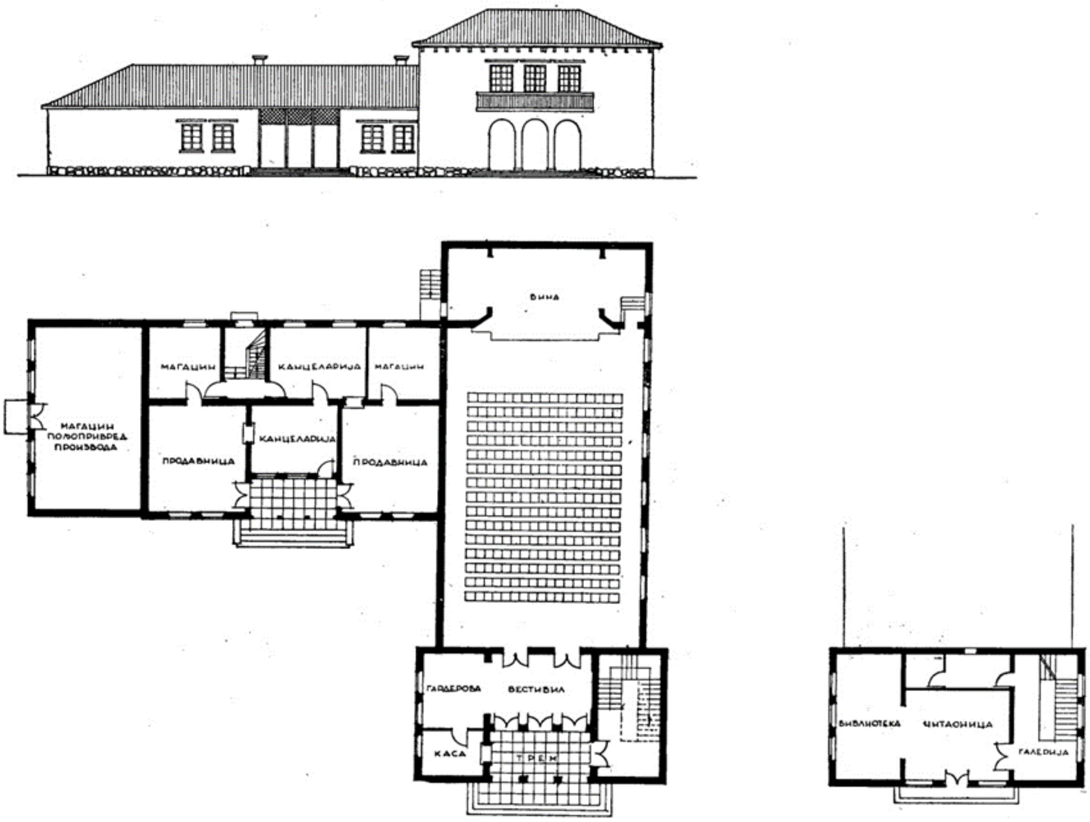


Figure 3. *Cooperative home type 4, architect Dragomir Simić (the most frequently executed project). (J. Krunić, ed. Zadružni domovi: Zbirka projekata masovne izgradnje na teritoriji uže Srbije, Autonomne Pokrajine Vojvodine i Autonomne Pokrajine Kosovsko Metohijske oblasti u 1948. godini. Beograd, Srbija: Zadružna knjiga, 1948. p.27)*

However, a large number of co-operative homes are currently falling into disrepair, while only a part of them has been adapted and brought to a new purpose. When analyzing the genesis of their origin and development, the fact that their concept was conceived in such a way that it satisfied both spatial and physical as well as functional criteria is observed. Excluding the ideological framework of these buildings and the fact that they were built on the model of Soviet kolkhoz homes, it can be considered that they represented an ideal combination of elements that included agricultural (a station for the purchase of agricultural products with an accompanying warehouse) and socio-cultural contents (a universal hall for events, festivities, cinema screenings, local office, post office, library ...). Depending on the type of cooperative home, the content structure varied (Figures 2, 3). According to this, perhaps their role has gained importance again today, because with the possible reconstruction, repurposing or planning some new contents, they can be integrated into the modern development processes of rural areas [12].

The arrangement of village centers and the construction of cooperative homes in practice were able to be accompanied by adequate infrastructure (traffic, electric power,...). To a large extent, traffic connections have always meant the survival of settlements, enabling the exchange of goods and the placement of agricultural products. Today, however, some other trends are in force, so that sometimes the existence of traffic and other forms of infrastructure are not a guarantee of the village's survival. Simply put, the culture of living and changed ways of understanding life (life priorities), the desire for an easy life, primarily in the city, degraded the countryside in every sense. But this does not mean that the population that remained living in the countryside remains excluded from the context of providing basic life services.

4. DISPLACING THE IDEA OF A RURAL CENTER FROM TRADITIONAL FRAMEWORKS: CONTEMPORARY PRACTICE

The development of tourism on a global level initiated new models of providing tourist and hospitality services. Contemporary tourism practice, following the contemporary rhythm of life and habits, today implies shorter stays that enable a more dynamic experience of natural and created values, local environments and culture. Following these changes, there is a need to improve existing and plan new contents within rural areas.

The newer practice of planning and building tourist facilities in rural areas is certainly represented by visitor centers in the most diverse forms. As information points or as multi-purpose spatial complexes that unite different contents (service-hospitality, cultural-educational) with the idea of promoting tangible and intangible heritage. Essentially, visitor centers are an ideal example of multipurpose structures as a reflection of complex social processes and needs [13]. Similar to cooperative homes, they enable the combination of agricultural production contents with educational and catering facilities. Modern wineries are certainly an example of that, which very often grow into serious hotel and spa centers providing countless other services. The advantage of the multi-purpose character of such facilities is precisely the possibility of providing different services and organizing different manifestations with the aim of attracting different users who contribute to the possibility of functioning throughout the year.

For instance, wineries in the former socialist context of Serbia represented exclusively production facilities, typologically defined as production, storage or combined spaces, while according to their position on the ground they could be underground, above ground or combined (Figure 4). Similar to cooperative homes, they were made as typical buildings devoid of any detail of aesthetic-shape specificities. Today, on the other hand, they represent complex structures that generate a wide variety of contents and that, based on their architecture and scope, create striking spaces.

The essence of the subject research is not the analysis of the content and structure of visitor centers,wineries and other tourist facilities, but the suggestion of the possibility that such spaces, in addition to their tourist and hospitality facilities, may have some other facilities that can be of great benefit to the local population. Bearing in mind the fact that tourist hospitality facilities represent a different type of public purpose facilities, one can think, for example, about harmonizing and integrating with some facilities such as a local office for the provision of certain administrative services, which, by the way, can form part of the information spatial unit (info-point) of the visitor center . Or to find contents intended for culture and education within a visitor center as universal spaces (halls, classrooms, workshops,...) which can be of much greater importance for the local population than for tourists. Such an approach would certainly have an even greater impact on the integration of all factors and actors of the local community, raising the level of service provision in the specific area. Regardless of whether they represent newly formed individual facilities and contents or are adapted spaces of existing facilities such as cooperative homes.

The example of the Loisium winery (Langenlois, Austria, architect: Steven Holl, 2003 (Figures 5-7)) indicates precisely the above-mentioned possibility of combining related contents with the aim of economic and cultural sustainability [14]. In addition to the hotel facilities (rooms, wellness program,...), wine cellar and restaurant, the visitor has at his disposal a multi-purpose area, a bookstore and a store of local products. Also within the complex there are spaces intended for holding seminars that can function independently from the others. Within the multipurpose role, we should mention open spaces in the form of terraces and plateaus in the immediate surroundings of the building and vineyards, suitable for various events such as concerts and film screenings (or lectures), which may or may not be directly related to the culture of winemaking. The specific example of the Loisium visitor center is only one in a series of similar buildings in contemporary architectural practice that has in every sense moved the previous boundaries and standards both in terms of performing touristic activities and in terms of planning production and agricultural capacities in rural areas.

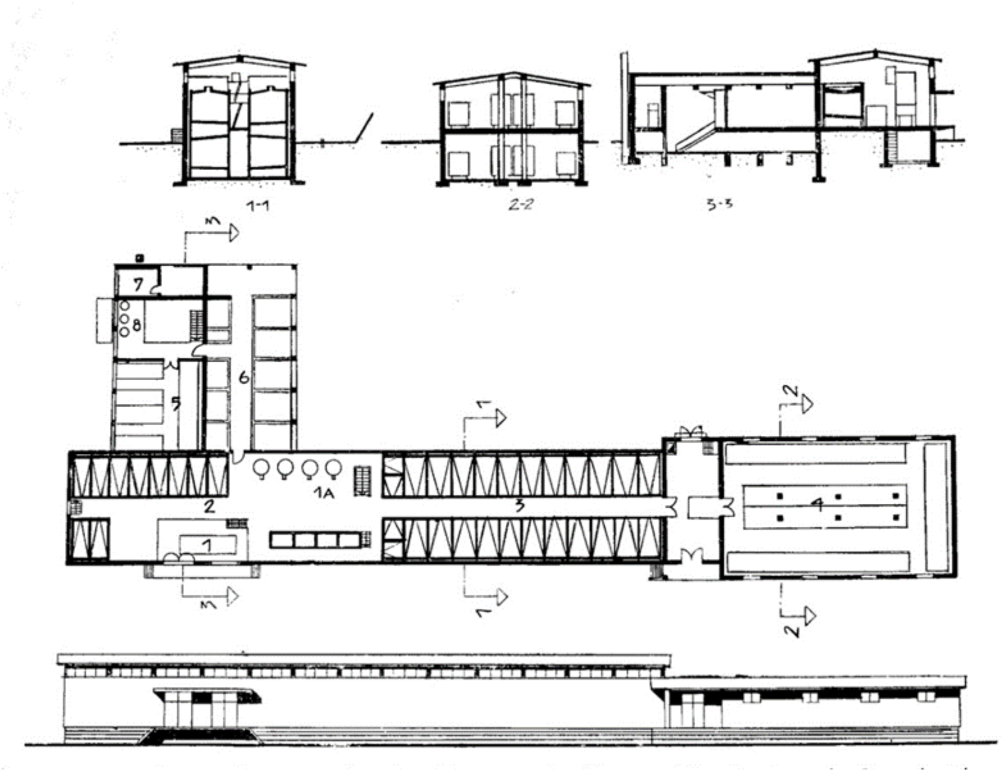


Figure 4. Project of a winery in the village of Rajac with a capacity of 150 wagons („Invest zavod“Belgrade) (Б. Којић, Ђ. Симоновић, Пољопривредне зграде и комплекси, Београд: Грађевинска књига, 1978. p.163.)

Figure 5. Loisium Winery (Langenlois, Austria, architect: Steven Holl, 2003) (https://www.loisium.com/en/weinwelt-langenlois)

Figure 6. View of the Loisium winery in relation to the settlement (https://www.archiweb.cz/en/b/vinarske-centrum-loisium)

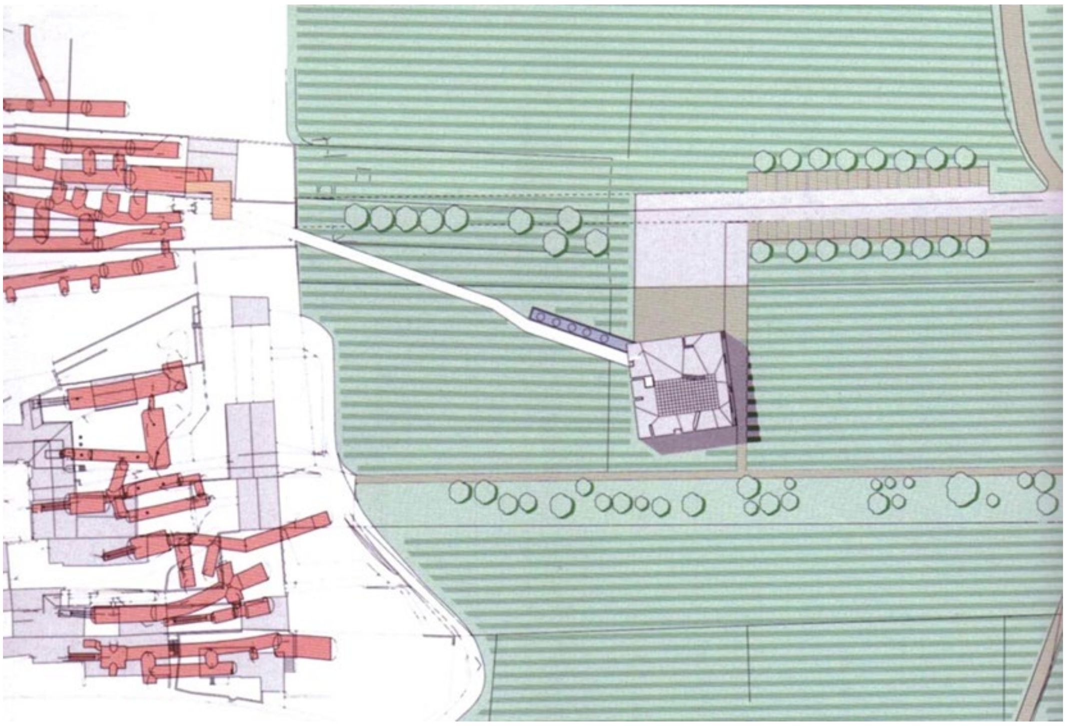


Figure 7. Loisium winery, situation. (https://www.archiweb.cz/en/b/vinarske-centrum-loisium)

5. CONCLUSION

The modern way of life and the changed conditions of functioning in rural areas have called into question the need to return the deprived functions to the countryside or, if they did not exist until now, to integrate them. The existence of public purpose facilities such as the local office, ambulance, post office and similar facilities essentially mean the survival of the population on their hearths, ie. sustainability of the settlement. If the trend of their non-existence continues, the smallest problem is that the centers of settlements will disintegrate spatially and functionally. A much bigger problem will be the deepening of the depopulation process, which will inevitably lead to the closure of most settlements in rural areas. It must be understood that the new contents do not have an exclusive role in the provision of certain services, but create the possibility of employment and also the active presence of state institutions by providing certain services of a public nature (administration). On the other hand, the improvement of the content should not be exclusively viewed as a need of the local population, but should indicate a situation in society that clearly does not recognize the natural, economic, cultural and other potentials of rural settlements and areas in a global context.

Bearing in mind the spatial-geographic criteria of the structure of most rural settlements, for example in the Republic of Serbia (broken and semi-broken settlements), the integration of various contents within the newly formed centers would mean enormous support for rural development. Carrying out tourist activities in this sense should be on the second plan, that is, it should be the initiator of all other activities, and above all agricultural production as one of the basic determinants of rural areas.

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28
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ARCHITECTURAL PHOTOGRAMMETRY APPLIED TO THE CATALOGING OF HISTORICAL HERITAGE. A CASE STUDY OF A BUNKER IN LA LÍNEA DE LA CONCEPCIÓN, SPAIN

Abstract

Photogrammetry is an emerging tool in architecture, conservation, cataloging, and maintenance of heritage, offering a precise and efficient methodology for generating three-dimensional digital models. This work presents a comparative study of photogrammetric methods, focused on a low-cost software application, with the aim of evaluating its effectiveness in capturing and faithfully representing architectural and cultural elements, such as the bunkers located in La Línea de la Concepción (Spain), where the seismic hazard is not neglectable. The results reveal that the method choice depends on the object being digitized. Some programs are more suitable for capturing fine details, while others excel in reconstructing more complex structures.

Keywords: Photogrammetry, bunker, historical heritage, 3D modeling

ПРИМЈЕНА АРХИТЕКТУРНЕ ФОТОГРАМЕТРИЈЕ НА КАТАЛОГИЗАЦИЈУ ИСТОРИЈСКЕ БАШТИНЕ. СТУДИЈА СЛУЧАЈА БУНКЕРА У МЈЕСТУ ЛИНЕА ДЕ КОНСЕПСИОН, ШПАНИЈА

Сажетак

Фотограметрија је нова алатка у архитектури, очувању, каталогизацији и одржавању баштине, која нуди прецизну и ефикасну методологију за генерисање тродимензионалних дигиталних модела. Овај рад представља компаративну студију фотограметријских метода, са фокусом на примјену приступачних софтвера, са циљем процјене његове ефикасности у снимању и вјерном представљању архитектонских и културних објеката, као што су бункери који се налазе у мјесту Линеа де Консепсион (La Línea de la Concepción) у Шпанији, гдје се сеизмичка опасност не може занемарити. Добијени резултати откривају да избор методе зависи од објекта који се дигитализује. Неки програми су погоднији за снимање ситних детаља, док се други истичу у реконструкцији сложенијих објеката.

Кључне ријечи: фотограметрија, бункер, историјска баштина, 3Д моделирање

1. INTRODUCTION

In the advancements of architectural analysis, photogrammetry has emerged as a fundamental tool in a wide range of fields, such as precise data collection and the generation of three-dimensional models. Its application extends from cartography and topography to archaeology and civil engineering, even combined with Light Detection and Ranging (LiDAR) technology for peculiar subjects such as monitoring indigenous settlements [1]. Additionally, it can be used for aerial modeling like the works done with Reality Capture software [2]. This opens up the possibility of investigating and promoting the cataloging of elements that may be forgotten over time and through the degradation of elements.

Indeed, a series of investigations were carried out with aerial photogrammetry using drones and LiDAR, describing the advantages and disadvantages within the framework of architecture and landscape [3]. This provides precise archaeological information, although the method of aerial overflight via airplane requires subsequent orthophotographic restitution. The main studies conducted by Rouco Collazo et al. [4] focused on Órgiva and Poqueira, cities located in Sierra Nevada (Granada, Spain). Similarly, there are applications for the evaluation of archaeological sediments in different historical stages [5].

Therefore, photogrammetry not only plays a fundamental role in the cataloging and documentation of buildings, facilitating efficient management of architectural inventories and tracking changes over time. Furthermore, its application in aerial surveying brings a unique perspective for inspecting large areas and urban planning.

Particularly concerning architecture, it offers innovative solutions to a variety of challenges in the preservation, design, and monitoring of structures [6]. Hence, the importance of historical documentation of architecture is emphasized in a study aimed at recreating historical elements from old photos taken from different angles [7]. For example, the Structure for Motion (SfM) process applied to Caltanissetta Centrale Station consisted of detecting and matching features to result in a three-dimensional virtual model. Kutlu & Soyluk used photogrammetry to support structure calculations through the Finite Element Method (FEM), revealing that photogrammetric use yields similar values to traditional calculation methods [8].

One of the most impressive applications is in the so-called "living architecture". It requires a more complex geometric analysis, as the geometric shapes of trees are more intricate than practically orthogonal ornamentation. This type of element requires multiple 360º photographic shots around the figure. Still, the definition is much more complex, as the point cloud is not as well defined for analyzing specific small-scale details. However, in this regard, Middleton et al. [9] allowed for the evaluation of tree growth in a very interesting way between March 2018 and March 2019, monitoring their behavior and being able to anticipate future interventions.

In the field of historical heritage restoration, photogrammetry serves as a valuable tool for the detailed documentation of deteriorated architectural elements, allowing for a precise and faithful reconstruction of them. Additionally, its ability to recreate constructions at any scale opens up new possibilities in the field of architectural design, allowing for the creation of detailed 3D models that can be used for subsequent prints, digital visualizations, and structural analysis [8]. From another point of view, the practice of this technique is being developed in more disciplines similar to traditional architecture, such as interior design. In these cases, the dense point cloud is usually used to recreate the space as realistically as possible [10]. Besides, Firzal conducted a low-cost study to document medium-sized historical buildings, specifically a temple located in Indonesia [11]. The methodology was based on capturing images with appropriate overlap, both from a ground position and through drone shots. Therefore, with close-range photogrammetry (CRP), a three-dimensional model of the actual state can be obtained with the appropriate level of detail according to the final use of that model. Asadpour utilizes photogrammetry to catalog important architectural artworks located in Iran, focusing on simple ornamental elements such as bunkers [12]. They also recreate, based on the obtained model, the arrangement of the construction elements, especially those located on the roofs of mosques. Similarly, Brenner et al. undertook a study on photogrammetry and laser scanning as a method to obtain precise details of special pieces [13]. That study demonstrated that these techniques can take an accurate and realistic image of structural nodes on complex facades to proceed with a more precise intervention. This allows, in the event of having to repair a specific piece, to create a replacement through laser scanning and subsequent 3D printing.

Among the most promising areas of application of photogrammetry in architecture is its ability to assess structural pathologies in buildings [14]. Through the analysis of photogrammetric images, it is possible to identify and evaluate defects in the structure without the need to use continuous monitoring methods, offering an efficient and non-intrusive alternative for assessing the condition of buildings. In the same line, photogrammetry shows great potential in the large-scale determination of macroseismic models, constituting a first step in the automatization of the identification of seismic vulnerability parameters, such as in-plan and vertical irregularities, level of preservation or main dimensions.

To carry out this evaluation, in this research, different low-cost software will be used, such as Meshroom or ReCap Photo. Tests will be conducted in open environments and field situations, using objects of different sizes and shapes to simulate real conditions. Special attention will be paid to the accuracy of the three-dimensional reconstruction, spatial resolution, and the ability to capture specific details. Additionally, a comparative analysis of the results obtained with each software will be carried out in order to identify specific strengths and limitations of each tool in terms of scope and accuracy.

2. STUDY AREA

La Línea de la Concepción is a town located in southern Spain, specifically in the province of Cádiz (Figure 1). It is situated on the coast of the Strait of Gibraltar, on the northern shore of the isthmus that connects the Iberian Peninsula with the African continent, in an area called Campo de Gibraltar. This location grants it considerable historical and commercial importance, as it is one of the main points of connection between Europe and Africa [15].

Figure 1. Location map of La Línea de la Concepción (Spain). EPSG: 25830. Source: www.ign.es

During the Spanish Civil War (1936-1939), La Línea de la Concepción became a key strategic point for the Republican defense due to its proximity to Gibraltar and its military port [16]. To protect this position, bunkers were built along the coast and in the surrounding hills. These constructions, mainly made of reinforced concrete and cement as dictated by the construction boom of the time [17], were designed to withstand aerial and ground attacks [18], providing shelter and firing points for Republican troops. Strategically located, these bunkers had privileged views of the terrain and were equipped with firearms and communication systems to coordinate defense. They represent tangible evidence of the conflict and the military architecture of the time, highlighting the importance of La Línea de la Concepción in the history of the Spanish Civil War. Currently, these remnants form a part of the intrinsic value of the city, being relics of a very important armed conflict for the country's history [19].

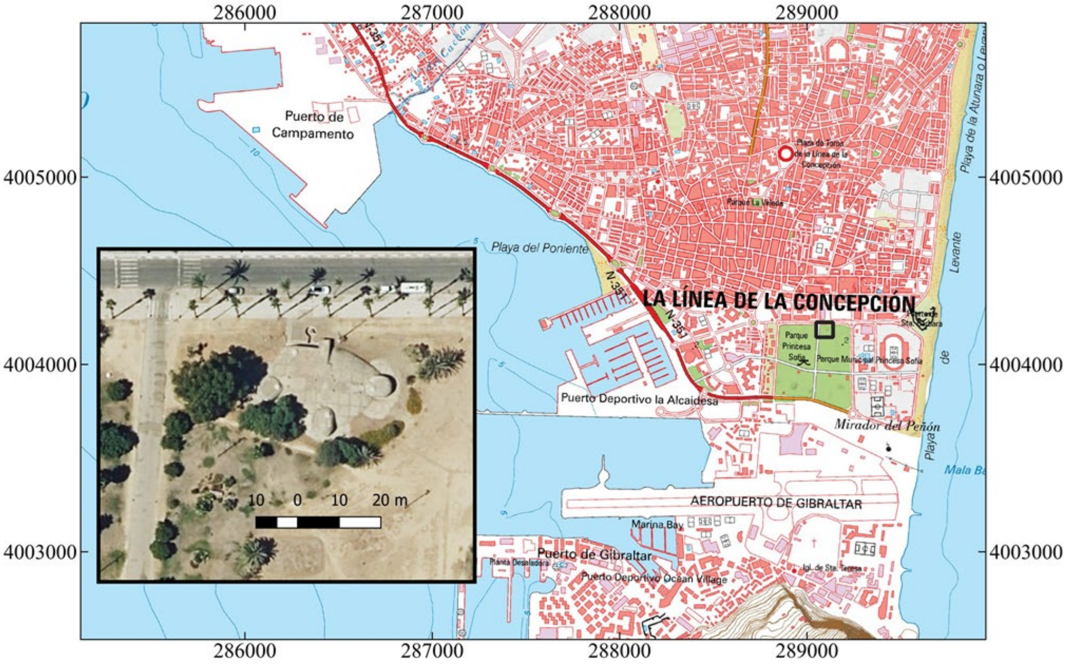

Figure 2. Site map of the bunker in La Línea de la Concepción (Spain). EPSG: 25830. Source: www.ign.es

The bunkers built during the Spanish Civil War are an important historical and architectural legacy that, in many cases, is unprotected and in a state of decay. These structures, also located in other places in the Campo de Gibraltar, face challenges in terms of conservation due to exposure to climatic and chemical elements such as environmental salinity. This reveals a lack of resources for their maintenance. However, the application of photogrammetry can offer a viable solution for documenting, evaluating, and planning the conservation of these historical sites.

The use of photogrammetric applications, as a method for obtaining three-dimensional models, has revolutionized the way we understand and preserve architectural heritage. Its ability to accurately recreate elements of different dimensions and shapes has found applications in the restoration and conservation of historic structures. Particularly in this case where one of the abandoned bunkers located in La Línea de la Concepción is being analyzed (Figure 2). Architectural restoration is a complex process that requires a precise understanding of the original structure and the damages suffered over time [20]. Therefore, these types of techniques offer an efficient and precise solution for capturing the geometry and characteristics of historical buildings. This technology streamlines the documentation process and provides a basis for restoration planning, minimizing the loss of important details and ensuring the authenticity of the intervention.

Hence, the conservation of the historical architecture of bunkers is important for cultural and heritage reasons, as well as for its value in preserving historical memory. These sites bear witness to significant events that are part of the collective identity of a society [21], and their loss or degradation represents an impoverishment of historical narrative. Additionally, early intervention in the conservation of these structures can result in significant long-term savings. Photogrammetry is a precise and cost-effective tool for documenting and evaluating damages, allowing for the identification of structural problems and the establishment of conservation strategies before they become more expensive to remedy. Drap et al. [22] developed a study combining laser scanning techniques, short-range photogrammetry, and field analysis, for the cataloging of archaeological objects, reducing the cost of intervention.

Another essential aspect in the current era for the conservation of military and defensive architectural heritage is access to affordable technologies. Low-cost photogrammetry has enabled access to the creation of realistic three-dimensional models for professionals who need its support. This has allowed conservators and local communities to document and study their heritage in a cost-effective manner [23]. This form of photogrammetry, which uses consumer cameras and open-source software, has expanded the possibilities for heritage conservation in environments with limited resources [24].

Therefore, photogrammetry has established itself as a highly useful tool in the recreation and conservation of heritage, especially in contexts of those forgotten elements that suffer degradation over time, such as climatic agents or natural actions like earthquakes. In fact, in terms of seismic hazard, La Línea de la Concepción (Spain) is estimated to experience a peak ground acceleration (PGA) of 0.10 g for a return period of 475 years. This implies that the maximum expected intensity according to EMS-98 scale is VII (Damaging) [25].

3. METHODOLOGY

The methodology followed for the study involves the use of various low-cost photogrammetry software with the aim of creating a detailed model of the composition of the remains of the aforementioned bunker, specifically number 162 according to the La Línea de la Concepción City Council's cataloging. Different techniques and tools were used to capture images from various angles and heights, ensuring complete coverage of the object.

In order to graphically reconstruct a historical object or building using photogrammetry with software, a general process combining image capture techniques and digital processing is followed. First, a series of photographs of the building are taken from multiple angles using a digital camera with sufficient resolution. These images serve as input data for the software. Next, the images are imported into the software, which utilizes computer vision algorithms to reconstruct the three-dimensional geometry of the building from the photographs. The reconstruction process involves identifying common points in the images (matching), estimating the camera position in each image, and triangulating points in three-dimensional space.

The software to be used in this study is Meshroom and ReCap. These programs employ spatial data structure techniques and optimization algorithms to produce a detailed three-dimensional model of the building, including its shape and textures. The final result is a 3D digital model that can be visualized and manipulated in Computer-Aided Design (CAD) software or 3D visualization applications.

Firstly, Meshroom is an open-source software that facilitates the 3D reconstruction of scenes and objects from photographic images [23]. Its intuitive graphical interface and automated process simplify the workflow, while it has the ability to leverage CPU processing. Meshroom can be combined with other modeling programs such as MeshLab and the non-free Agisoft software [24].

On the other hand, ReCap Photo is an Autodesk software that offers solutions for reality capture and modeling for architectural projects. Using images captured with standard cameras, it generates accurate 3D models with dense point clouds [26], which can be used for visualization, analysis, and design in architecture. This tool allows obtaining a realistic image of the architectural shape of an element.

Meshroom, offering advanced features such as SfM and Multi View Stereo (MVS), requires a deeper technical knowledge and may be more suitable for experienced users focused on virtual reality tasks, supporting more than 1000 images. On the other hand, ReCap, part of the Autodesk suite, provides a more intuitive interface and is optimized for large amounts of data, although its free version supports up to 100 images. The final quality of the models depends on various factors, including the quality of the input images and the software configuration. Processing time may vary, with Meshroom being slower due to its processing from the computer itself. Whereas ReCap can be faster thanks to its optimization and cloud processing.

For the creation of the virtual model, photographs have been captured following the provided scheme (Figure 3). Each image has been selected and processed with appropriate overlap to ensure the accuracy and fidelity of the model and environment. Different angles and perspectives have been used according to the scheme, thus achieving every detail necessary to accurately recreate the object.

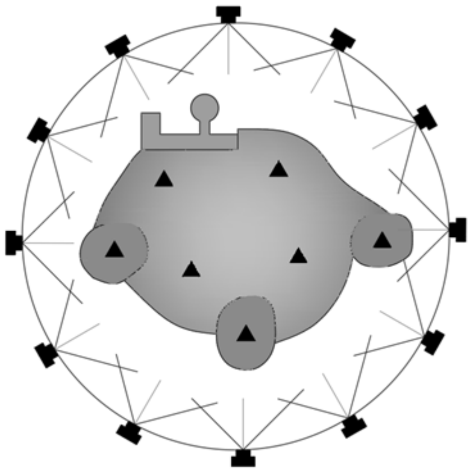

Figure 3. Camera position around the bunker with image capture angles.

Initially, the Meshroom software version 2023.23.0 was used to generate an initial model of the bunker. A total of 336 photographic shots were captured from the entire perimeter of the bunker, with an approximate minimum overlap of 30% between the photographs. This coverage ensures the capture of hidden details and creates a representation of the structure as a whole. These images were taken with a Xiaomi mobile device model 2201113PG, with an estimated focal distance of 5.948 m, which was determined from the metadata procured by Meshroom.
Subsequently, an additional survey was conducted using the ReCap Photo program. At this stage, 100 photographs were captured with an approximate minimum overlap of 30%, focusing especially on the top part of the bunker (Figure 4). For these shots, a pole was used, and photos were taken from different angles, even climbing onto the bunker's roof, in order to obtain a complete and detailed perspective of this area. In the scheme of the Figure 3, areas where the photos were taken from high points are marked with a triangle.

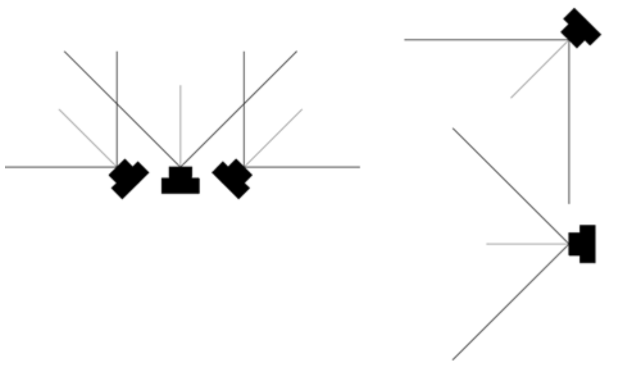

Figure 4. Camera position from image capture angles. Left: plan view position, Right: vertical position.

Finally, a specific survey of particular parts of the bunker was carried out. 94 photographs were captured for one of the main faces, and 26 photographs were taken concentrically around two upper vents. The first vent shows advanced wear, while the second one is in a more preserved state. In both cases, the interior reinforcement is rusted, and the metal elements supporting it have broken.

4. RESULTS

The results of the photogrammetric study reveal several important observations:
Meshroom produces a dense point cloud but fails to fully define the element (Figure 5 and Figrure 6). It places elements in incorrect positions, which may compromise the accuracy of the model.

Figure 5. High correspondence of the photos taken with the points obtained by Meshroom.

Figure 6. Low correspondence of the photos taken with the points obtained by Meshroom.

ReCap provides a more complete survey of the bunker as a whole compared to Meshroom (Figure 7 and Figure 8). Despite this, it still fails to define much of the element, indicating limitations in its ability to capture details.

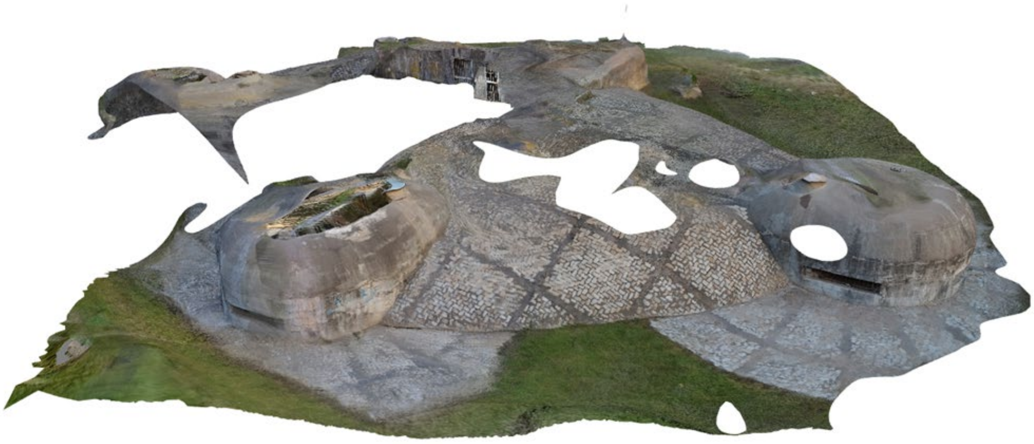

Figure 7. Realistic representation of the entire bunker. Aerial view of the South face.

Figure 8. *Realistic representation of the entire bunker. Aerial view of the North face.*

A much more complete image of one of the bunker faces is obtained compared to the other technology. Although the definition improves, some errors are still found at the top of the element (Figure 9), suggesting possible difficulties in the accuracy of certain areas. This fact is more evident in the mesh (Figure 10).

Figure 9. *Realistic representation of a bunker dome.*

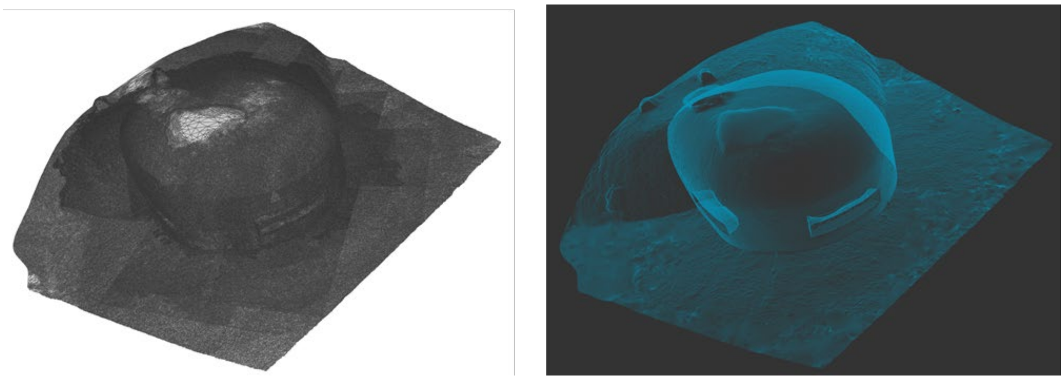

Figure 10. *Mesh representation of a dome. Left: point correlation version, Right: laser-type meshing.*

The survey of two vents is carried out with total detail and precise definition (Figure 11 and Figure 12), indicating that ReCap can be especially effective in capturing smaller or detailed objects.

Figure 11. *Representation of a poorly preserved vent. Left: realistic version, Right: point correlation version.*

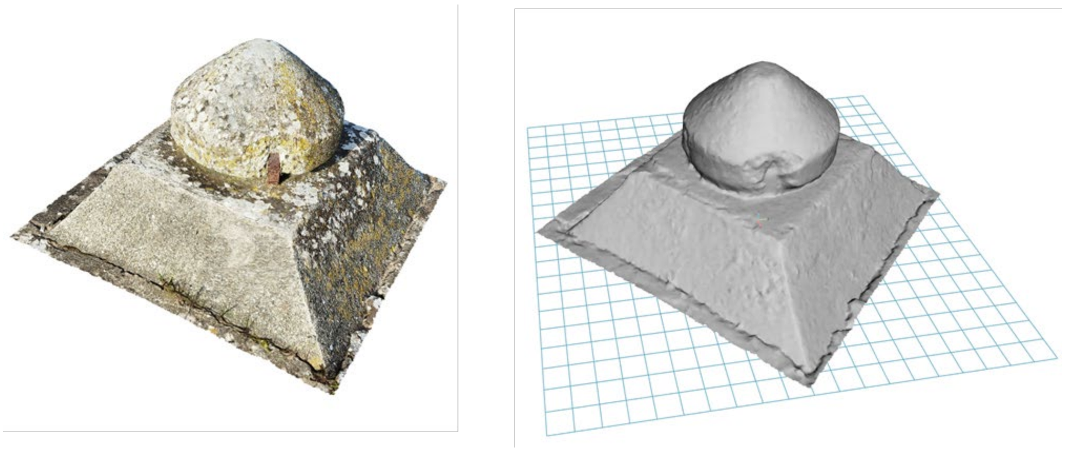

Figure 12. *Representation of well-preserved vent. Left: realistic version, Right: extruded version.*

5. DISCUSSION AND CONCLUSIONS

Although photogrammetric methods are considered extremely useful in generating three-dimensional models, it is important to consider some limitations, especially regarding the size of the elements to be developed. It is recommended to focus the analysis on objects of medium size, as the difficulty of precision increases significantly with larger elements. By focusing on medium-sized objects, the precision and definition capabilities of these methods can be maximized, thus optimizing the obtained results and rendering time. In this way, a balance between the utility of photogrammetry and the inherent limitations of its application in large objects and low-cost programs can be achieved.

The results obtained through various photogrammetric methods have demonstrated the ability to create high-quality three-dimensional models for small-sized objects. However, when attempting to reproduce larger elements, significant problems arise in low-cost methods. Despite this, it has been shown that these techniques are very useful in the field of cataloging, especially for the conservation of forgotten architectures within cities.

During the research development, it has been found that the Meshroom program is capable of generating a dense point cloud, although it fails to fully define large elements. On the other hand, ReCap, while improving precision compared to Meshroom, still faces difficulties in clearly defining such elements. However, for specific parts of the construction, ReCap demonstrates considerable ability to accurately define details.

In the photogrammetric tests carried out on the bunker vents, being small but valuable elements, remarkably precise definition has been observed. Additionally, they provide an interesting perspective on the pathologies presented by the vents, such as oxidation and elevation, as well as other information for their cataloging and possible restoration processes. Similarly, as in this case study, photogrammetry applied to small ornamental objects of historical value can greatly assist in their recreation and restoration. In the study by Triviño-Tarradas et al., pieces were recreated through computer numerical control (CNC), which yielded excellent and very precise results [27].

As a final reflection, according to Shults, these systems should be used in engineering and architecture faculties to improve education and digital visualization for students [28], allowing them to handle different tools and promoting their utility for the preservation of heritage.

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29

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THE RELATION OF SPATIAL PLANNING DOCUMENTATION TO GREEN OPEN PUBLIC SPACES IN BOSNIA AND HERZEGOVINA

Abstract

Open public spaces in urban and rural areas are essential because they encourage interaction between citizens and connect the built urban fabric. That is why the planning and maintenance of these spaces are vital and require constant improvement following modern man's needs. For this reason, special attention must be paid to these areas when planning documents are in creating. This work investigates the relationship between planning practice in Bosnia and Herzegovina and green open public spaces. Given that Bosnia and Herzegovina has a specific planning system, spatial planning documentation of different spatial levels will be analyzed in the paper. The results should indicate ways of treating green open public spaces in the spatial planning process.

Keywords: open public spaces, spatial planning documentation, planning levels

ОДНОС ПРОСТОРНОПЛАНСКЕ ДОКУМЕНТАЦИЈЕ ПРЕМА ЗЕЛЕНИМ ОТВОРЕНИМ ЈАВНИМ ПРОСТОРИМА У БОСНИ И ХЕРЦЕГОВИНИ

Сажетак

Отворени јавни простори у урбаним и руралним срединама су неопходни јер подстичу интеракцију између грађана и повезују изграђено урбано ткиво. Зато су планирање и одржавање ових простора од виталног значаја и захтијевају стално унапрјеђење пратећи потребе савременог човјека. Због тога се овим областима мора посветити посебна пажња приликом израде планских докумената. Овај рад истражује однос између праксе планирања у Босни и Херцеговини и зелених отворених јавних површина. С обзиром на то да Босна и Херцеговина има специфичан систем планирања, у раду ће бити анализирана просторно-планска документација различитих просторних нивоа. Резултати треба да укажу на начине третирања отворених јавних простора у процесу просторног планирања.

Кључне ријечи: отворени јавни простори, просторнопланска документација, нивои планирања

1. INTRODUCTION

The development and improvement of the use of space within the borders of a specific state, region, city or municipality directly depends on the existing spatial planning documentation created for those spaces. Spatial plans represent a main planning document of a particular spatial level and provide guidelines for developing and improving infrastructural, economic, housing, and natural systems. More precisely, the key objectives of spatial planning are the resolution of changes in land use, the determination of different land uses, and the realization of public interests in terms of land use [1]. In this way, the holders of spatial planning documents tend to change the space according to the needs of modern man and current trends of spatial development. The creation of the mentioned documentation certainly requires a detailed analysis of the existing state of the infrastructure systems, the degree of development and construction of the area, analysis of demographic parameters, etc. It also requires projections of possible impacts of the proposed solutions on the planned space.

Spatial planning practice today differs in many ways from the 20th century and even from the practices adopted at the beginning of this millennium. Sustainable development has undoubtedly been one of the priorities in spatial planning for years, but today, special attention is paid to climate change, which significantly impacts almost all urban and rural areas. That is why planning, improving and maintaining open public spaces, especially green open public spaces in urban areas, is considered one of the most critical tasks of planning practice [2]. It is important to emphasize that in spatial planning documents, land is divided into urban and rural areas (rural areas include forests, agricultural land, waters, natural areas, etc.). At the same time, land in urban areas is further classified according to purpose into zones of industry, housing, infrastructure systems, protective belts, etc. Green areas, belts, and corridors indeed take their place in this division. Unfortunately, in urban development, primacy has been taken over by the increase in population density, which directly causes the dramatic appropriation of green areas and other public amenities in residential areas [3]. Although the plans generally envisage different purposes for these spaces, the interests of investors, city authorities, and other space users lead to neglecting the planning documentation or changes to the spatial planning vision. That is why changes in legislation, spatial planning documents, and various concessions are adopted to make changes possible. Although spatial planning documents do not define the final development and appearance of green open public spaces, these documents, as the main ones, contain guidelines and recommendations that lower-order plans, such as urban plans and regulatory plans, must adopt and apply. Therefore, in analyzing the development and maintenance of green open public spaces, it is important to investigate the process from the main planning document to the realization itself. In this regard, this research can be the first in a series to examine the complete planning process for developing green open public spaces and the relationship of all planning documents to these essential urban areas. As primary documents, spatial planning documents should contain guidelines, recommendations and obligations that lower-order plans must comply with regarding developing open public spaces. The approach to this problem differs from country to country, from one planning practice to another. Of course, this is conditioned by the degree of development of a specific area and the fundamental goals of spatial planning documents.

Open public spaces, especially green spaces, according to the interpretation of Alexander Wandl and his associates [4], are essential in cities and other smaller communities. These spaces contribute to urban and rural environments in three ways. First, open public spaces are vital for the population because they encourage well-being, interaction, socializing, and recreation. Also, open public spaces contribute to the protection of biodiversity and the development of ecosystem services. Indeed, the economic aspect of these spaces should not be neglected because they directly affect the increase in the value of the surrounding land.

The spatial planning system in Bosnia and Herzegovina is very specific. Compared to the systems in other countries, there is no single main planning document in Bosnia and Herzegovina, but planning is organized differently. Considering the political and social structure of Bosnia and Herzegovina, spatial planning has three primary planning documents, namely the Spatial Plan of the Federation of Bosnia and Herzegovina, the Spatial Plan of the Republika Srpska, and the Spatial Plan of the Brčko District of BiH. All spatial plans of a lower order in the entities Federation of Bosnia and Herzegovina and the Republika Srpska must be harmonized with the already mentioned spatial plans. The spatial plan is the primary document in the Brčko District of Bosnia and Herzegovina, while the Urban Plan is the next most powerful. Based on the above, it is clear that in Bosnia and Herzegovina, the planning, development, improvement and maintenance of open public spaces, including green areas, does not have a single policy but depends on the visions and goals of the primary planning documents.

In connection with that, this paper examines ways of treatment, that is, planning and developing green open public spaces in Bosnia and Herzegovina. For this reason, the paper will analyze and compare five plans of different spatial levels, i.e., their approach to developing green open public spaces. The plans that will be analyzed are the Spatial plan of the Republic of Srpska, the Spatial plan of the Brčko District of BiH, the Spatial plan for the area of Tuzla Canton, the Spatial plan of the City of Banja Luka, the Spatial plan of the Municipality of Čelić. The mentioned plans were selected for research to analyze the relationship between spatial plans of all spatial levels in Bosnia and Herzegovina and green open public spaces. In other words, one spatial plan was selected for entity, city, municipal and cantonal levels, as well as the spatial plan of Brčko District of BiH as a single administrative unit of local self-government under the sovereignty of Bosnia and Herzegovina [5] . Due to the complexity of the planning system, the spatial plan of the Federation of Bosnia and Herzegovina was omitted from the research, but the cantonal and municipal spatial plans belonging to the territory of the mentioned entity were analyzed. On the other hand, the paper analyzes the spatial plan of the entity Republika Srpska, as well as the largest administrative unit on the territory of this entity that has the status of a city, namely the city of Banja Luka.

The work aims to conclude how planning practice and spatial plans (as a finished product) treat open public spaces and green areas. Indeed, through comparative analysis, we try to find answers to how this space segment is treated in plans intended for different spatial levels. Based on the results, conclusions will be drawn about spatial planning practices in Bosnia and Herzegovina regarding open public spaces, and guidelines and recommendations will also be given as to how the considered area of planning can be improved and improved in order to protect green open public spaces from the expansion of construction and rapid disappearance of these spaces.

2. BACKGROUND RESEARCH

Open public spaces are essential in urban areas. These spaces in the urban structure represent links or fabric between different city entities. Also, open public spaces allow citizens to socialize, connect, spend their free time there, and perform recreational activities [6]. The main difference between open public spaces and other open spaces, such as courtyards of residential buildings, is that open public spaces are common areas that belong to everyone, i.e. they are open to all people, and at the same time, they are controlled and maintained by the state [7]. In this regard, it is clear that these spaces must be subject to planning and design processes managed by city, regional or national authorities. Indeed, it is essential to note that open public spaces can be classified into specific categories, and one of them is the one that speaks about the structure of these spaces, i.e. whether they represent grey or green public spaces. According to this division, open green public spaces include parks, city forests, green promenades along rivers, and other bodies of water. According to the data from the valid Urban Plan of the city of Brčko adopted for the period 2007 - 2017 (validity period extended until the adoption of the new plan), green areas in the city are divided into Green areas of public use, green areas of limited use, green areas of particular purpose, forests and forest lands And other green areas [8]. In addition to the already mentioned roles in urban environments, these spaces enable users to connect with nature, i.e., escape from the built environment space [9]. Based on the above, it is clear that these spaces directly impact citizens' quality of life precisely through the opportunities they provide. Of course, not all of the mentioned areas have the same importance in terms of the quality of life of citizens. The most significant are green areas for public use, including city parks, parks in settlements, parks along water bodies, and green spaces along roads and other public spaces. Also, if they are represented in urban areas, forests and forest lands are extremely important precisely because they allow citizens to connect with nature. These spaces are the subject of research in this work. In connection with the mentioned importance of the mentioned spaces on the one hand and the role of spatial planning documentation on the other hand, which is an instrument for improving the quality of life of space users as well as for the rational and clearly defined use of space, it is crucial to define the commitment of the planning process to improving the quality of life precisely through the segment of planning and development of green open public spaces in urban areas.

However, the attitude towards these areas is not identical in all spatial planning documents. Spatial planning practice is very heterogeneous around the world. Differences can also be seen in creating a plan, collecting data, involving all interested users of the space, and, therefore, also in the finished product, which is the spatial plan of a specific space. However, within countries or regions, certain principles and postulates are respected so that the development of infrastructure systems, built spaces, and open, common areas follows a certain continuity. In other words, the aim is to create a homogeneous, compact space by coordinating and making plans. When it comes to green open public spaces from research conducted by Tüzin Baycan-Levant and Peter Nijkamp [10], it is possible to conclude that planning processes and spatial planning documents are entirely coordinated in terms of development and maintenance of the mentioned areas. However, they state that through a comparative analysis of 23 European cities, a result was obtained that indicates that in the green image of Europe, three geographical regions appear that can be divided into northern, southern, and eastern Europe. Also, when comparing planning policies worldwide, it is evident that different terms are used for green areas. So, for example, the term urban green place in Russia means urban land covered with vegetation that can be used by all citizens and arranged by the municipality. On the other hand, in Europe and the USA, this term also includes private open green areas that are not allowed to be accessed by the public [11].

In this paper, as mentioned, we strive to find answers to how spatial plans in Bosnia and Herzegovina treat green open public spaces. Considering the very heterogeneous spatial planning system and the insufficient coordination of spatial plans, this paper will reveal how spatial plans of different spatial levels treat green open public spaces. More precisely, do these plans envisage the development of new green areas, the revitalization and reconstruction of existing ones, and their maintenance, or do they ignore and marginalize green open public spaces in Bosnia and Herzegovina? Spatial planning in Bosnia and Herzegovina is divided and entrusted to the entity authorities of the Republika Srpska and the Federation of BiH and the authorities of the Brčko District of BiH. There is no main planning document for the country's entire territory, but it has been replaced by three plans for the mentioned territorial units. In Brčko District, the spatial plan is the primary planning document, and the next in power is the urban plan. The system is different in the RS and FBiH entities. After the primary planning documents are adopted for the entire territories, the next in force in the RS are the plans of cities and municipalities, while in the FBiH, there are plans for each canton, and after that, spatial plans adopted for cities and municipalities [12].

This paper analyzes five spatial plans for each of the spatial levels, namely the Spatial Plan of the Republic of Srpska, the Spatial Plan of the Brčko District of BiH, the Spatial Plan of the Tuzla Canton, the Spatial Plan of the City of Banja Luka and the Spatial Plan of the Municipality of Čelić. Based on comparative analysis, an attempt is made to investigate how planners treat green open public spaces in the mentioned plans. Also, an attempt is made to answer whether the practice of spatial planning is complementary within the state or whether each level of government has a certain degree of autonomy to treat the same concepts and elements of space in its way. Concerning the already mentioned importance of open green public spaces, after the results have been obtained, the paper tries to make a final judgment about the spatial planning process and the approach to solving the problem of open green public spaces in Bosnia and Herzegovina. That is, their planning, development and maintenance. Also, based on the results, they try to give clear guidelines and recommendations for the practice of planning in which way the attitude towards these areas could be harmonized so that they are developed according to the same principles. The citizens' needs and the increasing degree of climate change indicate that the attitude towards these areas must be harmonized with regional and global spatial planning practices.

3. METHODOLOGY

The treatment of a specific public space with spatial planning documentation must be harmonized with the needs of all users of the space. This implies the necessity of involving all actors in the planning process, from city authorities and planners to private capital owners and citizens. Only in this way can spatial planning provide results that direct the city's development following its inhabitants' needs [13]. These results imply the achievement of spatial and social well-being and the realization of spatial planning solutions. On the one hand, we can assess its quality based on the methods and policies through which the spatial planning document was created.

On the other hand, we can evaluate a particular spatial planning document if we analyze it thoroughly or single out one of its segments, i.e. planning solutions and visions created for a particular spatial system or area. In this regard, in this paper, an attempt is made through a comparative analysis to find an answer to how spatial planning documents, that is, planning practice, treat open public spaces. More precisely, the paper aims to answer the question: How do spatial planning documents in Bosnia and Herzegovina treat green open public spaces, such as city parks, city forests, promenades along rivers, and others? Considering the fact mentioned in the paper that the spatial

planning system in Bosnia and Herzegovina is highly heterogeneous, and very often, plans of different spatial levels are not coordinated, it is necessary to analyze many plans. In this way, it is possible to get an answer to the question of whether green open public spaces have the same importance in all parts of Bosnia and Herzegovina or whether specific plans aim only to ensure their existence while others envisage the development of new areas, their maintenance and revitalization.
In further research, five spatial planning documents that are currently in force will be analyzed. As mentioned in the paper, spatial planning documents do not deal with detailed planning, design and development of green open public spaces. However, this level of planning still contains specific guidelines, goals, strategies and visions that lower-order plans must respect in the development of the aforementioned public spaces. For this reason, those segments of valid spatial planning documents of certain spatial levels in Bosnia and Herzegovina will be further analyzed. Also, concerning the previously mentioned division of green open public spaces (according to the Urban Plan of the City of Brčko), the focus is on the relationship of guidelines, goals, strategies and visions to green areas of public use (parks, green spaces along rivers, etc.) as well as city forests. In order to include all levels of planning, the relation of spatial planning documentation to green open public spaces will first be analyzed at the level of entities and Brčko District of BiH. After that, at the canton level in the Federation of Bosnia and Herzegovina, the area with the city's status, and finally, the spatial plan prepared for the municipal level.
The plans that will be analyzed are the following:

Table 1. Spatial plans that will be analyzed in the paper

Plan name	Duration	Year of adoption	Holder of the creation	Spatial coverage
Amendments and additions to the spatial plan of the Republic of Srpska until 2025	The plan initially lasted until 2015, and after the amendments to the first amendment, its duration was extended until 2025.	2015	JU „NOVI URBANISTIČKI ZAVOD REPUBLIKE SRPSKE''	The territory of the Republika Srpska entity.
Spatial plan of the Brčko District of Bosnia and Herzegovina 2007-2017	The spatial plan was adopted in 2006 with an expected duration of 10 years, but by the decision of the Assembly of the Brčko District of BiH, its validity was extended until the adoption of the new plan.	2006	Synerghia Spa, Italy	Area of the Brčko District of Bosnia and Herzegovina.
Spatial plan for the area of Tuzla Canton 2005 - 2025	The planning document is valid for 20 years, from 2005 to 2025.	2006	Zavod za urbanizam, Tuzla	Area of Tuzla Canton (the canton belongs to the Federation of BiH entity).
Spatial plan of the City of Banjaluka 2014 - 2034	The document is valid for 20 years, from 2014 to 2034.	2014	Institut za građevinarstvo ''IG'' Banja Luka	The tertian plan includes the area of the City of Banja Luka, the largest city of the RS entity.
Spatial plan of the municipality of Čelić for the period 2012 – 2032	The planning document is valid for 20 years, from 2012 to 2034.	2016	IPSA INSTITUT, Sarajevo	The document covers the territory of the municipality of Čelić, located northeast of the Federation of BiH.

4. RESULTS

As already mentioned, the paper will make a comparative analysis of spatial plans created and adopted for different levels of planning. In this part of the work, those parts of spatial plans that deal with the topic of green open public spaces will be extracted, and the approach of each of the already mentioned plans to the problem of development and maintenance of these spaces will be analyzed. Indeed, it is essential to note that higher-order spatial plans will not contain guidelines for developing specific, precisely defined city parks, etc., but will undoubtedly contain recommendations and specific planning policies.

4.1. RELATION OF SPATIAL PLANS TO GREEN OPEN PUBLIC SPACES

Spatial plans as a tool in space development have highly great power. In addition to the vision and guidelines a specific area provides, these documents can also influence specific systems to develop faster or have a higher priority than others through their implementation. Although this should not be the case, these documents can still influence specific systems to be developed at the expense of others. For example, a spatial plan can favour certain particular purpose zones in a certain way while at the same time neglecting the development of public or other spaces.

Amendments and additions to the Spatial plan of the Republic of Srpska until 2025

The Spatial Plan of Republika Srpska [14] was initially created with a period of validity until 2015, but by the decision of the Government of Republika Srpska, the time horizon was moved to 2025, and changes and additions to the original planning document were made accordingly. This planning document has a strategic development character and serves as a basis for further spatial and urban planning and the preparation of appropriate sector strategies. The essential vision of the plan is to activate the territorial capital of Republika Srpska and its constituent units.

This plan defines specific goals in terms of planning the further development and maintenance of green open public spaces. It is important to emphasize that this document analyzes significant green open public spaces on the entity's territory, such as rainforests, nature parks, national parks, and the like, and defines them as protected nature assets. Regarding the richness of these areas, the plan states on page 97: "Republika Srpska is characterized by a diversity of natural values. In this area, there is a whole series of natural assets that man has influenced by his actions, fitting them into urban spaces without taking away their basic value. In addition to rainforests (Perućica, Lom and Janj), of which there are more in such a small area than anywhere in Europe, there are also natural values created and nurtured by man in urban areas (parks, alleys, artificial lakes), from some of which deserve to be protected due to their characteristics."

The primary goal of protection and preservation of these areas stated in the plan, on page 97, reads: "Maximum protection and preservation of natural assets and retention of all values for the purpose of sustainable development - starting from air and water quality, plant cover, fauna, to global protection regions and areas, and the preservation of natural areas through activities, programs and projects to preserve biodiversity and protected natural assets."

However, although this planning document gives importance to open green public spaces, it is still important to emphasize that these are spaces of this type that belong to green areas not created by man and are not primarily located in urban areas. Of course, we are talking about national parks, nature parks, forest resources, etc. When it comes to green areas for public use in the city, the Spatial Plan of Republika Srpska does not provide clear guidelines and goals for their development, except the mention on page 138 where, in terms of stimulating the increase in the birth rate, it is stated that it is necessary, among other things, to plan and develop parks in cities.

Spatial plan of the Brčko District of Bosnia and Herzegovina 2007-2017

As mentioned, the spatial plan prepared for the territory of the Brčko District of Bosnia and Herzegovina [15] is the primary planning document on the territory of this municipality. This plan is the first document of this type for the territory of the District since its creation in 2000. The drafting of the plan was entrusted to an Italian firm that deals with these matters to minimize any national or political influences. The essential obligations of the plan were the change of land use, which has been disputed since the period of unification of the two municipalities in the Brčko District of BiH, as well as the determination of the course of transformation of the space. Although the plan was initially valid until 2017, it was extended until adopting the new Spatial Plan for the Brčko District of BiH territory.

When it comes to green open public spaces in this plan, public green areas are considered to be areas of children's playgrounds, public local parks, city parks, and parks outside the city. When it comes to these areas, the Spatial Plan prescribes the development of an Environmental Conservation Plan for two main goals, namely, guaranteeing the necessary protection and valuation of the environment and natural resources and supporting the economic and social development of the zone through the spread of popular science and adequately regulated forms of tourism and excursions.

Spatial plan for the area of Tuzla Canton 2005 - 2025

The spatial plan drawn up for the area of Tuzla Canton [16] is regional because it provides guidelines and recommendations for the development of the territory, including many cities and municipalities. Also, it is essential to emphasize that this plan must be harmonized with a higher-order plan, which in this case is the Spatial Plan of the Federation of Bosnia and Herzegovina. The plan was drawn up by the Urban Planning Institute from Tuzla in July 2006 and was adopted by the cantonal assembly in the same year. It was created to regulate the rational use of natural resources, protection of space, direction of economic development, and direction of social development. In terms of open green public spaces, this planning document decisively lists landscape park areas, i.e., the central parks of each municipality and natural areas in the canton.

Regarding the guidelines and recommendations and the further development and maintenance of these areas, the plan states on page 330 the following goals: "As a special and basic measure for the protection of natural areas, the implementation of the geodetic reambulation procedure and the completion of cadastral plans with the obtained data are determined. - preparation and adoption of the landscape basis of the Tuzla Canton for mandatory classification of all landscape areas into landscape types based on criteria (diversity of natural, architectural and traditional heritage)". The plan also provides measures for the protection of green public spaces and states the following on page 335:,, Protection measures primarily refer to: - reambulation of these areas, in order to prevent their permanent spatial reduction, - biological revitalization and rehabilitation, - installations park furniture and other contents."

Spatial plan of the City of Banjaluka 2014 – 2034

The Spatial Plan of the City of Banja Luka [17], which was prepared by the Institute for Construction "IG" Banja Luka, was adopted in 2014. This planning document had to be prepared following the higher-order plan, which is the Spatial Plan of the Republic of Srpska. The main concepts of the plan are balanced territorial development, activation of economic potential, development of tourism, protection and activation of natural values and potential, and environmental protection under current trends.

Regarding open green public spaces, the plan provides clear guidelines that must be applied to develop lower-level plans. Those guidelines determine the formation of a network of city parks, spacious avenues with walkways and tree rows, and neighbourhood parks. On page 37 of this planning document, the following is stated:,,Regarding the system of green areas, it is necessary to have a variety of organized green areas area, a large number of parks evenly distributed throughout the city, alleys, promenades, squares, green squares. Strive for the formation of linear green structures (rows of trees, etc.) which all green elements (parks, squares, etc.) will be connected. Take into account when planning the following parameters:

-Total area of public green areas in relation to no. residents of urban areas should be min. 12 - 15 m2/inhabitant, and it is desirable to achieve a greater representation of minimum.

- The minimum area of the park necessary for one visitor is 60 m2, while the percentage of visits in the summer period is 15% of the total number of residents of the urban area."

This plan also clearly defines nature parks, urban forests and other green public areas and describes them with further guidelines and recommendations for further development.

Spatial plan of the municipality of Čelić for the period 2012 – 2032

This planning document was prepared for the territory of the municipality of Čelić [18], which is located in the Tuzla Canton on the territory of the Federation of Bosnia and Herzegovina entity. In this regard, this planning document must be harmonized with higher-order plans, which in this case are the Spatial Plan of the Federation of Bosnia and Herzegovina and the Spatial Plan of Tuzla Canton. The plan was developed by the IPSA Institute from Sarajevo and adopted in 2016. The plan envisages rational use of land, protection of space from negative impacts of all kinds and improvement of spatial conditions for organizing life and work.

Because of the planning and development of green open public spaces, this document envisages green zones in urban areas, especially near roads, to reduce the negative effects of noise and air pollution and increase the visual-aesthetic component. The plan clearly defines the areas of parks in the settlements that belong to the municipality and analyzes the landscaped park areas. For further development of these areas, the plan states that it is necessary to create appropriate documentation, carry out the valorization of natural values, and determine the appropriate degree of protection of natural heritage in accordance with international criteria and valid FBiH laws.

4.2. COAST COMPARATIVE ANALYSIS OF PLANS

The mentioned planning documents were prepared and adopted in the previous 10-20 years. All plans were, therefore, made in the 21st century, with more or less the same or similar technologies and techniques, as well as according to existing legal regulations. The spatial plans this paper analyzes cover the territory from the entity to the municipality. Although the plans' contents, goals and vision are mostly the same, the way certain areas are treated is different.

Spatial plans that represent the primary planning documents for the territories for which they were created, which in this case are the Spatial Plan of the Republika Srpska and the Spatial Plan of the Brčko District of BiH treat green open public spaces in such a way that they pay more attention to more essential nature parks, national parks and other larger green open public spaces. City, neighbourhood or block parks are not analyzed in these plans. Also, these plans provide general goals and obligations for developing open green public spaces but do not include specific solutions and recommendations, as expected from lower-level plans.

Unlike the previous two plans, the spatial plan prepared for the territory of the Tuzla Canton clearly states the city parks for each of the municipalities and cities in the territory of the canton. Like the spatial plans previously analyzed, this plan does not enter into further analysis of these areas but provides mandatory guidelines that should influence further planning and development. Thus, this plan requires the completion of cadastral plans and the mandatory preparation and adoption of a landscape basis for the entire territory of the canton. The landscape basis should contain clear policies for further developing and maintaining green open public spaces in each municipality.

Spatial plans created for the territory of the City of Banjaluk and the Municipality of Čelić are the lowest-order spatial plans for the territories for which they were adopted. Unlike those previously analyzed, these plans still provide more detailed guidelines and recommendations for planning green open public spaces. For example, the spatial plan of the City of Banjaluka determines the mandatory square footage that every user of these spaces must have and regulates the mandatory areas of these spaces concerning a certain percentage of the city's population. The plan also classifies different open green public spaces in the city territory according to their importance and the area they cover. On the other hand, the spatial plan of the municipality of Čelić, although it clearly states the neighbourhood parks and their areas, unfortunately, does not determine clear guidelines like the City of Banjaluka planning document. However, it still requires the further development of appropriate planning documentation and the valorization of existing areas to define clear priorities for further development.

5. DISCUSSION AND CONCLUSIONS

Spatial planning is a significant segment of urban and rural development. Although planning policies and practices differ between cities and countries worldwide, the plans' primary goals and visions are very similar. For the most part, all spatial plans state a rational approach to using natural resources, environmental protection, balanced territorial development, coordinated social and economic development, and protection of natural and cultural heritage as primary goals. Following these goals, planners develop unique goals for each area of the spatial plan in the process of making plans. Through this process, and under the policies of the area and the needs of the users of the space, planners pay more or less attention to certain areas, which is mostly in accordance with the previous development of the space and the standard of living.

In this paper, five plans prepared for different territorial coverage within the state of Bosnia and Herzegovina are analyzed. The work aimed to examine the relationship between plans and green open public spaces. More precisely, the paper tried to answer the question of how different levels of spatial planning in Bosnia and Herzegovina treat green open public spaces and what guidelines, strategies and goals they set before lower-order plans regarding the development and maintenance of these areas. As stated in the paper, these spaces are essential in all environments. Namely, these spaces affect citizens' quality of life precisely through the opportunities they provide. High-quality open public space, especially green areas such as city forests, parks, promenades along rivers, allow citizens to escape to nature from everyday city duties and built-up space. Also, green open public spaces, like all other open public spaces, influence the creation of different flows of city life because they connect citizens and allow them to achieve different interactions with each other and with the surrounding space.

The main conclusion of the work is that all analyzed plans treat green open public spaces similarly. Plans generally list and describe existing green open public spaces and classify them into predetermined categories. Also, all plans give guidelines and recommendations for further development without overemphasizing the importance of green open public spaces regarding environmental protection and positive effects on citizens' health. Spatial plans of a lower order, such as the plan of the City of Banjaluk and the plan of the municipality of Čelić, pay more attention to these areas. This is understandable because the scope of space that these plans treat is far smaller than that of other plans. Nevertheless, it is essential to emphasize that both the spatial plan of the Brčko District of Bosnia and Herzegovina, although it covers a smaller area compared to the spatial plan of the Republika Srpska and the spatial plan of the Tuzla Canton, does not pay too much attention to green open public spaces.

Due to its complexity, the level of planning analyzed in this paper should not even deal with more detailed planning and development of green open public spaces in cities. Nevertheless, when the development process of grey, built-up areas is expanding worldwide, especially in poorly developed countries such as Bosnia and Herzegovina, greater focus must be on areas of this type. First of all, these areas ensure a better structure of cities because they reduce the harmful effects of natural disasters such as floods, etc. Also, as mentioned, these spaces reduce air pollution and city noise. Because of its importance, a better approach to creating clearer, binding guidelines, goals, and strategies for developing open green public spaces in urban areas must be ensured during the development of spatial plans. In doing so, no other segment of spatial planning must be neglected or neglected.

Following the conclusions mentioned above, at the very end of the work, the following guidelines and recommendations are given in order to improve the way of treating and further developing green open public spaces in the process of making plans:

- Planning the development and maintenance of green open public spaces must be harmonized with European and world practices resulting from relevant recent research. In this way, these spaces will be planned and maintained in accordance with the global policies of contemporary urbanism and the current level of environmental pollution.
- The area of green open public spaces that must exist in spatial planning documentation should be created with the apparent involvement of space users so that parks and other green areas are planned and maintained according to the needs of modern man, that is, according to the needs of the citizens of a particular area.
- The attitude towards planning and developing green open public spaces should be raised to a higher level in all planning policies in Bosnia and Herzegovina. The current trends in developing cities and municipalities in Bosnia and Herzegovina significantly affect the reduction of green areas, which in the future can have substantial negative impacts on both the quality of life and the quality of urban space.

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CIVIL ENGINEERING

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A NOTE ON BEAM-TO-BEAM CONTACT DYNAMICS

Abstract

Two approaches for beam-to-beam contact modeling are considered in the paper. The first is the classic continuum approach with point-to-point contact discretization. The other is the coarse-grained approach where the physical intermolecular fields are applied for the modeling of interaction of continuous bodies. To describe the contact, the repulsive steric potential is utilized here. The advantages and disadvantages of both approaches are discussed, and the results are compared with those obtained in Abaqus. An involved computational simulation of multiple collisions between elastic beams is considered as a numerical example.

Keywords: beam-to-beam contact dynamics; coarse-grained model; intermolecular forces

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Сажетак

У раду су размотрена два приступа моделирању контакта греда-греда. Први је приступ класичне механике континуума са дискретизацијом контакта на нивоу тачка-тачка. Други је модел грубе апроксимације код кога користимо физичка интермолекуларна поља да опишемо међудјеловање континуалних тијела. За описивање контакта, примијењен је одбојни стерични потенцијал. Размотрене су предности и мане оба приступа, те су добијени резултати упоређени са онима из Абакуса. Као нумерички примјер, размотрена је сложена рачунска симулација вишеструких судара између еластичних греда.

Кључне ријечи: динамика контакта греда-греда; модел грубе апроксимације; међумолекуларне силе

1. INTRODUCTION

Slender bodies are readily found in nature, nanotechnology, biomechanics, engineering, etc. Due to the well-known limitations of physical experiments, numerical simulations of systems involving slender bodies are of utmost importance. One of the most successful mechanical models is that of a beam. The mechanical beam model allows accurate and efficient simulations of real-life systems involving slender bodies. When a mechanical system consists of multiple beams undergoing large deformations, there is a possibility that the beams will interact with each other. From a macroscopic point of view, this interaction is often perceived as a *mechanical contact* caused by the impenetrability of the interacting bodies. However, on the micro- and nano- level, the interaction can be both attractive and repulsive, due to the effects of various intermolecular fields. These fields manifest themselves as intermolecular forces that are the gradients of interaction potentials between molecules/particles. Some well-known interaction potentials are gravitational, electrostatic, van der Waals, steric, etc.

The interaction between assemblies of molecules is readily modeled as a particle-particle interaction via *molecular dynamics* [1]. Within this approach, we apply the laws of motion on each particle, which results in an accurate, but computationally expensive simulation, Fig. 1a.

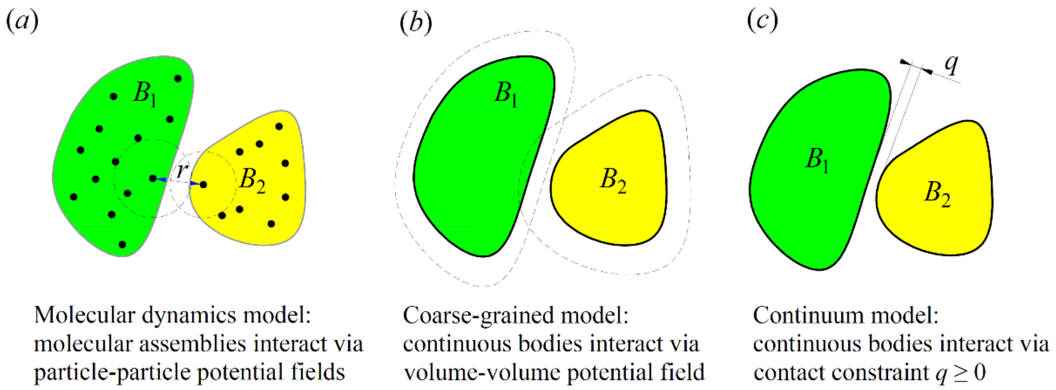

Figure 1. Contact interaction models. (adopted from [2])

On the other hand, the continuum contact approach considers the interaction between continuous bodies and imposes the contact conditions, e.g. impenetrability of interacting bodies, Fig. 1c. This approach is well-established and efficient [3], but lacks a rigorous physical foundation. A middle ground between these two approaches is the *coarse-grained* method, Fig. 1b, which combines the fundamental physics of intermolecular forces and the efficiency of the continuum mechanics [2].

In this paper, we consider one type of the penalty point-to-point method for the contact interaction between arbitrarily curved elastic beams. The interacting closest points are selected from a set of discrete integration points. The proposed formulation provides a straightforward description of contact, ensuring a simple implementation while preserving good accuracy. Additionally, we consider the coarse-grained method that is based on the homogenization of interaction potential and its pre-integration over the beam cross-sectional areas [4].

The NURBS basis functions are utilized for the spatial discretization of the Bernoulli-Euler beam model within the framework of the isogeometric analysis (IGA) [5]. For the time discretization, the well-known HHT implicit scheme is applied.

The paper is organized as follows. The main ingredients of the employed contact models are introduced in the next section. Then, the fundamental aspects of the Bernoulli-Euler beam theory and implicit time discretization are presented. Section 4 deals with the definition and properties of the NURBS functions, while the numerical experiment is discussed in Section 5. Conclusions and guidelines for future research are given in the last section.

2. CONTACT MECHANICS

The total potential energy, Π_{tot}, of a conservative mechanical system consists of the internal strain energy Π_{int}, the kinetic energy Π_{kin}, and the work of external forces Π_{ext}. If the bodies interact with each other, the interaction contact energy, Π_{con}, must be taken into account as well. The weak form of equilibrium requires that the variation of the total potential energy with respect to the generalized coordinates is zero, i.e.

$$\delta\Pi_{tot} = \delta\Pi_{int} + \delta\Pi_{kin} + \delta\Pi_{ext} + \delta\Pi_{con} = 0. \tag{1}$$

The strain and kinetic energy are readily derived in the literature, and we will only briefly refer to them in Section 3. The work of external forces is not considered in this paper. Our focus is on the contact interaction potential. Two approaches for the definition of contact contribution Π_{con} are discussed in this section.

2.1. CONTINUUM APPROACH

Computational contact mechanics provides accurate and efficient numerical methods for the modeling of contact interaction between solid bodies [3]. A special case of the contact between solid bodies is the contact between beams. The beam-to-beam contact is a well-researched area [6], but many issues are yet to be tackled [7]. The existing continuum formulations for the beam-to-beam contact differ in various aspects of computational modeling, such as: the definition of contact condition, contact discretization, contact search, optimal integration strategy, etc. Some of the well-known approaches for enforcing the contact condition are the penalty method, the Lagrange multipliers, the augmented Lagrange method, etc. Regarding the contact discretization, there are point-to-point, point-to-segment, segment-to-segment approaches, and various variations.

In this paper, we focus on the penalty point-to-point beam contact formulation. Let us consider two arbitrarily curved beams with the cross-sectional radii R_1 and R_2, see Fig.1.

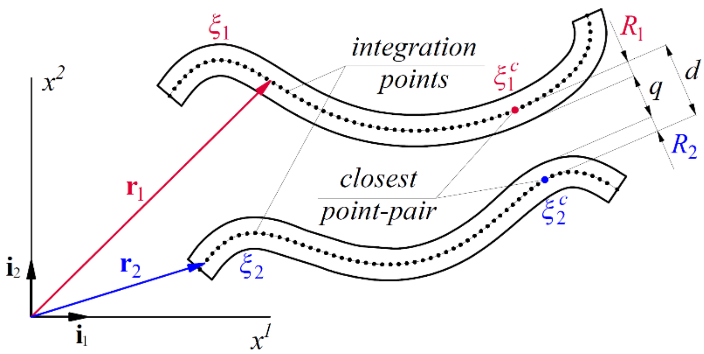

Figure 2. Interaction of two planar beams. Integration point-to-integration point contact discretization.

The beam centerlines are defined with curves $\mathbf{r}_1(\xi_1)$ and $\mathbf{r}_2(\xi_2)$. To determine the location of contact between the beams, it is necessary to identify the closest point positions where the prohibited penetration is enforced by the contact constraints. The closest point positions, ξ_1^c and ξ_2^c, can be found by minimizing the distance between beam axes, $d = \|\mathbf{r}_1 - \mathbf{r}_2\|$. The minimization requires that the tangents of both beams at the closest points are perpendicular to the distance vector $\mathbf{d} = \mathbf{r}_1 - \mathbf{r}_2$. This procedure leads to two nonlinear equations with unknown positions of closest points.

The non-penetration condition at the closest point-pair is formulated using an inequality constraint

$$q = d_{min} - R_1 - R_2 \geq 0, \tag{2}$$

where q is the gap function. This constraint allows us to define the contact interaction energy as

$$\Pi_{con} = \begin{cases} \frac{1}{2}\varepsilon q^2, & q \leq 0 \\ 0, & q>0 \end{cases}, \tag{3}$$

where ε is the penalty parameter. The variation of the gap with respect to the configuration of a system gives

$$\delta q = \delta d_{min} = \delta[(\mathbf{r}_1 - \mathbf{r}_2)\cdot(\mathbf{r}_1 - \mathbf{r}_2)]^{1/2} = \hat{\mathbf{d}}(\delta\mathbf{r}_1 - \delta\mathbf{r}_2), \tag{4}$$

where $\hat{\mathbf{d}}$ is the unit distance vector that equals the normal vector for the closest point-pair. The variation of the contact potential results with the point contact contribution to the weak form, i.e.

$$\delta\Pi_{con} = \varepsilon\,\delta q = \varepsilon\, q\,\hat{\mathbf{d}}(\delta\mathbf{r}_1 - \delta\mathbf{r}_2) = \mathbf{f}_{con}\delta\mathbf{r}_1 - \mathbf{f}_{con}\delta\mathbf{r}_2, \tag{5}$$

where $\mathbf{f}_{con}$ is the contact force [7]. With this formulation, the contact interaction between two beams manifests as a discrete point force acting at the closest points of the beam centerlines along the normal direction.

One issue with the described point-to-point approach is that the closest point procedure does not have a guaranteed unique solution, e.g. when considering parallel beams. Another issue is that the contact traction is modeled as a point force, while we anticipate the distributed traction for the case of contact between nearly parallel beams. These issues can be tackled by specific procedures, such as the line-to-line contact discretization [7].

In this paper, we address the issue of the non-uniqueness of closest point-pairs by searching for the closest discrete point-pairs. We define a dense distribution of integration points, and search for the closest point-pairs between them, see Fig. 2. As the number of integration points increases, this approach converges to the previously described closest point algorithm. We refer to this approach as the integration point-to-integration point (IPIP) contact discretization. Importantly, this dense distribution of integration points is only used for the integration of the contact potential. The proposed approach stems as a special case of the algorithm used for the coarse-grained formulation which is discussed in the next subsection. Additionally, the bias of the standard master-slave approach can be avoided with the proposed discretization, but further investigation on this issue is required.

2.2. COARSE-GRAINED APPROACH

The idea behind the coarse-grained (CG) approach is to assume that the interaction potential between assemblies of molecules (interacting bodies) can be smeared over the volumes, allowing us to replace the summation with the integration. The method is well-established and applied in various scenarios for both long- and short-range interactions [2, 4, 8]. In this subsection, we give a brief introduction to the CG approach.

An interaction potential $\hat{\Phi}_m$ between two particles is usually assumed as an inverse-power law:

$$\hat{\Phi}_m = k_m r^{-m}, \tag{6}$$

where k_m is the physical constant, and r is the distance between the particles, see Fig. 1a. The usual assumption is that the total interaction potential between two bodies, B_1 and B_2, can be approximated as a pairwise summation of individual interactions, i.e.

$$\Phi_m = \sum\nolimits_{I\in B_1}\sum\nolimits_{I\in B_2} k_m r_{IJ}^{-m}, \tag{7}$$

where r_{IJ} is the distance between particles *I* and *J*. This expression corresponds to the molecular dynamics approach. By assuming that the interaction potential can be coarse-grained and homogenized over the interacting bodies, we can write

$$\Phi_m \approx \Pi_{con} = \int_{V_1}\int_{V_2} k_m \beta_1 \beta_2 r_m^{-m}\, dV_1 dV_2, \tag{8}$$

where β_i are the densities of interacting particles. This expression represents the basis of the CG approach, see Fig. 1b.

The calculation of two nested 3D integrals in (8) is complicated and several simplifications have been introduced for specific applications [8]. For the beam-to-beam interaction, a so-called *section-section interaction potential* approach is introduced in [4]. By pre-integrating the interaction potential over the cross sections, the integral (8) reduces to 2D, i.e.

$$\Phi_m = k_m \beta_1 \beta_2 2^{5/2-m} \pi^{3/2} \sqrt{\frac{R_1 R_2}{R_1 + R_2}} \frac{\Gamma(m-7/2)}{\Gamma(m/2)^2} \int_{L_1} \int_{L_2} q^{-m+7/2} ds_2 ds_1, \tag{9}$$

where $\Gamma(z)$ is the Gamma function. The expression (9) is only approximate since it disregards the offset between cross sections [9]. However, it is arguably well-suited for contact modeling based on the steric repulsion field with $m = 12$.

Many issues need to be addressed for the successful implementation of the CG approach, such as the regularization of the potential law, accuracy of the section-section interaction, efficient integration, etc. Let us discuss one important feature - the cutoff distance. Since the interaction potentials are defined as the inverse-power laws with respect to the distance, it is practical to consider some cutoff value. For this, we define the cutoff distance as the radius of a circle around the particle, outside of which the effect of the interaction force is neglected. It allows us to reduce the number of interacting point-pairs and to keep only the important contributions. If the short-range interactions are considered ($m > 3$), the introduction of the cutoff distance can improve the efficiency without significantly affecting the accuracy.

The main advantages of the CG approach are: (i) it is based on the fundamental intermolecular laws and (ii) it models contact as distributed traction. The main disadvantages are: (i) accurate pre-integration is difficult and often impossible and (ii) the integration is more involved, in comparison with the IPIP approach, since more points interact with each other.

3. IMPLICIT DYNAMIC ANALYSIS OF BERNOULLI-EULER BEAM

According to the Bernoulli-Euler (BE) hypothesis that a beam's cross section is rigid and perpendicular to the beam axis in all configurations, a 3D continuum model of the planar beam degenerates into a 1D model, which can be an arbitrarily shaped line, Fig. 3.

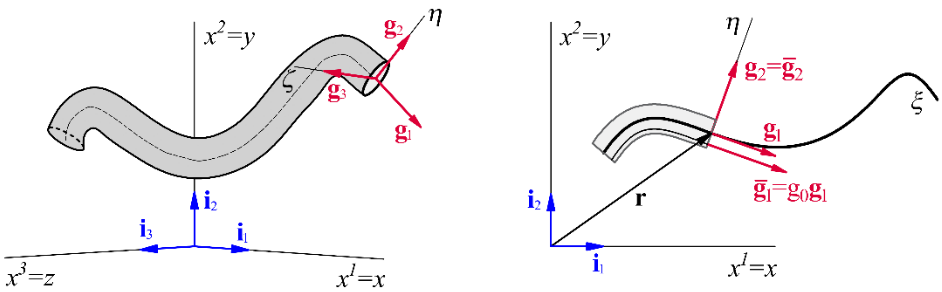

Figure 3. Degeneration of an arbitrarily curved planar beam from 3D to 1D. Coordinate axes and base vectors.

The convective frame of reference (ξ, η, ς) with its base vectors ($\mathbf{g}_1, \mathbf{g}_2, \mathbf{g}_3$) is attached to the beam. The curvilinear coordinate axis ξ coincides with the beam axis while η and ζ are aligned with the principal axes of the second moment of area of the cross section. Due to the BE hypothesis, ξ is the only independent variable in the present analysis [10].

In this section, the lowercase and uppercase boldface letters are used for vectors and second-order tensors, respectively. An overbar designates quantities at the equidistant line of the beam, and the asterisk sign denotes the deformed configuration.

3.2. METRIC OF THE PLANAR BERNOULLI-EULER BEAM

In this paper, only planar beams are analyzed. The position vector of the beam axis is defined with the Cartesian coordinates, $\mathbf{r} = x^\alpha \, \mathbf{i}_\alpha$, where $\mathbf{i}^\alpha = \mathbf{i}_\alpha$ are the base vectors of the Cartesian coordinate system, see Fig. 3. The tangent base vector $\mathbf{g}_1$ of the beam axis, with respect to the parametric coordinate ξ, is

$$\mathbf{g}_1 = \mathbf{r}_{,1} = \frac{d\mathbf{r}}{d\xi} = x^\alpha_{,1} \, \mathbf{i}_\alpha, \quad \alpha = 1,2, \tag{10}$$

while the unit tangent vector follows from the differentiation of the position vector with respect to the arc-length coordinate $\mathbf{r}_{,s} = \mathbf{t}$. The second base vector, $\mathbf{g}_2$, is defined by the rotation of the unit tangent in the counterclockwise direction [11]

$$\mathbf{g}_2 = \Lambda \mathbf{t}, \quad \Lambda = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}. \tag{11}$$

Now, the metric tensor of a centerline follows as

$$g_{\alpha\beta} = \begin{bmatrix} g_{11} & 0 \\ 0 & 1 \end{bmatrix}, \quad g_{11} = \mathbf{g}_1 \cdot \mathbf{g}_1 = \det\left(g_{\alpha\beta}\right) = g. \tag{12}$$

For an *equidistant line,* which is a set of points with $\eta = const$, the position and the tangent base vectors are

$$\begin{aligned} &\overline{\mathbf{r}} = \mathbf{r}(\xi) + \eta \, \mathbf{g}_2, \\ &\overline{\mathbf{g}}_1 = \overline{\mathbf{r}}_{,1} = \mathbf{g}_1 - \eta K \, \mathbf{g}_1 = g_0 \, \mathbf{g}_1, \qquad g_0 = 1 - \eta K, \end{aligned} \tag{13}$$

where K is the so-called *signed curvature* measured with respect to the Frenet-Serret frame of reference [10]. The other base vector of the equidistant line is the same as that of the beam axis, $\overline{\mathbf{g}}_2 = \mathbf{g}_2$, and the metric tensor of the equidistant line is

$$\overline{g}_{\alpha\beta} = \begin{bmatrix} g_0^2 g & 0 \\ 0 & 1 \end{bmatrix}, \quad \det\left(\overline{g}_{\alpha\beta}\right) = g_0^2 g = \overline{g}. \tag{14}$$

3.3. KINEMATICS

The deformed configuration of the beam axis is defined by adding the displacement vector of the beam axis $\mathbf{u} = u^\alpha \mathbf{i}_\alpha$ to the beam axis at the reference configuration, $\mathbf{r}^* = \mathbf{r} + \mathbf{u}$. According to this, expressions (11) and (13) are valid for all configurations.
The displacement vector of an arbitrary point is defined as

$$\overline{\mathbf{u}} = \overline{\mathbf{r}}^* - \overline{\mathbf{r}} = \mathbf{u} + \eta \mathbf{u}_{,2}, \quad \mathbf{u}_{,2} = \mathbf{g}_2^* - \mathbf{g}_2 = \Lambda(\mathbf{t}^* - \mathbf{t}). \tag{15}$$

To define the variation of the kinetic energy, it is necessary to define the acceleration of the beam continuum. First, let us define the velocity of the beam as the material time derivative of displacement [12]

$$\dot{\overline{\mathbf{u}}} = \overline{\mathbf{v}} = \dot{\mathbf{u}} + \eta \dot{\mathbf{u}}_{,2} = \mathbf{v} + \eta \mathbf{v}_{,2}, \quad \dot{\mathbf{u}}_{,2} = \mathbf{v}_{,2} = \dot{\mathbf{g}}_2^*. \tag{16}$$

The velocity of the basis vector $\mathbf{g}_2$ is defined as

$$\mathbf{v}_{,2} = \Lambda \dot{\mathbf{t}}^* = \Lambda \frac{1}{\sqrt{g^*}} (\mathbf{I} - \mathbf{t}^* \otimes \mathbf{t}^*) \mathbf{v}_{,1} = -\frac{1}{g^*} (\mathbf{v}_{,1} \cdot \mathbf{g}_2^*) \mathbf{g}_1^*. \tag{17}$$

This expression can also be found from the Bernoulli-Euler condition of the zero shear strain rate [13]. The angular velocity of the planar BE beam cross section is [12]

$$\omega = \omega^3 = \frac{1}{\sqrt{g^*}} \mathbf{g}_2^* \mathbf{v}_{,1}, \tag{18}$$

which allows us to write Eq. (17) as

$$\mathbf{v}_{,2} = -\frac{1}{g^*} (\mathbf{v}_1 \cdot \mathbf{g}_2^*) \, \mathbf{g}_1^* = -\omega \mathbf{t}^*. \tag{19}$$

The previous relation shows that the velocity of $\mathbf{g}_2$ basis has the direction of the current tangent while its magnitude equals the angular velocity of cross section.
The acceleration of an arbitrary point is obtained as

$$\ddot{\bar{\mathbf{u}}} = \bar{\mathbf{a}} = \dot{\mathbf{v}} + \eta \dot{\mathbf{v}}_{,2}, \tag{20}$$

where

$$\dot{\mathbf{v}}_{,2} = \ddot{\mathbf{g}}_2^* = \frac{3}{g^*}\left(\mathbf{v}_{,1} \cdot \mathbf{t}^*\right)\left(\mathbf{v}_{,1} \cdot \mathbf{g}_2^*\right)\mathbf{t}^* - \frac{1}{\sqrt{g^*}}\left(\mathbf{a}_{,1} \cdot \mathbf{g}_2^*\right)\mathbf{t}^* - \frac{1}{g^*}\left(\mathbf{v}_{,1} \cdot \mathbf{g}_2^*\right)\mathbf{v}_{,1}. \tag{21}$$

Finally, for the variation of both strain and kinetic energy, the virtual displacement of an arbitrary point needs to be defined, i.e.

$$\delta\bar{\mathbf{u}} = \delta\mathbf{u} + \eta\delta\mathbf{u}_{,2}, \qquad \delta\mathbf{u}_{,2} = -\frac{1}{\sqrt{g^*}}(\mathbf{t} \otimes \mathbf{g}_2^*)\delta\mathbf{u}_{,1}. \tag{22}$$

3.4. STRESS AND STRAIN

The only non-zero Green-Lagrange component of strain in the BE theory is the axial strain along the tangential direction [13]

$$\bar{\varepsilon}_{11} = g_0\left[\left(1 - \eta K\right)\varepsilon_{11} + \eta\kappa\right] + \eta^2\chi\left(\frac{1}{2}\kappa - K\varepsilon_{11}\right), \tag{23}$$

where ε_{11} is the axial strain of the beam axis

$$\varepsilon_{11} = \frac{1}{2}\left(g_{11}^* - g_{11}\right), \tag{24}$$

while κ and χ are the changes of bending curvatures of the beam axis with respect to the parametric and arc-length convective coordinates [14]

$$\kappa = K^* g_{11}^* - K\, g_{11}, \qquad \chi = K^* - K. \tag{25}$$

Considering hyperelastic St. Venant-Kirchhoff material, the only non-zero stress component of the 2nd Piola-Kirchhoff stress is

$$\bar{S}^{11} = E\left(\bar{g}^{11}\right)^2 \bar{\varepsilon}_{11}, \tag{26}$$

where E is the Young's modulus of elasticity and $\bar{g}^{11} = 1/\bar{g}$ is the determinant of the contravariant metric tensor at an arbitrary point.

3.5. VARIATION OF THE STRAIN AND KINETIC ENERGY

The variation of the kinetic energy is

$$\delta\Pi_{kin} = \int_V \rho\bar{\mathbf{a}}\,\delta\bar{\mathbf{u}}\,dV, \tag{27}$$

where

$$\bar{\mathbf{a}} \cdot \delta\bar{\mathbf{u}} = \mathbf{a} \cdot \delta\mathbf{u} + \eta^2\mathbf{P}, \tag{28}$$

and

$$\mathbf{P} = -\frac{2}{g^* g^*}(\mathbf{v}_{,1} \cdot \mathbf{g}_1^*)(\mathbf{v}_{,1} \cdot \mathbf{g}_2^*)(\delta\mathbf{u}_{,1} \cdot \mathbf{g}_2^*) + \frac{1}{g^*}(\mathbf{a}_{,1} \cdot \mathbf{g}_2^*)(\delta\mathbf{u}_{,1} \cdot \mathbf{g}_2^*). \tag{29}$$

The variation of the strain energy is

$$\delta\Pi_{int} = \int_V \bar{S}^{11}\delta\bar{\varepsilon}_{11}\,dV, \tag{30}$$

where the variation of the equidistant strain can be found in [13].

With equations (4), (9), (27), and (30) at hand, it is straightforward to find the spatially discretized equilibrium equation (1). This step is skipped here for brevity.

3.6. TIME DISCRETIZATION

For the time discretization of the spatially discretized equilibrium equation, the well-known HHT-α method is employed. The method is a generalization of the Newmark-β method and it is commonly used in structural dynamics. The equilibrium equation is modified with parameter α that introduces a numerical lag in the internal, external, and contact forces. Basic equations are given in this section while more details can be found in [15].
We are considering the implicit approach where the equilibrium equation is defined at the current, unknown, configuration ($n+1$). The velocity at this configuration is assumed as a sum of the velocity at the previous time increment and acceleration at some point, scaled with the time step

$$\dot{u}_{n+1} = \dot{u}_n + \ddot{u}_\gamma \Delta t. \tag{31}$$

Here, the acceleration at some point is a function of the parameter γ

$$\ddot{u}_\gamma = (1-\gamma)\ddot{u}_n + \gamma \ddot{u}_{n+1}, \quad 0 \le \gamma \le 1. \tag{32}$$

Now, the displacement at the current configuration can be represented as

$$u_{n+1} = u_n + \Delta t \dot{u}_n + \frac{1}{2}\Delta t^2 \ddot{u}_\beta, \tag{33}$$

where the acceleration is assumed as a function of the parameter β, see Eq. (34)

$$\ddot{u}_\beta = (1-2\beta)\ddot{u}_n + 2\beta \ddot{u}_{n+1}, \quad 0 \le 2\beta \le 1. \tag{34}$$

From the previous two equations, it follows that the acceleration at the current configuration can be expressed as

$$\ddot{u}_{n+1} = \frac{1}{\Delta t^2 \beta}(u_{n+1} - u_n) - \frac{1}{\Delta t \beta}\dot{u}_n - \frac{1-2\beta}{2\beta}\ddot{u}_n. \tag{35}$$

The discretized equilibrium equation for one degree of freedom can be written as

$$\begin{aligned} u_{n+1} &= u_n + \Delta t \dot{u}_n + \frac{1}{2}\Delta t^2 [(1-2\beta)\ddot{u}_n + 2\beta \ddot{u}_{n+1}], \\ \dot{u}_{n+1} &= \dot{u}_n + \Delta t (1-\gamma)\ddot{u}_n + \Delta t \gamma \ddot{u}_{n+1}, \\ m\ddot{u}_{n+1} &+ (1+\alpha)(f_{n+1}^{int} - f_{n+1}^{ext} + f_{n+1}^{con}) - \alpha(f_n^{int} - f_n^{ext} + f_n^{con}) = 0. \end{aligned} \tag{36}$$

where m is the mass, f^{int} is the internal force, f^{ext} is the external force and f^{con} is the contact force. The parameter α introduces numerical damping into the system and it is related to parameters β and γ as

$$\frac{-1}{3} \le \alpha \le 0, \quad \beta = \frac{(1-\alpha)^2}{4}, \quad \gamma = \frac{1}{2} - \alpha. \tag{37}$$

The equation (36) is nonlinear and it can be solved using the Newton-Raphson method.

4. NON-UNIFORM RATIONAL B-SPLINES

The non-uniform rational B-splines (NURBS) are the standard tool for geometry modeling in computer-aided design and computer graphics. The aim of this section is to present a brief overview of definitions and properties of the NURBS-based IGA. For a more in-depth discussion on this topic, refer to [16].
A B-spline curve is defined as

$$\mathbf{r}(\xi) = \sum_{i=1}^{n} B_{i,p}(\xi)\mathbf{P}_i, \tag{38}$$

where $\mathbf{P}_i$ are the control points and $B_{i,p}$ are the p^{th} order B-spline basis functions. With a given knot vector $\boldsymbol{\xi} = \{\xi_1, \xi_2, ..., \xi_{N+p+1}\}$, the basis functions can be defined recursively by using the Cox-de Boor formula

$$B_{i,p}(\xi) = \frac{\xi - \xi_i}{\xi_{i+p} - \xi_i} B_{i,p-1}(\xi) + \frac{\xi_{i+p+1} - \xi}{\xi_{i+p+1} - \xi_{i+1}} B_{i+1,p-1}(\xi), \quad B_{i,0}(\xi) = \begin{cases} 1 & \text{if } \xi_i \le \xi < \xi_{i+1} \\ 0 & \text{otherwise} \end{cases}. \tag{39}$$

Fig. 4 shows an example of the cubic B-spline curve and its corresponding basis functions.

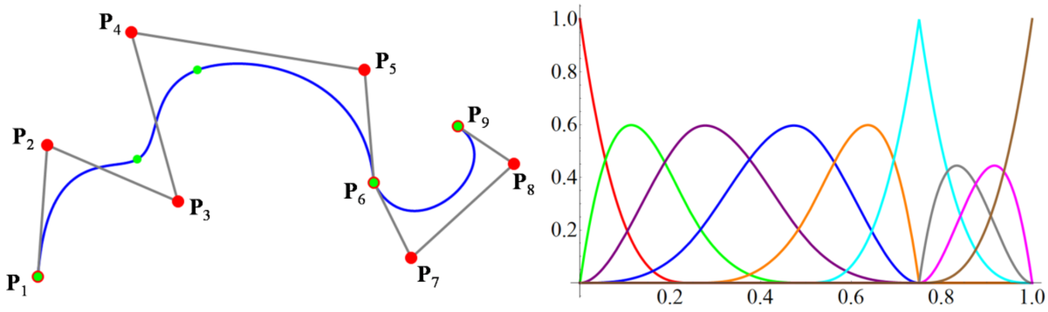

Figure 4. Cubic B-spline curve and corresponding basis functions defined with knot vector $\boldsymbol{\xi} = \{0,0,0,0,0.25,0.5,0.75,0.75,0.75,1,1,1,1\}$.

The curve is interpolatory, and the control polygon is tangent to the curve at the both first and last control points, due to the fact that the knot vector is open. Additionally, the curve is also interpolatory at the control point $\mathbf{P}_6$, because the multiplicity of the knot ξ=0.75 is equal to the polynomial order $p = 3$. The B-spline basis functions constitute a partition of unity, they are non-negative for any value of parameter ξ, and they are C^{p-m} continuous at knots of multiplicity m.

The more general NURBS is defined as

$$\mathbf{r}(\xi) = \sum_{i=1}^{N} B_{i,p}(\xi) w_i \mathbf{P}_i \Bigg/ \sum_{j=1}^{N} B_{j,p}(\xi) w_j = \sum_{i=1}^{N} R_{i,p}(\xi) \mathbf{P}_i, \tag{40}$$

where w_i are the weights and $R_{i,p}$ are the rational basis functions. The rational basis functions have the same main properties like the B-spline basis. The NURBS curve becomes B-spline when all weights are equal.

The main idea of IGA is to use these NURBS functions for both the initial geometry and unknown fields. This results in a higher-order accurate spatially discretized model that is applicable in various fields of computational mechanics [5].

5. NUMERICAL EXPERIMENT

To test the CG and IPIP approaches in the contact dynamics, an example of the impact and multiple collisions of two beams is considered in this section. The problem setup is given in Fig. 5. The upper beam falls due to gravity and hits the lower beam. After the initial impact, both beams start to oscillate, and a range of further collisions occur. No physical damping is introduced into the system, and the complete dissipation of the energy is due to the numerical damping. For the comparison of different approaches, the deflection of the point A is followed. We will first consider the results obtained with the adopted numerical models, and then discuss the effects of some input parameters.

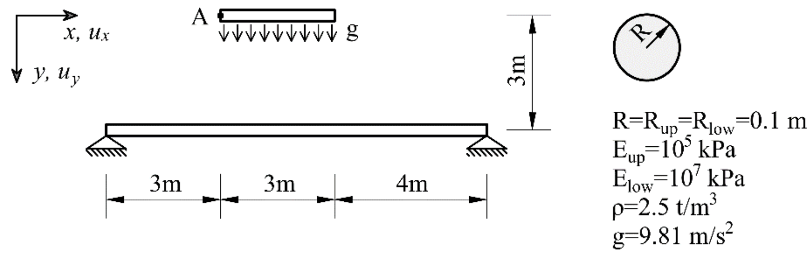

Figure 5. Free fall of an elastic beam onto another beam. Problem setup.

The simulation snapshots obtained with the adopted CG model are shown in Fig. 6. The complicated dynamical behavior with multiple collisions is evident. The results obtained with the adopted CG, IPIP, and Abaqus models are presented in Fig. 7. All three computational models give different results, but the general behavior is similar. The process starts with the free fall of the upper beam and continues with the first impact at $t = 0.75\,s$. Due to this impact, the lower beam accelerates, deflects, and separates from the upper beam, which slows down and continues its free fall until the next collision. The point of the first impact is the same for all models, but the point of the second collision differs. This collision occurs when the lower beam rises, impacts the upper beam, and launches it upwards. As a result, we can observe the first amplitude that is similar for all models ($\approx -2.25\,m$) but occurs in different instances. The process continues with subsequent falls, oscillations, and collisions.

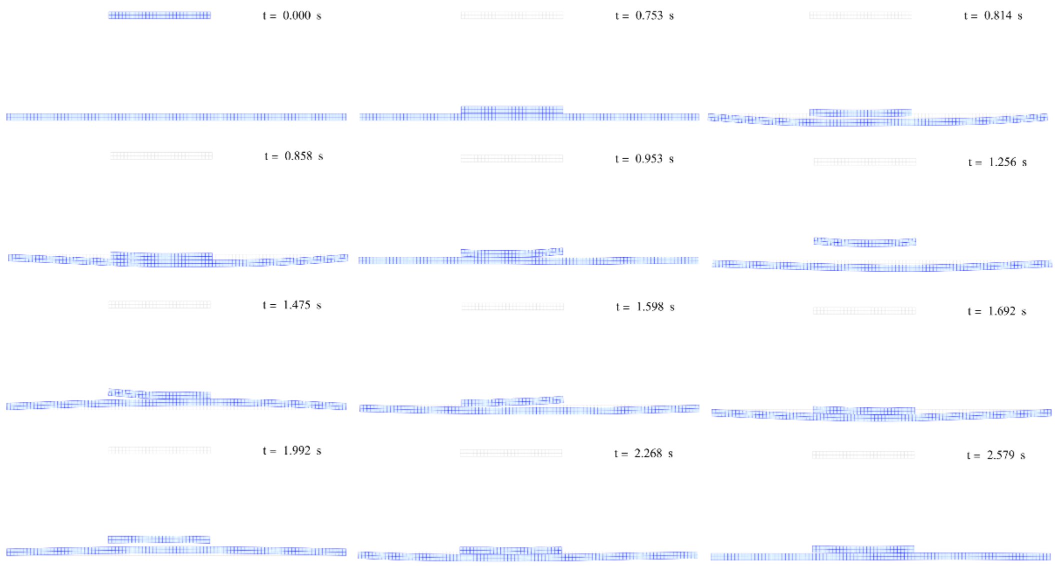

Figure 6. Simulation snapshots. Animation is available as supplementary data at [17].

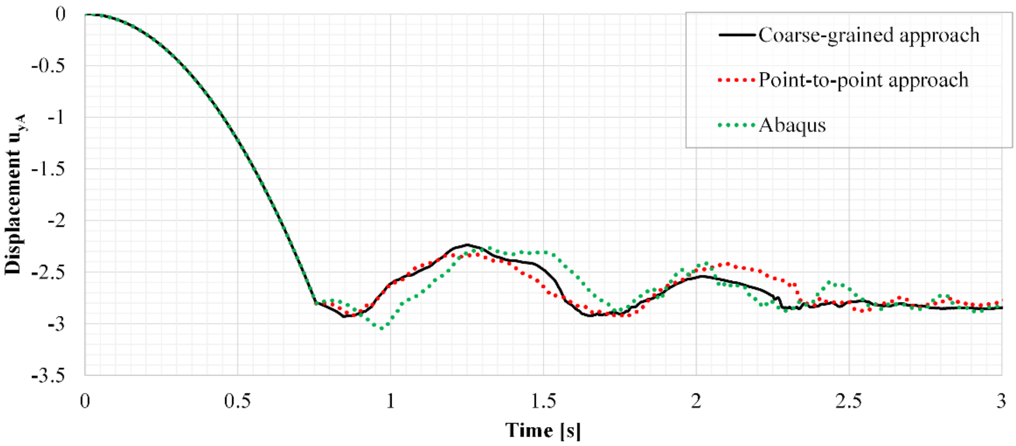

Figure 7. Comparison of the deflection of point A. Adopted models: Abaqus vs. CG approach vs. IPIP approach.

Next, let us discuss some details of the adopted models. The CG and IPIP models are discretized with 20 elements for the lower, and 6 elements for the upper beam. Quartic B-spline basis functions with C^1 continuity are employed. For the integration of the contact energy term Π_{con}, each element is divided into 20 segments with one integration point per segment. The integration of the internal and inertial contributions is made with 5 integration points per element.

The simulation results obtained with the IPIP approach are very sensitive with respect to the penalty parameter ε, see Fig. 8. The first displacement amplitude after the initial impact increases with the decrease of the parameter ε. For the comparison of different models in Fig. 7, the value of 10^6 is adopted since it fits best the other approaches. Regarding the numerical damping, the effect of the α parameter is considered in Fig. 9 for the IPIP model. As expected, smaller values of the parameter α provide an additional numerical damping. This is evident from the comparison of the first amplitudes. However, after this amplitude, it is difficult to make a clear conclusion about the energy dissipation due to the multiple collisions. The value that provides the highest numerical damping is adopted, $\alpha = -0.33$.

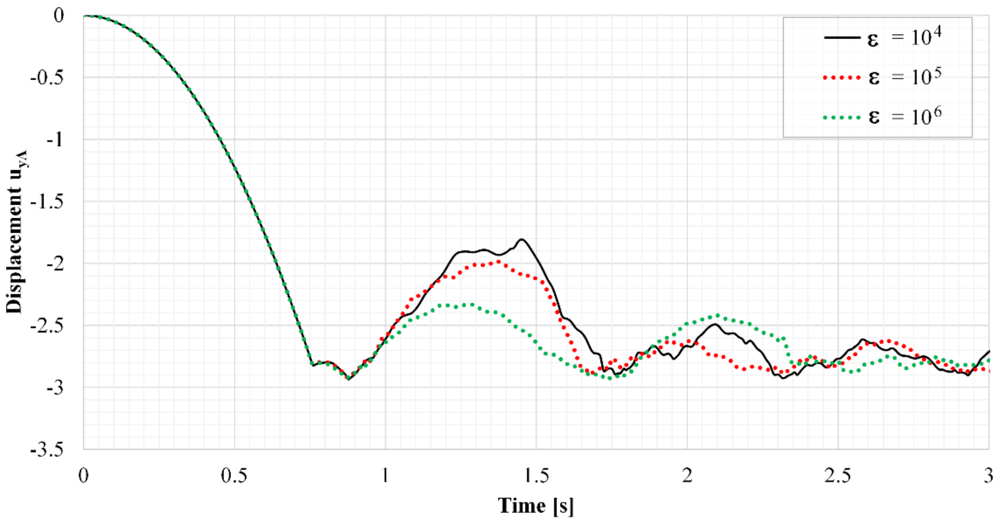

Figure 8. Comparison of the deflection of point A. IPIP approach: influence of the penalty parameter.

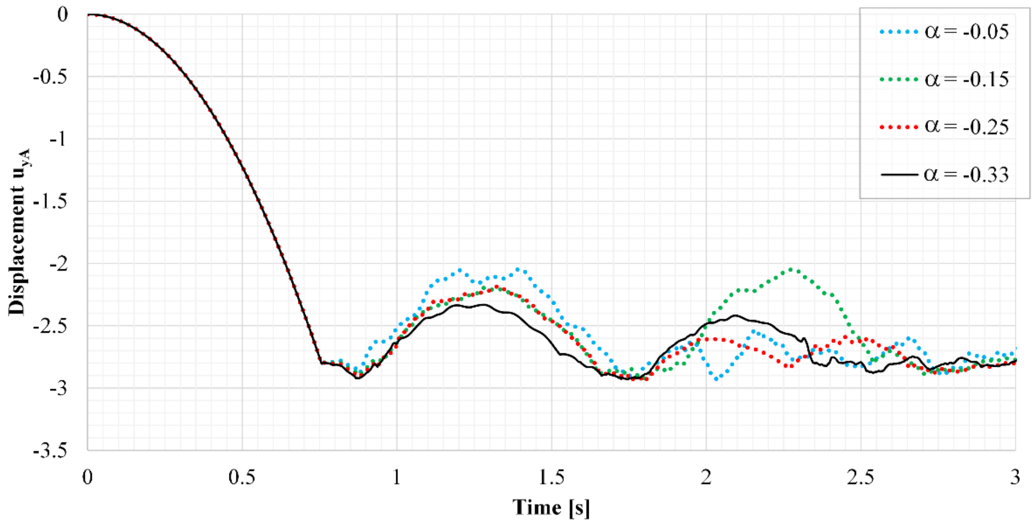

Figure 9. Comparison of the deflection of point A. IPIP approach: influence of the parameter alpha.

Regarding the CG approach, the contact is modeled with steric interaction potential, $m = 12$. Particle densities are set as $\beta_1 = \beta_2 = 1$ while the material constant is $k_m = 5 \cdot 10^{-25}$. The effect of the cutoff distance on the CG simulations is investigated and the results are given in Fig. 10. The cutoff distance does not have a significant influence on the first amplitude, but its effect increases as the simulation develops further. For the comparison in Fig. 7, the cutoff distance of 0.3 is adopted in our CG model.

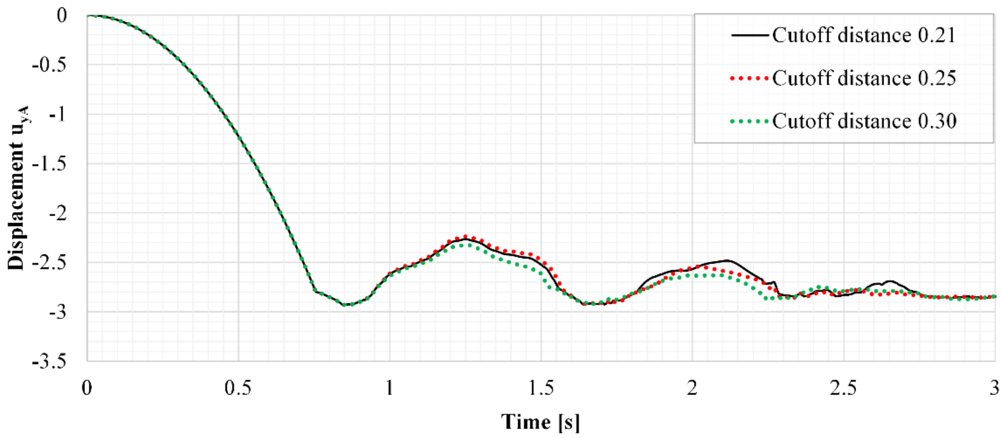

Figure 10. Comparison of the deflection of point A. CG approach: influence of the cutoff distance.

The Abaqus model is discretized with 28304 solid C3D8R elements (8-node linear brick, reduced integration, hourglass control) [18]. Our initial model was based on beam elements, but an issue with unphysical penetration between beams occurred. Therefore, we have utilized the 3D solid model with a restrained displacement component perpendicular to the beams' plane. Explicit analysis and general contact are selected as a contact dynamics procedure, while the normal contact property and the bulk viscosity parameters are varied. The bulk viscosity introduces numerical damping into the system. The results obtained with three combinations of the bulk viscosity parameters are shown in Fig. 11. We can observe that the quadratic parameter practically does not influence the response during the first 2 seconds. The default values of the linear/quadratic bulk viscosity parameters are adopted, i.e. 0.06/1.2. Regarding the normal contact property, we have considered two overclosure-contact pressure relations: the *hard* contact model and the linear contact model. The tangential part of the contact is modeled as frictionless. The comparison of models with different normal contact properties is shown in Fig. 12 where the values of contact stiffness for the linear contact model are varied. With the increase of the stiffness parameter, the results of the linear model approach those of the *hard* contact model. Significant changes in the simulated contact dynamics problem due to relatively small changes in the contact properties are observed. For the comparison of approaches, we have adopted the model with the linear overclosure-contact pressure relation and the contact stiffness of 10^7 .

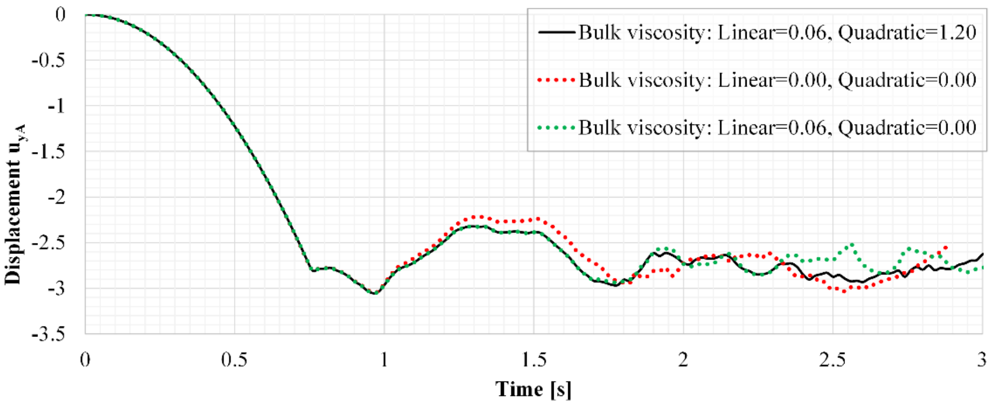

Figure 11. Comparison of the deflection of point A. Abaqus: influence of the bulk viscosity parameters.

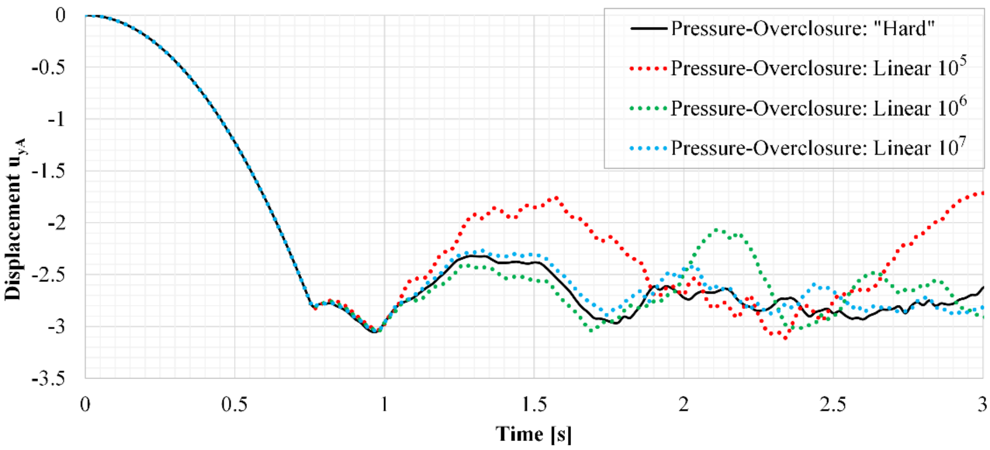

Figure 12. Comparison of the deflection of point A. Abaqus: influence of the overclosure-contact pressure relation.

6. CONCLUSIONS

The contact dynamics between planar beams is considered. Two computational approaches are utilized for contact modeling: the standard continuum approach and the coarse-grained approach. For the continuum approach, we consider the point-to-point contact discretization, while the contact constraint is introduced by the penalty function. The closest point-pairs are found from a set of densely distributed integration points.

The coarse-grained approach uses the section-section interaction potential between circular disks to reduce the underlying integral from 6D to 2D. This formulation is more computationally expensive than the point-to-point approach, but provides a more accurate distribution of contact tractions.

For the adopted example, all utilized approaches are sensitive with respect to a variety of input parameters, such as contact stiffness and numerical damping. Future research should focus on a detailed analysis of spatial beams and include the effects of material and structural damping.

ACKNOWLEDGMENTS

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31

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STEPGRAD
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EFFECT OF THE HRWRA QUANTITY ON DURABILITY PROPERTIES OF SELF-COMPACTING CONCRETE

Abstract

The paper presents the results of our own experimental research on the effect of the high range water reducing admixture content – HRWRA (applied in the range from 0.8 to 1.2% by mass of cement – m_c) on the properties of self-compacting concrete in the fresh and hardened state.

The research showed that increasing the HRWRA content leads to the entrapped porosity reduction – up to 44%, increase of flowability – up to 13%, reduction of viscosity – up to 31%, improvement of passing ability – up to 15% and degradation of sieve segregation resistance of concrete in fresh state – up to 60%. The beneficial effect of the increase in HRWRA was shown on the analysed properties in the hardened state: compressive strength at the age of 28 days – up to 13%, water absorption – up to 61% and freeze/thaw resistance – up to 10%. The difference in the participation of HRWRA from 0.8 to 1.2% m_c does not have a statistically significant effect on the density and freeze/thaw resistance with a de-icing agent.

Keywords: high range water reducing admixture, self-compacting concrete, durability, experimental research.

УТИЦАЈ КОЛИЧИНЕ СУПЕРПЛАСТИФИКАТОРА НА ТРАЈНОСТ САМОУГРАЂУЈУЋЕГ БЕТОНА

Сажетак

У раду су приказани резултати сопственог експерименталног истраживања утицаја количине суперпластификатора високе моћи редукције воде – *HRWRA* (примијењеног у интервалу од 0,8 до 1,2% масе цемента – m_c) на својства самоуграђујућег бетона у свјежем и очврслом стању.

Истраживањем се показало да повећање учешћа *HRWRA* утиче на смањење заостале порозности – до 44%, повећање флуидности – до 13%, снижење вискозности – до 31%, побољшање способности проласка – до 15% и деградацију отпорности према сегрегацији бетона у свјежем стању – до 60%. Повољан утицај повећања учешћа *HRWRA* показао се на анализираним својствима у очврслом стању: чврстоћи при притиску при старости од 28 дана – до 13%, упијању – до 61% и отпорности према дејству мраза – до 10%. Разлика у учешћу *HRWRA* од 0,8 до 1,2% m_c нема статистички значајан утицај на запреминску масу и отпорност бетона према симултаном дејству мраза и соли.

Кључне ријечи:суперпластификатор високе моћи редукције воде, самоуграђујући бетон, трајност, експериментално истраживање.

1. INTRODUCTION

As self-compacting concrete technology is relatively new in our region, concrete manufacturers mostly rely on the production of conventional concrete based on established mix designs that have been tested multiple times. However, experience has shown that these concretes often lack satisfactory durability characteristics suitable for the environmental conditions of the elements in which they will be placed. As a consequence, the degradation and destruction of concrete structures are frequent occurrences, not only in domestic practice but also in many developed countries around the world [1, 2]. The durability of concrete is currently considered a significant topic, both within professional and scientific communities. The relevance of this issue is particularly emphasized by the fact that concrete serves as the fundamental material in the construction industry, and no forecasts are indicating the emergence of a viable replacement material in the near future [3-7]. Considering the above stated, it is important to direct research efforts towards finding solutions that will enhance the durability properties of concrete composites. As one such solution, many researchers recommend the production of self-compacting concrete (SCC), which demonstrates superior durability properties compared to the conventional concrete technologies [8-14]. In this regard, the society in one country needs to find a way to produce self-compacting concrete using component materials from domestic resources, which can respond to high durability requirements [15, 16]. This way, in the long term, better durability of concrete structures is ensured, enhancing their resistance and serviceability, leading to economic savings in maintenance, repair, rehabilitation, etc., as well as savings due to the reduced need for increasingly scarce qualified labour, etc. Given all the aforementioned needs to address the issue of concrete structure durability, the paper in question presents own experimental tests related to concrete used in traffic barriers, which have high durability requirements [1, 17, 18]. The presented research specifically focuses on determining the influence of high range water reducing admixture (HRWRA) content on the durability properties of self-compacting concrete for traffic barriers, manufactured using materials sourced from the domestic market.

2. HIGH RANGE WATER REDUCING ADMIXTURE

Superplasticizing admixture (high range water reducing admixture) is added to fresh concrete to reduce the water content significantly (it reduces the amount of water by more than 12% compared to the control mix), without affecting the consistency, or to increase the slump-flow (an increase in slump ≥ 120 mm compared to the control mix (30±10) mm), i.e., flow (an increase in flow ≥ 160 mm compared to the control mix (350±20) mm), without affecting the water content, or to achieve both effects simultaneously, according to EN 934-2 [19]. Superplasticizing admixtures of the newer generation enable the reduction of water content by up to 40%. Table 1 [20-22] provides an overview of the evolution of admixtures from plasticizers to high range water reducing admixtures.

Table 1. Admixture basic substances and water reduction effects [20, 22]

Year	Product	Water reduction	Capillar porosity	Technical advantages
1930	Lignosulfonates	≤ 10%	20%	Improved concrete workability
1940	Gluconates	≤ 10%	20%	Improved concrete workability
1970	Naphthalene sulfonate	≤ 20%	20%	Concrete with a low water-cement ratio
1980	Melamine polycondensates	≤ 20%	10 – 20%	High properties; controlled binding time
1990	Vinyl copolymers	≤ 25%	10 – 20%	Increased concrete workability with a low water-cement ratio; high early strength; controlled binding time
2000	Modified polycarboxylates	≤ 40%	5 – 10%	Significantly improved concrete workability with a low water-cement ratio and without the segregation risk; increased concrete compactness; better appearance of the final surface

Most admixture manufacturers offer a range of superplasticizing admixtures customized to specific user requirements and their effects on other components in the concrete mix. In addition to ensuring the necessary fluidity of the fresh concrete and water reduction, these admixtures must also maintain the dispersion effect during the time required for transport and application. The retention of the required consistency depends on the concrete application – precast concrete requires a shorter retention time for the required consistency than concrete that needs to be transported and placed on-site [23].

The new generation of HRWRA, based on modified polycarboxylic-ether, differs significantly from traditional plasticizing admixtures, providing better workability and higher concrete strength. This is achieved through the constant release and absorption of polymer chains during cement hydration, thereby preventing early setting. The result is a superior compact microstructure of concrete with a low water-cement ratio and increased mechanical properties compared to concrete using traditional plasticizers [24, 25]. Therefore, this type of admixture is considered an indispensable component for the production of self-compacting concrete, high-strength concrete, and high-performance concrete [22, 26-28].

In Nadhim's experimental research [26], the effects of different dosages of HRWRA on the fresh properties of self-compacting lightweight concrete (SCLCs) were studied using various percentages of HRWRA – 1, 1.3, 1.5, 1.7, and 2% by mass of binder. The results of this research show that increasing the dosage of HRWRA increases flowability. Both the time required to reach a 500 mm slump-flow (t_{500}) and the time required to flow through the V-funnel (t_v), which defines viscosity, decreased as the dosage of HRWRA increased up to 8.25 kg/m^3 (1.5% by mass of binder). After reaching this dosage, both of these parameters (t_{500} and t_v) decreased with further increases in HRWRA dosage. It was observed that increasing the HRWRA content resulted in a gradual increase in the L-box height ratio (H_2/H_1) of SCLC mixture up to a content of 8.25 kg/m^3, which reached 0.97, after which it decreased with further increases in HRWRA content.

It is important to note that the application of these admixtures, due to their significant reduction in the required amount of water, substantially alters the arrangement of pores in the microstructure of concrete, namely in the cement stone. Experimental tests have indicated a decrease in the percentage of larger pores (pores larger than 10^{-4} mm), that negatively impact concrete strength and increase its water permeability, vapour permeability, etc., while there is an increase in the percentage of smaller pores (pores smaller than 10^{-4} mm). These effects result in a denser cement stone structure, significantly enhancing durability and strength [11, 22, 29, 30]. However, an excessive amount of HRWRA can have a negative effect on concrete properties. Previously mentioned research [26] has shown that HRWRA participation up to 1.5% by mass of binder improves the compressive strength of concrete, but a dosage higher than that percentage diminishes strength. Therefore, it is crucial to determine the optimal amount of HRWRA in concrete mixes to ensure the enhancement of concrete properties.

In the present research, the impact of HRWRA is investigated within the optimal interval recommended by admixture manufacturers, based on own research and that of the scientific community. Additionally, the water content is kept constant for all mixtures designed in the experiment to establish the effects of HRWRA on the properties of self-compacting concrete in both fresh and hardened states.

3. EXPERIMENTAL STUDY

In this chapter, the results of own experimental research conducted in the Quality Control Department Laboratory of the Binis Concrete Factory in Banja Luka and the Laboratory of Center for Materials and Structures at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka, is presented.

The research includes laboratory tests on 3 types of self-compacting concrete for the production of traffic barriers, for which the amount of admixture – HRWRA based on polycarboxylic-ether polymers varied in amounts of 0.8, 1.0, and 1.2%, by the applied mass of cement. Other quantities of component materials – cement, addition type I – limestone filler, aggregate and water were constant for all designed concrete mixtures.

The experimental research aims to determine the impact of the amount of the subject admixture on the characteristics of the concrete in the fresh and hardened state, with an emphasis on durability properties, crucial for concretes used for traffic barriers.

The concrete mixtures labels and corresponding HRWRA percentage are listed below:

C1 – self-compacting concrete produced with 1.2% HRWRA by mass of cement,

C2 – self-compacting concrete produced with 1.0% HRWRA by mass of cement and

C3 – self-compacting concrete produced with 0.8% HRWRA by mass of cement.

Preparation of concrete, molding and curing the samples for all 3 mixtures was carried out in the same manner and under equal thermo-hygrometric conditions, namely at a temperature of 23±0.5°C, with a relative humidity of 65±5%. The samples were kept in molds for the first 24 hours, covered with foil, and then up to 28 days in a chamber with constant spraying.

3.1. EXPERIMENTAL PLAN AND PROGRAMME

Following the regulations of the Republic of Srpska, the testing of the designed concretes was carried out according to SRPS standards, except for the properties of self-compacting concretes in the fresh state, for which EN standards were applied.

3.1.1. EXPERIMENTAL TESTING ON FRESH CONCRETE

The following characteristics were tested on fresh concrete:

- temperature, according to SRPS U.M1.032 [31],
- entrapped air content, according to SRPS U.M1.032 [32],
- density, according to SRPS U.M1.009 [33],
- flowability using the slump-flow test, according to EN 12350-8 [34],
- viscosity by measuring time t_{500}, according to EN 12350-8 [34] and V-funnel test, according to EN 12350-9 [35],
- passing ability using the L-box test, according to EN 12350-10 [36],
- segregation resistance using the sieve segregation test, according to EN 12350-11 [37].

In Figures 1-3, the tests conducted on the fresh concrete are presented.

Figure 1. Measuring of temperature (left), entrapped air content (middle) and density of fresh concrete (right)

Figure 2. Flowability measurements using the slump-flow test (left), fresh concrete during V-funnel test (right)

Figure 3. Passing ability testing, using the L-box (left), segregation resistance testing (right)

3.1.2. EXPERIMENTAL TESTING ON HARDENED CONCRETE

On hardened concrete, the following characteristics were tested:

- density, according to SRPS U.M1.009 [33],
- compressive strength at the age of 28 days, according to SRPS U.M1.020 [38],
- water absorption by gradual immersion test, according to SRPS B.B8.010:1981 [39] (in the absence of a suitable standard for testing SCC water absorption, stone material water absorption regulations were used),
- freeze/thaw resistance (100, 150 and 200 cycles) according to SRPS U.M1.016[40],
- freeze/thaw resistance with a de-icing agent (f/t) according to SRPS U.M1.055 [41].

Concrete cores used for water absorption by gradual immersion test and freeze/thaw resistance test, and prisms used for freeze/thaw resistance with a de-icing agent test are subsequently extracted from hardened concrete at the age of 28 days.

In Figure 4, the tests conducted on the hardened concrete are shown.

Figure 4. Compressive strength test (left), freeze/thaw surface resistance with a de-icing agent (middle), samples for freeze/thaw resistance (right)

3.2. COMPONENT MATERIALS

For the subject experimental research, component materials available on the domestic market were used, specifically:

- cement CEM II/B-M(S-LL) 42,5 N, manufacturer CEMEX d. d. Split, Republic of Croatia,
- addition type I – limestone filler, manufacturer "Herc gradnja", quarry site "Drakuljica", Bileća, Republic of Srpska, Republic of Bosnia and Herzegovina,
- crushed aggregate "Dobrnja", manufacturer BINIS d. o. o. Banja Luka, Republic of Srpska, Republic of Bosnia and Herzegovina,
- admixture – superplasticizer "Dynamon PC 25 ES", manufacturer MAPEI, Austria,
- tap water.

The applied crushed three-fraction aggregate has a nominal maximum grain size of 16 mm, where two fractions of a fine aggregate of different sizes were used – fraction 0/4 mm and mid-size fraction 0/2 mm, and coarse fractions 4/8 and 8/16 mm. The granulometric curve of the mixture is continuous (Figure 5).

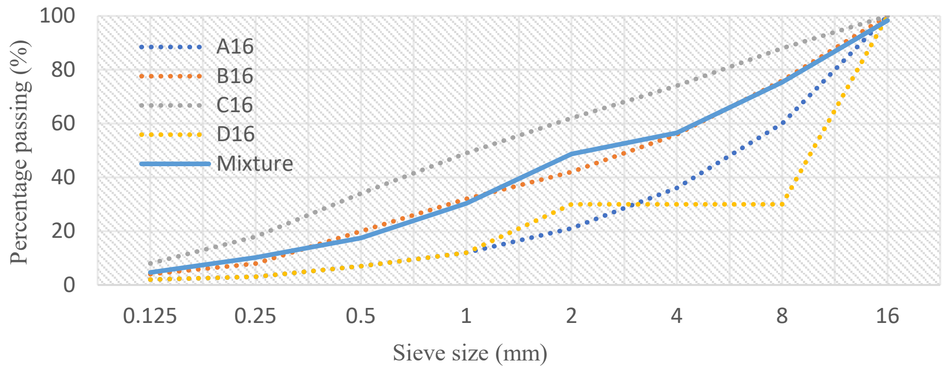

Figure 5. Granulometric curve for mix design

The properties of the subject admixture, taken from the manufacturer's technical sheet, are listed in Table 2.

Table 2. Admixture technical data

State of aggregation	Colour	Density [g/cm^3]	pH value	Chloride content [%]	Alkali content [%]
Liquid	Brown	1.04 – 1.08	5.5 – 7.5	< 0.10	< 2.5

3.3. MIX DESIGN

For the experimental research, three types of self-compacting concrete with component materials of domestic origin were designed. High requirements were set for the properties of the fresh concrete mixture in terms of placeability, workability and resistance to segregation, and also for the high quality of the concrete surface and durability properties of the hardened concrete.

3.3.1. DESIGN CRITERIA

The initial criteria for designing the subject mixtures, from the perspective of achieving the required characteristics of concrete in its fresh state, were related to:

- achieving compactness without the use of mechanical means for placing, i.e. the entrapped air content is limited to a value of 3%,
- achieving consistency class SF2 and/or SF3, i.e. to provide the requisite slump-flow greater than 660 mm,
- achieving passing ability class PL2, where passing ability ratio is ≥ 0.80 with three rods,
- achieving segregation resistance class SR2, where segregated portion is ≤ 15 %.

Additional common characteristics of the subject concrete mixtures were:

- the amount of cement 420 kg/m^3,
- the amount of addition type I – limestone filler 160 kg/m^3,
- the amount of powder (cement, addition type I and aggregate with grains less than 0,125 mm) 630 ± 5 kg/m^3 and
- the amount of water 180 kg/m^3.

Considering the significant amount of applied addition type I – limestone filler, of 160 kg/m^3, a viscosity modifying agent was not applied.

The requirements for the properties of the designed concretes in the hardened state were as follows:

- achieving a freeze/thaw resistance class of M_{200}*,
- achieving a class "resistant" after the freeze/thaw resistance test with a de-icing agent.

* Considering that for concrete traffic barriers used on roads, according to the SRPS U.N2.060 [42] standard, the M_{200} class is required in terms of freeze/thaw resistance, the same requirement has been adopted for this property of concrete that will be used in the production of traffic barriers.

3.3.2. MIX PROPORTION

Table 3 shows the component materials contents in 1 m^3 of the designed concrete mixtures, as well as the calculated values of concrete density in the fresh state.

Table 3. Mixture compositions, water-cement ratio and density of designed SCC

Mix identity			C1	C2	C3
Cement		[kg/m³]	420	420	420
Limestone filler		[kg/m³]	160	160	160
Aggregate	0/2	[kg/m³]	635	635	636
	0/4	[kg/m³]	260	260	260
	4/8	[kg/m³]	276	276	276
	8/16	[kg/m³]	454	454	455
Admixture – HRWRA		[kg/m³]	5.04	4.20	3.36
Water		[kg/m³]	180	180	180
Water-cement ratio		[%]	0.43	0.43	0.43
Admixture-cement ratio		[%]	1.20	1.00	0.80
Density		[kg/m³]	2401	2402	2403

3.4. TEST RESULTS AND DISCUSSION

3.4.1. CONCRETE IN FRESH STATE

Table 4 shows the findings of testing concrete in fresh state – temperature (T), density (D), entrapped air content (A_c), the slump-flow (SF), t_{500} time, V-funnel flow time (t_v and $t_{v,5min}$), L-box test results – the ratio of concrete heights at the horizontal and the vertical section of the L-box (H_2/H_1) and segregated portion SR.

Table 4. Test results of fresh concrete properties

Mix identity	T	D	A_c	SF	t_{500}	V		H_2/H_1	SR
						t_v	$t_{v,5\ min}$		
	[°C]	[kg/m³]	[%]	[mm]	[s]	[s]	[s]	[-]	[%]
C1	23.5	2400	1.8	852.50	2.60	10.10	11.94	1	11.72
C2	22.5	2390	2.1	775.00	2.85	10.03	10.55	1	10.78
C3	23.5	2370	2.6	740.00	3.42	11.52	12.60	0.85	4.66

All designed self-compacting concretes are of normal-weight concrete, with a high level of compactness, i.e. with an amount of entrapped air of less than 3%. However, the applied amount of superplasticizer affects the entrapped air content in fresh concrete. Concrete made with 1% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, exhibits a 17% higher entrapped air content. Also, concrete made with 0.8% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 44% higher entrapped air content.

Flowability test showed that concretes C1 and C2 have a consistency class of SF3, while the concrete with the least HRWRA participation – concrete C3 has a consistency class of SF2. Specifically, concrete made with 1% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 9% smaller diameter of the flow spread. Also, concrete made with 0.8% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, shows a 13% smaller diameter of the flow spread.

Viscosity testing showed that all designed concretes are class VS2, determined by measuring time t_{500}, or class VF2, determined by measuring the V-funnel flow time. The flow rate of fresh concrete does not significantly differ between concretes C1 and C2. However, in comparison to concrete C1, concrete C3 exhibits a 32% longer time t_{500} and a 14% longer time t_v. Moreover, all designed concretes demonstrate viscosity stability, with the difference in discharge speed from the V-funnel t_v and $t_{v,5min}$ being less than 3 seconds. Concrete containing 1% HRWRA by mass of cement exhibits the best viscosity stability.

The passing ability results, tested using L-box with three bars, showed that all designed concrete mixtures meets the requirements for class PL2. In this regard, concretes C1 and C2 have the ideal passing ability ratio, while concrete C3 exhibits a 15% higher mean depth of fresh concrete in the vertical section of the box, than the mean depth of fresh concrete in the horizontal section of the box. By testing the segregation resistance, it was shown that all designed concretes meet the requirements for class SR2. Additionally, increasing the superplasticizing admixture content in concrete affects the increase of the segregated portion. The best segregation resistance test result was obtained for concrete C1. In this regard, concrete made with 1% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 0.94% larger segregated portion, i.e. 8% more favourable result in terms of segregation resistance. Also, concrete made with 0.8% HRWRA by mass of cement, compared to concrete made with 1.2% HRWRA by mass of cement, has a 7.06% larger segregated portion, i.e. 60% more favourable result in terms of segregation resistance.

3.4.2. CONCRETE IN HARDENED STATE

Table 5 presents the results of the compressive strength at 28 days of age ($f_{c,cube,28}$), density (D), absorption by the gradual immersion method (A_b) after 12 days, the frost resistance coefficient (r_{FTR}), and freeze/thaw resistance with de-icing salt, expressed in mass loss (L), depth of scaling (H) and scaling degree, after 25 cycles (surface scaling degree is presented in Figure 6).
Frost resistance coefficient is calculated as the ratio of the mean value of the compressive strength of the specimens subjected to f/t cycles and the mean value of the compressive strength of the reference samples tested at the equivalent age, after 100, 150 and 200 cycles of freeze/thaw (M_{100}, M_{150}, M_{200}). For all the mentioned f/t cycles, 6 concrete samples were tested.

Table 5. Test results of hardened concrete properties

Mix identity	$f_{c,cube,28}$	D	A_b	Freeze-thaw			Freeze/thaw with de-icing salt		
				M_{100}	M_{150}	M_{200}	L	H	scaling degree*
	[MPa]	[kg/m^3]	[%]	[%]	[%]	[%]	[mg/mm^2]	[mm]	
C1	57.93	2404	1.52	0.98	0.91	0.89	0	0	0
C2	55.77	2376	2.39	0.93	0.88	0.87	0	0	0
C3	50.40	2393	2.45	0.88	0.85	0.80	0	0	0

** Note: 0 – without scaling (L≈0mg/mm², HFTR-S≈0 mm), 1 – a little scaling (L≈0.2 mg/mm², HFTR-S≈1.0 mm), 2 – medium scaling (L≈0.5 mg/mm², HFTR-S≈4.0 mm), 3 – severe scaling (L≈1.0 mg/mm², HFTR-S≈10.0 mm).*

Figure 6. Surfaces appearance after 25 f/t cycles with de-icing salt

Characteristic changes of impact parameters in relation to the varied property are shown graphically in Figure 7.

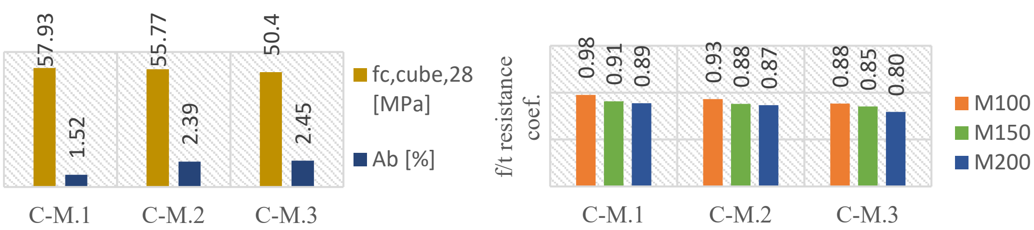

Figure 7. Test results of hardened concrete properties

Compressive strength test results showed that the application of HRWRA has a beneficial effect – by increasing the amount of admixture, higher values of compressive strength at the age of 28 days are obtained.

In that sense, it was shown that concrete C1 has a higher compressive strength value by 2.16 MPa, i.e., 4% at the age of 28 days compared to concrete C2, and by 7.53 MPa, i.e., 13%, at the age of 28 days compared to concrete C3.

Also, it has been shown that an increase in the proportion of HRWRA has a favourable effect on the value of water absorption by the test of gradual immersion at atmospheric pressure. The lowest value of water absorption has concrete with the highest proportion of HRWRA. Specifically, concrete C1 has 0.87% less absorption than concrete C2, or a 57% more favourable value. Additionally, concrete C1 has 0.93% less absorption than concrete C3, or a 61% more favourable value.

The results of testing the frost resistance revealed that the frost resistance coefficient is not below 75% for all of the concretes tested. According to the criterion [40], all tested types of concrete meet the quality requirements after 100, 150 and 200 f/t cycles. However, the results indicate that the proportion of HRWRA impacts freeze/thaw resistance. Specifically, after 200 freeze/thaw cycles, concrete C1 decreases strength by less than 0.02% than concrete C2, meaning it has a 2% more favourable value. Additionally, concrete C1 shows a decrease in strength of less than 0.09% than concrete C3 or a 10% more favourable value.

Testing for resistance to the simultaneous action of frost and de-icing salt revealed that none of the designed concretes exhibited surface spalling after 25 f/t cycles in the presence of a 3% salt solution. Consequently, all the mentioned concretes are classified as "resistant" after the freeze/thaw resistance test with a de-icing agent, in accordance with [41]. However, it is noted that concretes C2 and C3 exhibit visually noticeable less smooth surface (these concretes have a matte colour, as seen in Figure 7). Based on this, it can be assumed that concretes C2 and C3 may have lower resistance after a greater number of freeze/thaw cycles in the presence of a salt solution.

4. CONCLUSION

The conducted tests show that the applied amount of admixture, a superplasticizer based on polycarboxylate, influences the properties of both fresh and hardened self-compacting concrete. Considering that the focus of this research is concrete intended for use in traffic barriers, durability properties regarding freeze/thaw resistance and freeze/thaw resistance with a de-icing agent are of particular importance.

Tests on fresh concrete have shown that a higher quantity of HRWRA contributes to a reduction in the entrapped air content. For the application of superplasticizers ranging from 0.8 to 1.2% by mass of cement, every 0.1% of superplasticizer on average reduces entrapped porosity by 0.2% in the fresh concrete. Additionally, every 0.1% increase in superplasticizer content on average increases the diameter of the flow spread by 28 mm. Moreover, increasing the proportion of HRWRA accelerates the flow rate of fresh concrete, which describes viscosity. It has been demonstrated that the best viscosity stability is achieved for concrete produced with 1% HRWRA by mass of cement. Ideal passing ability is obtained for concretes with a 1% or more HRWRA participation by mass of cement. Such concretes can be applied in elements with congested reinforcement without loss of uniformity or blocking. In the case where the participation of HRWRA is less than 1%, occurrences of blocking and accumulation of coarse aggregate particles in narrow gaps between reinforcement bars are possible (although an acceptable passing ability ratio is achieved for the participation of 0.8% HRWRA by mass of cement).

The quantity of HRWRA ranging from 0.8 to 1.2% ensures satisfactory resistance to segregation, where an increase in the content of this admixture degrades the aforementioned resistance.

Considering the impact of HRWRA on the properties of fresh self-compacting concrete, in terms of improving fluidity and passing ability, reducing viscosity, and decreasing segregation resistance, it is concluded that for the designed types of self-compacting concrete with limestone filler, the optimal quantity of HRWRA is 1% by mass of cement.

The quantities of HRWRA do not have a statistically significant impact on the density, both in the fresh and hardened states.

Increasing the quantity of HRWRA has a positive impact on the increase in compressive strength of SCC at the age of 28 days. However, the function of the influence of increased strength due to the increase in the quantity of HRWRA is non-linear – concrete with 1.2% HRWRA has a higher compressive strength value of 4% compared to concrete with 1% HRWRA and of 13% compared to concrete with 0.8% HRWRA by mass of cement.

The greatest impact of HRWRA application on the properties in the hardened state is observed during testing water absorption using the gradual immersion method. Significantly lower amounts of absorbed water are obtained for SCC with the highest proportion of HRWRA. Similar to the influence of the quantity of HRWRA on compressive strength, the dependence function of the absorption reduction and quantity of HRWRA is non-linear. Concrete with 1.2% HRWRA is, in terms of absorption, 57% more favourable compared to concrete with 1% HRWRA, and 61% more favourable compared to concrete with 0.8% HRWRA.

Although SCC, with all analysed quantities of HRWRA, meets the frost resistance criterion for M_{200}, it has been shown that the applied quantity of HRWRA has an impact on the frost resistance coefficient. After 200 f/t cycles, concrete with 1.2% HRWRA is 2% more favourable than concrete with 1% HRWRA, and 10% more favourable than concrete with 0.8% HRWRA. Considering the importance of this property for concretes used in traffic barriers and similar exposure conditions during exploitation, it is recommended that the participation of HRWRA in such cases is a minimum of 1% by mass of cement.

The quantity of the applied admixture ranging from 0.8 to 1.2% for the analysed types of self-compacting concrete does not have a significant impact on the concrete's freeze-thaw resistance with a de-icing agent. Namely, all experimentally implemented types of self-compacting concrete exhibit a high level of quality of the final surface after the f/t cycles in the presence of de-icing salts. However, the optimal quantity of HRWRA concerning the high demand for the visible (final) surface of the concrete traffic barrier is 1.2%, with a 180 kg/m^3 of addition type I – limestone filler.

From the aforementioned conclusions regarding freeze-thaw resistance with and without de-icing agents, it is observed that the participation of HRWRA does not have an equal impact intensity. This is particularly emphasized due to the frequent misinterpretation of domestic practices suggesting that the impact intensity of certain admixture on these two properties is equal. Although the application of this specific admixture has the "same sign" of impact on both mentioned properties, research [5], [9] shows that some other admixture may even have a "different sign" of impact on these properties (favourable impact for one property and unfavourable impact for the other property).

In conclusion, it is determined that the application of self-compacting concrete technology, in which HRWRA is an essential component, enables the production of concrete elements with high durability requirements. Therefore, the importance of promoting this concrete technology, as well as analysing the properties of different types of self-compacting concrete prepared with domestically sourced component materials, is of utmost significance. This aims to increase the presence of these concretes in the domestic market compared to previous practices.

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32
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EVALUATION OF PROPERTIES OF MASONRY MORTARS BLENDED WITH CERAMIC WASTE POWDER

Abstract

Aiming to meet the principals of the modern circular economy, this study explores the possibility of using locally available waste materials in the production of innovative, eco-friendly mortar for masonry. The eco-binder, applied as a substitute for cementitious material, is ceramic waste powder (CWP) generated during the production of ceramic industry elements. Within the experimental program, compositions of twelve types of masonry mortars were designed with volumetric ratios of solid components 1:1:5, 1:0.7:4.2, and 1:1:4 (cement + eco-binder/lime/sand), varying the percentage of cement replacement with ceramic powder (up to 80%). The basic properties of masonry mortars were tested, including consistency, compressive strength, flexural tensile strength, capillary water absorption, and adhesion. The test results indicate that ceramic waste powder can be successfully used as a partial replacement for cement up to high substitution levels, yielding more sustainable masonry mortars for use in load-bearing or non-load-bearing masonry structures.

Keywords: masonry mortar, ceramic waste powder, cement replacement, sustainability

СВОЈСТВА МАЛТЕРА ЗА ЗИДАЊЕ СПРАВЉЕНИХ СА КЕРАМИЧКИМ ОТПАДОМ

Сажетак

У циљу испуњавања захтјева савремене циркуларне економије, у раду је урађено истраживање могућности примјене локално доступних отпадних материјала при производњи иновативних еко-прихватљивијих малтера за зидање. Еко-везиво, примијењено као замјењујући цементни материјал, је керамички отпадни прах (CWP) који настаје током производње елемената керамичке индустрије. У оквиру експерименталног програма, пројектовани су састави 12 врста малтера за зидање, запреминског односа чврстих компоненти 1:1:5, 1:0,7:4,2 и 1:1:4 (цемент+еко везиво/креч/пијесак) при чему је вариран проценат замене цемента керамичким прахом (до 80%). Испитана су основна својства малтера за зидање: конзистенција, чврстоћа при притиску и затезању при савијању, капиларно упијање воде и атхезија. Резултати испитивања показују да се отпадни керамички прах може успјешно користити као замјена дијела цемента до високих нивоа супституције, при чему се добијају одрживији малтери за зидање за примјену у носећим или неносећим зиданим конструкцијама.

Кључне ријечи: малтери за зидање, керамички отпад, замјена цемента, одрживост

1. INTRODUCTION

Recycling is a common technique to mitigate the negative effects of rapid industrialization, such as the depletion of natural resources and the generation of massive volumes of waste throughout the manufacturing, construction, and demolition processes. Thus, researchers are exploring the potential application of recycled materials processed from solid waste in new products or industries. Concrete, the world's most frequently used man-made material, has garnered substantial attention to utilizing recycled waste materials for increased mechanical, environmental, and durability characteristics.

Given that cement production accounts for 8% of worldwide yearly CO_2 emissions, numerous alternative byproducts are being examined as viable concrete constituents. Durable, renewable, and sustainable materials have recently gained popularity among researchers as a means of achieving cleaner and greener construction in the construction sector. The use of waste ceramic is unquestionably important for a greener global manufacturing and waste-based construction industry. The use of locally prevalent ceramic waste as a replacement for concrete materials may handle the essential environmental problem, as the limited utilization of cement and aggregates in locations where they are rare and costly.

Ceramic waste powder (CWP) is formed during manufacturing ceramic tiles, particularly in the process of final polishing. According to the literature reports 4.[1]4.[2], more than 22 billion tons of CWP are produced globally, generating significant negative environmental impacts in the form of soil, water, and air pollution. Several sorts of research have been undertaken on using ceramic wastes into cement-based composites, either as aggregates or cement substitutes. Some studies have investigated ceramic waste as coarse aggregates in traditional mortars and concrete 4.[3]4.[5]. Ceramic waste was shown to be an adequate (partial) replacement for natural coarse aggregates, however there was a decrease in compressive strength of concrete when replacement surpassed 25% by weight. It was also discovered that incorporating ceramic waste content as fine aggregate reduces the workability of fresh concrete, hence admixtures are necessary to mitigate such adverse effects. However, the performance of hardened concrete is not significantly impaired when fine aggregate is replaced by ceramic waste up to 50% (by weight) 4.[6]4.[7].

Studies concentrating on integrating CWP to partially replace cement are currently garnering interest, owing to its favorable chemical composition: high content of alumina and reactive silica. The majority of these experiments indicated the favorable pozzolanicity of finely powdered CWP and its role in the pozzolanic reaction at later ages 4.[8]4.[12].

So far, scarce research has been conducted on the utilization of CWP in masonry applications. Therefore, the authors of this paper investigated the effects of locally sourced CWP on various masonry mortar properties, such as workability, compressive and flexural strength, capillary water absorption, and adhesive bond strength. The study aims to substitute cement to a greater extent (up to 80%) in mortar formulations and create masonry mortar for structural and non-structural applications while improving the environmental impact and cost efficiency.

2. MATERIALS AND METHODS

2.1. MATERIALS

Ordinary Portland Cement (OPC), produced by the Lafarge cement plant in Vojvodina, was used. The cement has a Blaine fineness of 4.000 cm^2/g and a density of 3.1 g/cm^3.

Ceramic waste powder (CWP) was produced from ceramic manufacturing waste, consisting of damaged clay hollow blocks discarded in the production facility NEXE Stražilovo in Petrovaradin, Serbia. These elements were firstly roughly crushed and then finely ground in a lab ball mill up to the appropriate level of fineness. Table 1 summarizes the results of examining the chemical composition of the OPC and CWP. The main oxides of CWP are SiO_2 and Al_2O_3, which account for more than 75% of the total oxide weight. CWP is characterized with the pozzolanicity class 10, while it met the requirements regarding the activity index (the values of index at the age of 28 and 90 days are 93% and 99%, respectively), in accordance with EN 450-1.4.[13]

Table 1. Chemical composition of OPC and CWP

	LOI	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	MgO	CaO	SO_3	P_2O_5	Cl^-	Reactive SiO_2
OPC	/	17,34	4,53	20,64	0,20	0,59	1,93	50,26	3,06	0,00	0,00	/
CWP	3,3	60,86	16,38	6,81	0,77	2,39	3,89	9,38	0,80	0,14	0,00	50.26

The river-derived sand was used as a fine aggregate for mortar production. The specific gravity and fineness modulus were measured to be 2.3 g/cm^3 and 0.97, respectively.
The water-to-binder ratio (w/b) was adjusted aiming to achieve the required workability of masonry mortar (175±10 mm), as prescribed by SRPS EN 1015-2.4.[14]

2.2. METHODS

The chemical composition of raw materials was analyzed using SRPS EN 196-24.[15] and ISO 29581-2.4.[16]
The workability of fresh mortar (flow value) was assessed using EN 1015-34.[17].
Mechanical properties (compressive and flexural strength) were determined according to EN 998-24.[18] and EN 1015-114.[19] standards.
The water absorption coefficient produced by capillary action in hardened mortar was obtained using EN 1015-18.4.[20]
The EN 1015-124.[21] methodology was followed to measure the adhesive strength of hardened mortars on substrates.

2.3. MIXING AND PROPORTIONING OF MORTAR

Ten different mortar mixtures were cast within the experimental program. The mixing ratios of reference cement-lime mortar (C) were: 1:1:5, 1:0.7:4.2, and 1:1:4 (cement/lime/sand), by volume. In the remaining seven combinations, cement was partially substituted with CWP. In the first mortar series (the mixing ratio of 1:1:5), cement was replaced with 50% CWP, while in the remaining two series, cement was substituted with 50%, 60%, and 80%, by volume – Figure 1. The labels and quantities of component components for each masonry mortar are shown in Table 2.

Table 2. Labels and component materials quantities for designed masonry mortars

Mortar	m_c (g)	m_l (g)	m_s (g)	m_{cwp}(g)	w/b	m_w (g)
C1	161.4	74.0	1350	/	1.15	270.7
CWP1-50	80.7	74.0	1350	61.8	1.30	281.5
C2	193.7	59.2	1350	/	1.05	265.6
CWP2-50	96.9	59.2	1350	74.2	1.20	276.3
CWP2-60	77.5	59.2	1350	89.0	1.20	270.9
CWP2-80	38.7	59.2	1350	118.7	1.25	270.8
C3	201.8	92.5	1350	/	0.90	264.9
CWP3-50	100.9	92.5	1350	77.3	1.00	270.7
CWP3-60	80.7	92.5	1350	92.7	1.05	279.3
CWP3-80	40.4	92.5	1350	123.7	1.07	274.5

m_c-mass of cement; m_l-mass of lime; m_s-mass of sand; m_{cwp}-mass of CWP; m_w-mass of water; w/b-water to binder ratio.

Figure 1. Binder materials for the preparation of masonry mortar

3. TEST RESULTS AND DISCUSSION

3.1. WORKABILITY OF FRESH MORTAR

Figure 2 shows the influence of the water-to-binder ratio on the workability of mortar.

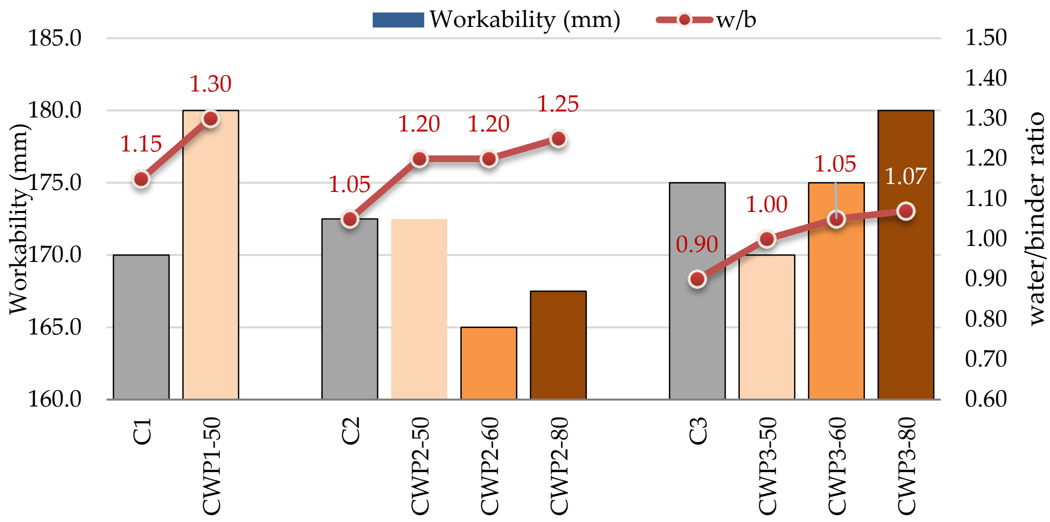

Figure 2. Flow values of fresh mortar

All blended mortar mixtures required more water to attain the desired flow value (175±10 mm). As the workability of cement composites is mostly determined by the shape of their particles, this impact can be attributed to the angularity and sharp edges of ash particles. As a result, w/b increases with CWP content.

3.2. COMPRESSIVE STRENGTH

Compressive strength results of the hardened masonry mortar are shown in Figure 3.

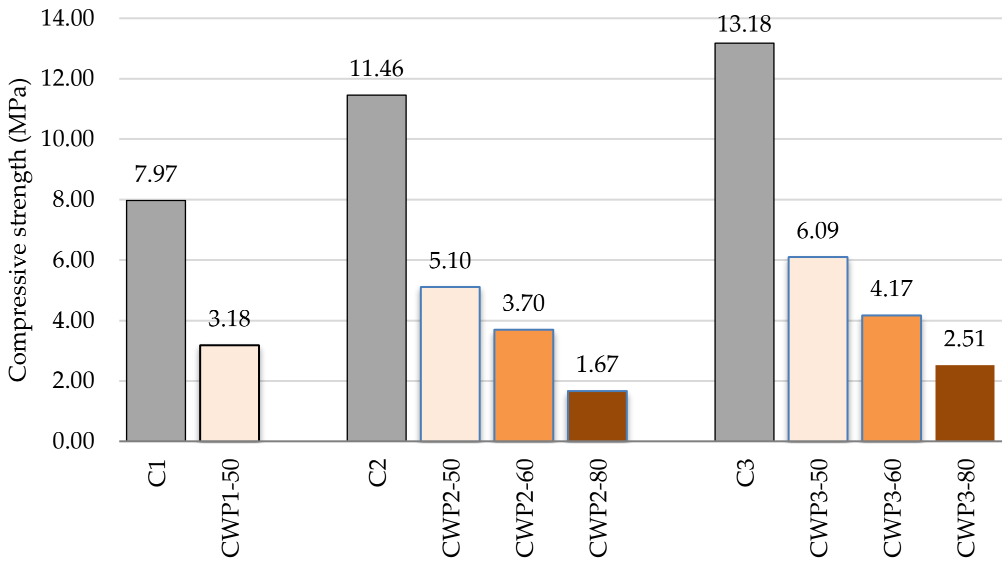

Figure 3. The compressive strength of mortars

When compared to the reference mix (C1), C2's compressive strength increased by 44% as the w/b ratio decreased from 1.15 to 1.05, while C3's strength rose by 65% as the w/b ratio decreased to 0.9.

In relation to the corresponding reference mortar values, the compressive strength of CWP1-50 was decreased by 60%, while for CWP2-50, CWP2-60, and CWP2-80, it was reduced by 55%, 68%, and 85%, respectively. Similarly, mortars CWP3-50, CWP3-60, and CWP3-80 showed a sharp strength drop of 54%, 68%, and 81%, respectively. These adverse effects can be explained by the increased effective w/b of blended masonry mortars. Higher w/b resulted in greater porosity and the permeability of the mix and, consequently, lower mechanical properties.

Masonry mortars are categorized into classes according to the mean compressive strength, as described by EN 998-24.[18]. Masonry mortars for load-bearing structures, classified as Class 5, require a minimum compressive strength of 5MPa, according to provisions of Eurocode 6 and Eurocode 8. Table 3 displays the average compressive strength and achieved class of each masonry mortar.

Table 3. Class of masonry mortars based on the achieved compressive strength

Mortar	C1	CWP1-50	C2	CWP2-50	CWP2-60	CWP2-80	C2	CWP3-50	CWP3-60	CWP3-80
Compressive strength (MPa)	7.97	3.18	11.46	5.10	3.7	1.67	13.18	6.09	4.17	2.51
Class	**5**	**2.5**	**10**	**5**	**2.5**	**1**	**10**	**5**	**2.5**	**2.5**

The reference mortars and mixtures CWP2-50 and CWP3-50 meet the criteria for masonry mortar for structural purposes, while the other mortars achieved the class of 2.5 and can thus be used successfully for non-load-bearing elements.

3.3. FLEXURAL STRENGTH

The results follow a similar pattern to the compressive strength tests. Figure 4 displays the results of the flexural strength of hardened masonry mortar.

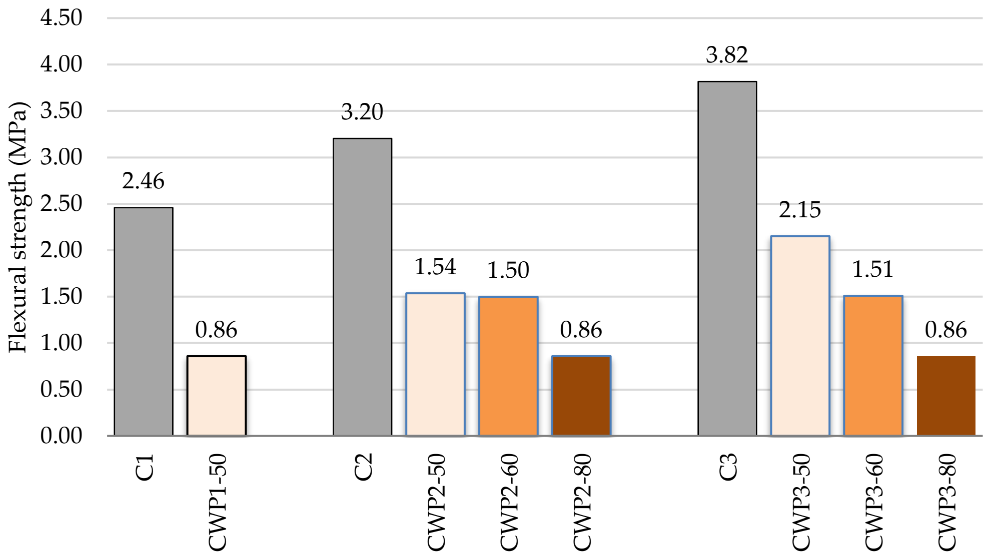

Figure 4. The flexural strength of mortars

The use of CWP as a cement substitute material resulted in a dramatic drop in flexural strength. At 28 days, the blended mixture CWP1-50 suffered strength loss of 65%, whereas CWP2-50, CWP2-60, and CWP2-80 achieved approximately 52%, 53%, and 73% of the reference flexural strength, respectively. Similarly, mortars CWP3-50, CWP3-60, and CWP3-80 showed a significant strength decrease of 44%, 60%, and 77% consequently. However, flexural strength is not the property of a greater importance for masonry mortars; hence, no criteria are provided in regulations.

3.4. CAPILLARY WATER ABSORPTION

Figure 5 shows the capillary water absorption coefficients of all examined mortar mixtures, as well as the limit values for the achieved absorption class.

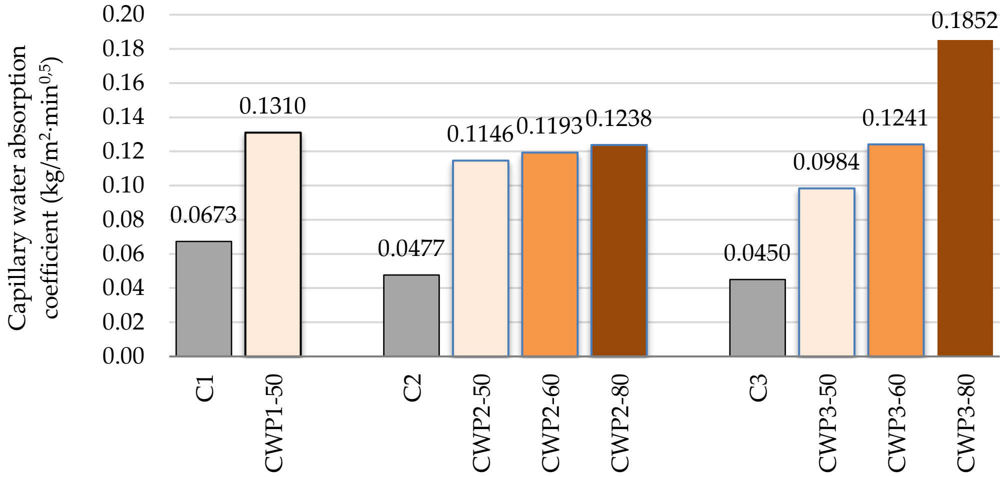

Figure 5. Capillary water absorption coefficients of mortars

Water absorption, which indirectly expresses capillary porosity, is one of the key elements determining the durability of cement-based composites. As a direct consequence of increased w/b, the capillary porosity of the mortar mixtures rose as the CWP content increased, resulting in a higher absorption coefficient. When compared to the reference mortar, the capillary water absorption coefficients of CWP1-50 increased by 95%, while those of CWP2-50, CWP2-60, and CWP2-80 rose by 140%, 150%, and 160%, respectively.

Masonry mortars CWP3-50, CWP3-60, and CWP3-80 followed the similar trend and exhibited significantly higher capillary absorption coefficients in relation to the reference values.

Masonry mortars can be classified into classes according to the computed water absorption coefficient at the age of 28 days, as recommended by EN 998-24.[18]. As all mortar formulations meet the W2 category criterion (≤ 0.2 kg/m^{2}min$^{0.5}$), it can be stated that replacing cement with CWP does not affect this property to a greater extent.

3.5. ADHESIVE STRENGTH OF MORTAR

One of the most important requirements for masonry mortar is adhesive strength, since a lack or loss of adhesion reduces construction integrity and functional life. Figure 6 displays the adhesive strength test results.

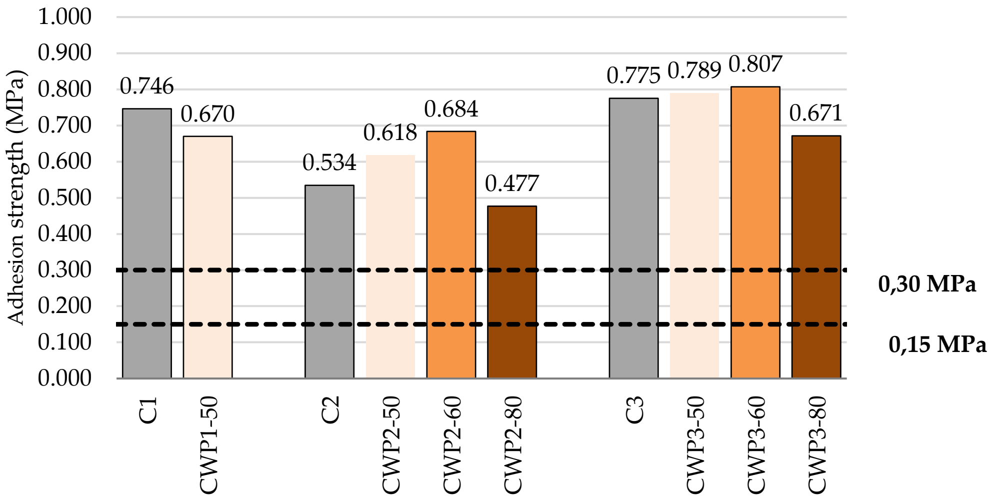

Figure 6. Adhesive strength of mortars

The results demonstrate that at a 1:1:5 mixing ratio, the adhesive strength of CWP1-50 is lowered by 10% when compared to the reference mortar. With a mixture ratio of 1:0.7:4.2, substituting cement by 50% and 60% (CWP2-50 and CWP2-60) resulted in a 16% and 28% strength improvement, respectively. However, CWP2-80 displayed the strength decline of 11% in relation to the reference value. There were no significant differences in adhesion measured at the 1:1:4 mixing ratio.

The EN 998-14.[18] mortar regulation requires a minimum value of 0.3 MPa for use in rendering or plastering, while the EN 998-24.[18] masonry mortar regulation requires a minimum value of 0.15 MPa. All tested mortar combinations satisfied the requirements for plastering and masonry applications.

3.6. COST EFFICIENCY

Cost efficiency is one of the major factors determining the sustainability of cement-based materials. The raw material unit costs were calculated using the Serbian raw material purchase price. The calculations did not include the costs associated with the transportation, handling, placement, and quality control. Table 4 lists the unit costs of all component materials used in masonry mortars.

Table 4. The unit costs of raw materials

Material	Sand	PC	Lime	Water	CWP
Price (EUR/t)	18	170	130	2	1

The incorporation of CWP in masonry mortar had a considerable economic impact, regardless of the mixing ratio used. The blended masonry mortars were less expensive than the reference mortars, as the price of CWP1-50 was lowered by 22%, while CWP2-50, CWP2-60, and CWP2-80 cut prices by 25%, 31%, and 40%, respectively. Similarly, mortars CWP3-50, CWP3-60, and CWP3-80 experienced considerable price declines of 24%, 28%, and 38%, respectively – Figure 7.

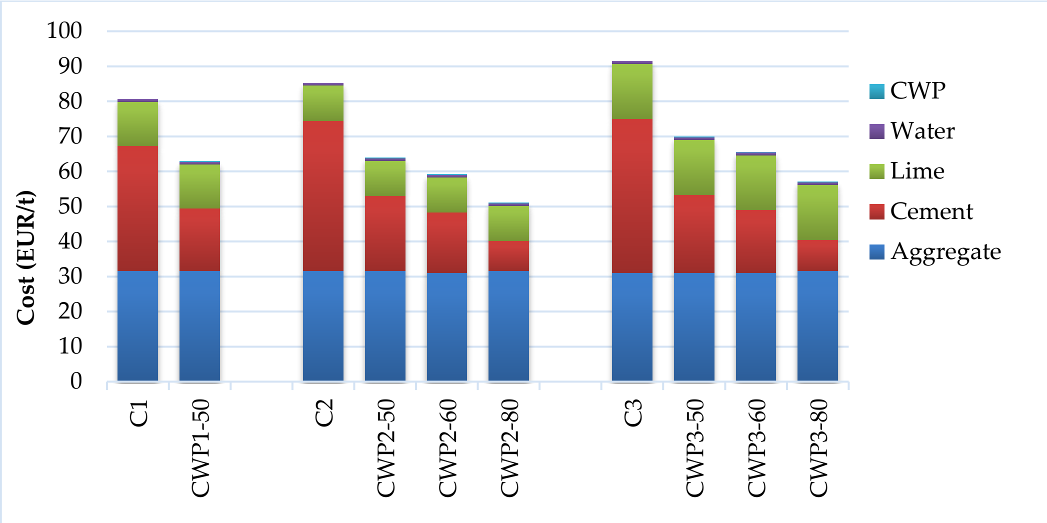

Figure 7. Cost price of analyzed mortar mixtures.

4. CONCLUSIONS

The principal findings of the study are as follows:

- Chemical composition of ceramic waste powder indicates a relatively high content of amorphous silica, which positively influences the pozzolanic activity and manifests in high activity index,
- CWP, as a conventional pozzolanic material, requires more water to ensure that the necessary workability can be attained when used as partial cement replacing material in masonry mortar,
- Considering the attained compressive strength, mixtures CWP2-50 and CWP3-50 meet the criterion for structural application, while the other mortars achieved the class of 2.5 and can thus be used successfully for non-load-bearing elements (such as partition walls),
- Due to the increased water to binder ratio, capillary water absorption of blended mortar increased significantly. Despite this trend, all mixtures had capillary water absorption coefficient values within the acceptable range of the W2 category,
- All tested mortar combinations met the required adhesive strength limit for the masonry mortar, exceeding the minimum value of 0.30 MPa,
- The incorporation of CWP in masonry mortar had a considerable economic impact, regardless of the mixing ratio used.

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33
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MODELING OF POROUS DRY MATERIALS USING RHEOLOGICAL-DYNAMICAL ANALOGY

Abstract

A theoretical model for porous viscoelastoplastic (VEP) materials under dry conditions is examined based on the principles of mass and energy conservation using rheological-dynamical analogy (RDA). The model provides the expressions for the creep coefficient, Poisson's ratio, modulus of elasticity, damage variable and strength in the function of porosity and/or void volume fraction (VVF). Compared with numerous versions of acoustic emission monitoring developed to analyze the behavior of the total wave propagation in inhomogeneous media with density variation, the RDA model is found to be comprehensive in interpretation and consistent with physical understanding. The reliability of the proposed model is confirmed by the comparison of numerical results with experimental ones on hardened concrete and rocks.

Keywords: porosity, RDA model, wave propagation, density variation, creep effects, cracks

МОДЕЛИРАЊЕ ПОРОЗНИХ МАТЕРИЈАЛА У СУВОМ СТАЊУ РЕОЛОШКО – ДИНАМИЧКОМ АНАЛОГИЈОМ

Сажетак

Теоријски модел за порозне вискоеластопластичне (VEP) материјале у сувом стању је испитан на основу принципа очувања масе и енергије примјеном реолошко – динамичке аналогије (RDA). Модел даје изразе за коефицијент течења, Поасонов коефицијент, модул еластичности, варијаблу оштећења и чврстоћу у функцији порозности и/или запреминског удјела празнина (VVF). У поређењу са бројним верзијама праћења акустичне емисије развијеним за анализу понашања укупног ширења таласа у нехомогеним медијима са варијацијама густине, RDA модел је свеобухватан у интерпретацији и конзистентан са физичким разумјевањем. Поузданост предложеног модела потврђује поређење нумеричких резултата са експерименталним на очврслим бетонима и стенама.

Кључне ријечи: порозност, RDA модел, пропагација таласа, паријацција густине, ефекти течења, пукотине

1. INTRODUCTION

So far, many relationships have been established between porosity and key mechanical properties such as strength and modulus of elasticity. However, the utility and physical significance of many of these relationships are often unclear as most theoretical models are based on some idealized physical microstructure, and the resulting correlations often cannot be applied to actual materials and practical applications, [1]. Spriggs's empirical equation for Young's modulus of porous materials [2], and the similar Ryshkewitch-Duckworth [3] equation for the strength of porous materials have long been accepted by the literature. Phani and Niyogi [4] derived a semi-empirical equation to describe the porosity dependence of Young's modulus of brittle solids. Wang [5] obtained theoretically the relationship between Young's modulus and porosity of porous alumina, in situations where the porosity percentage not only changes, but changes also occur from interconnected to disconnected pore structures. The dependence applies to the entire range of porosity and can treat the transition of the pore structure from interconnected to isolated. However, later, advances in predicting the elastic properties of porous materials over the entire porosity range were closely related to the relationship to Phani and Niyogi [4].

One of the most important factors that determine the mechanical properties of hardened concrete is its porosity, as well as the number, size, and interconnection of pores in hardened cement paste, [6]. Many proposed expressions can be found in the literature that establish the relationship between the porosity of hardened concrete and its mechanical properties - compressive strength and modulus of elasticity, [7], [8], [9], [10]. These connections are most often established by applying statistical processing of experimentally determined data on a limited number of samples of certain characteristics, and their accuracy in practical application is conditioned by the similarity of real concrete with these samples.

Rock porosity varies in a wide range. Theories for the poroelastic behavior of rocks can be developed based on two conceptual models of porous rock: a solid material permeated with an interconnected collection of voids [11] or aggregation of grains in partial contact with each other at various points [12]. The latter model is more appropriate for soils, whereas the former has proven to be more fruitful for studying rocks. An additional difficulty in establishing the relationship between porosity and mechanical properties of rocks is obtaining reliable data on the porosity in the rock masses, which usually are based on testing samples (e.g., using the method of porosimetry by mercury injection) taken from selected sites.

The main goal of this paper is to analyze predicted relationship form [13] between mechanical parameters and VVF of damaged materials. In this paper, it is considered that the principles of conservation of mass and energy are valid for wave motion between two cross-sections of the sample, regardless of how the material behaves in terms of the size and distribution of material particles. Damage evolution is considered to be an increase in degradation of material properties compared to their initial states due to the change of VVF.

2. DESCRIPTION OF MODEL PARAMETERS

The relationship between the creep coefficient and Poisson's ratio is given in [14]

$$\varphi = \frac{2\mu}{1-2\mu} \tag{2}$$

In the wave motion, a very short time T^D is, due to which the creep coefficient is converted into a quotient of two moduli

$$\varphi = \frac{E_H}{E_K} \tag{3}$$

Where E_H is elastic modulus and E_K is the viscoelastic (VE) modulus.

According to [15], [13] the linear dependence of creep coefficient as a function of porosity is proposed in a form

$$\varphi(p) = \varphi_1 - \frac{p(\varphi_1 - \varphi_E)}{p_E} \tag{4}$$

where φ_1 is at zero porosity, while φ_E is at the end of the porosity interval [0, p_E]. p_E is defined at the end of measurable porosity. On the other hand, due to points (p_E, φ_E) and $(p_{max}, 0)$, the creep coefficient φ_E is

$$\varphi_E = \varphi_1 \left(1 - \frac{p_E}{p_{max}}\right) \tag{5}$$

The creep coefficient is a linear function of the modulus of elasticity, while the VE modulus is independent of porosity as a consequence of the principle of mass conservation. Consequently, Eq. (3) implies the linear relationship between the modulus of elasticity and porosity.

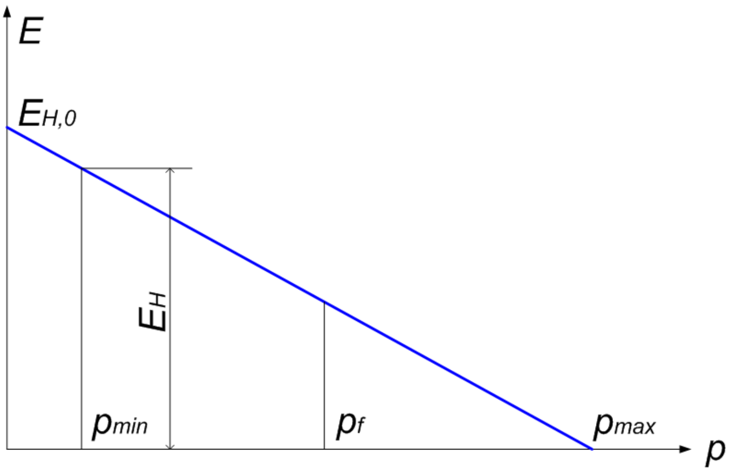

Figure 1. Young's modulus as a function of porosity.

According to the RDA model, the relationship between the Poisson's ratio and porosity for the interval [0, p_E] is

$$\mu_{RDA}(p) = \left[\varphi_1 - \frac{p(\varphi_1 - \varphi_E)}{p_E}\right] \Big/ \left\{2\left[1 + \varphi_1 - \frac{p(\varphi_1 - \varphi_E)}{p_E}\right]\right\} \tag{6}$$

The dynamic Poisson's ratio of solid material in its initial state can be obtained using the P and S wave velocities

$$\mu_1 = \frac{v_L^2 - 2v_T^2}{2\left(v_L^2 - v_T^2\right)} \tag{7}$$

where v_L and v_T are the velocities of the P and S waves of a solid material in its initial state. According to [14], the scalar damage variable of VEP material for the interval [0, p_E] is

$$\frac{\varphi_1}{1+\varphi_1} \geq D \geq \frac{\varphi_E}{1+\varphi_E} \tag{8}$$

where the initial (critical [16]) damage variable D_1 at zero porosity corresponds to the creep coefficient φ_1. Consequently, the nonlinear relationship between the damage variable and porosity is

$$D(p) = \left[\varphi_1 - \frac{p(\varphi_1 - \varphi_E)}{p_E}\right] \Big/ \left\{1 + \left[\varphi_1 - \frac{p(\varphi_1 - \varphi_E)}{p_E}\right]\right\}. \tag{9}$$

3. VOID VOLUME FRACTION

The solution of the quadratic equation derived by Milašinović et al. [17] are two values of Poisson's ratio

$$\mu_{1/2} = \frac{(\psi - 1) \pm \sqrt{\psi^2 - 10\psi + 9}}{4} \tag{10}$$

where Ψ is the ratio of the modulus of elasticity and dynamic modulus

$$\Psi = \frac{E_H}{E_D} \tag{11}$$

Based on two Poisson's ratios, the two stress-strain curves are obtained in [18], and they are:

$$\sigma_i = \frac{1}{2K_{E,i}}\left(\sqrt{1 + 4K_{E,i}E_i(0)\varepsilon} - 1\right), \quad i = 1,\ 2, \tag{12}$$

where

$$K_{E,i} = \frac{\varphi_i}{\sigma_{ef}}, \quad \varphi_i = \frac{2\mu_i}{1 - 2\mu_i}, \quad E_i(0) = E_H(1 + \varphi_i), \qquad i = 1,\ 2, \tag{13}$$

The effective stress σ_{ef} can be understood to represent not only the effect of reducing the geometric cross-section area due to damage, but also includes the effects of stress concentration in voids or the effects of interaction between voids, [19]

$$\sigma_{ef} = \frac{f_{cS}}{1 - D_1}, \tag{14}$$

where f_{cS} is the uniaxial unconfined compressive strength (UCS) of the damaged dry sample.

The damage state of ductile or VEP materials can be described by the VVF, [19]–[21]. The VVF is given by

$$VVF = \frac{dV - dV_0}{dV}, \tag{15}$$

where dV is the volume of a representative volume element (RVE) at a point in a material, while dV_0 is the volume of the matrix of RVE. It has been observed that the voids start to coalesce when they have grown to a size as large as the distance between them, [22], and the VVF at that stage is in the range of 0.15 through 0.25, [23].

Although Eq. (15) represents the definition of porosity, direct measurement of VVF is difficult. Because of that, it is rather easy to measure the density change of the material

$$VVF = 1 - \frac{\rho}{\rho_0}, \tag{16}$$

where the initial and the damage density of the material are denoted by ρ_0 and ρ.

Lemaitre and Dufailly [24] used the density change between the damaged and the initial state in interpreting the micromechanical model of a spherical void in a spherical RVE to prove the relation between the damage variable and porosity

$$D_{LD} = \left(1 - \frac{\rho}{\rho_0}\right)^{2/3}. \tag{17}$$

This is the relation between the surface damage and the variation of density or porosity.

In [13], Milašinović gave a detailed explanation of the limit values of VVF based on the strain energy densities shown in Figure 2, where

$$W_{el} = \frac{1}{2E_H}\sigma_{ef}^2,$$

$$W_{d1} = \int_0^{\varepsilon_{cF}} \sigma_1 d\varepsilon = \int_0^{\varepsilon_{cF}} \frac{1}{2K_{E1}}\left(\sqrt{1+4K_{E1}E_1(0)\varepsilon}-1\right)d\varepsilon = \\ = \frac{1}{2K_{E1}}\left[-\varepsilon_{cF} + \frac{-1+\left(1+4K_{E1}E_1(0)\varepsilon_{cF}\right)^{3/2}}{6K_{E1}E_1(0)}\right], \tag{18}$$

$$W_{d2} = \int_0^{\varepsilon_{cF}} \sigma_2 d\varepsilon = \int_0^{\varepsilon_{cF}} \frac{1}{2K_{E2}}\left(\sqrt{1+4K_{E2}E_2(0)\varepsilon}-1\right)d\varepsilon = \\ = \frac{1}{2K_{E2}}\left[-\varepsilon_{cF} + \frac{-1+\left(1+4K_{E2}E_2(0)\varepsilon_{cF}\right)^{3/2}}{6K_{E2}E_2(0)}\right].$$

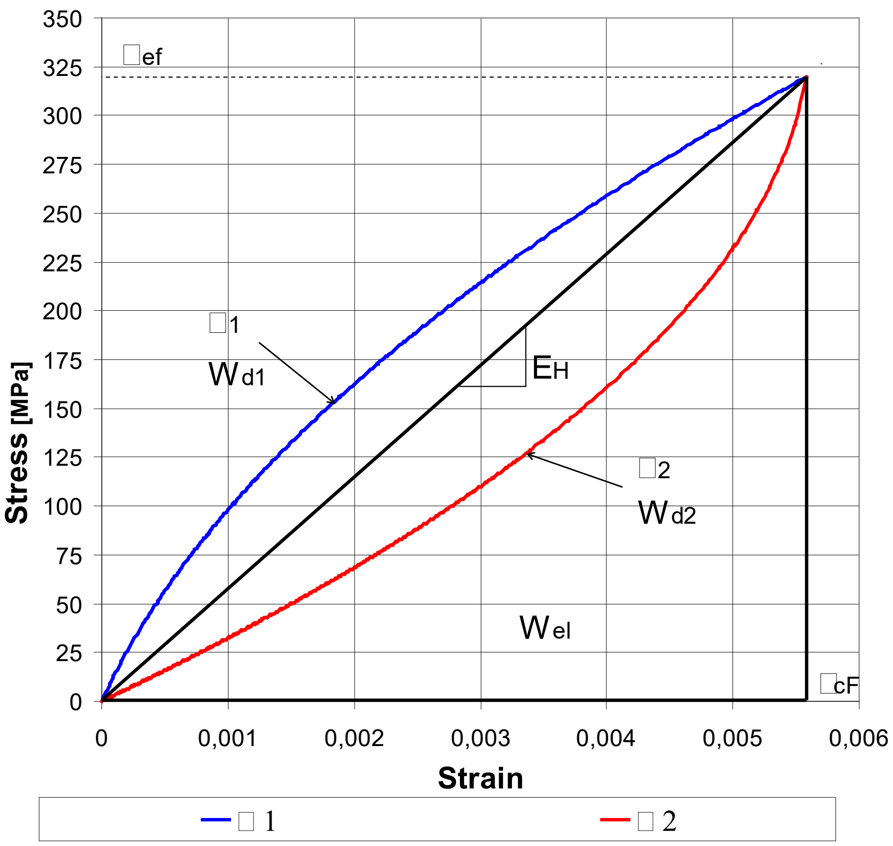

Figure 2. Strain energy densities: with positive Poisson's ratio (blue line) and with negative (red line)

The total energy density dissipation is

$$W_d = W_{d1} - W_{d2} \tag{19}$$

Consequently, the maximum VVF can be determined as follows

$$p_{max} = \frac{W_d}{W_{el}} = \frac{W_{d1} - W_{d2}}{W_{el}} . \tag{20}$$

It is well known that a positive Poisson's ratio is a measurable value, and a negative one is not. This fact allows us to determine the limit of measurable VVF

$$p_E = \frac{W_{d1} - W_{el}}{W_{el}} . \tag{21}$$

Using the difference between the W_{d1} and W_{d2} in relation to the W_d, the VVF which controls the macroscopic failure of the sample by the static strength f_{US2} [18] is

$$p_f = \frac{2W_{el} - W_{d1} - W_{d2}}{W_d} . \tag{22}$$

The previous difference in relation to the W_{el}, defines the minimum VVF which controls the dynamic strength f_{US1}

$$p_{min} = \frac{2W_{el} - W_{d1} - W_{d2}}{W_{el}} . \tag{23}$$

In [25] the relationship between the strength and the stress at the limit of elasticity is determined

$$\frac{\sigma_E}{f_{cS}} = \frac{\varphi_1}{1+\varphi_1} = D_1 . \tag{24}$$

So, the nonlinear relationship between the strength and VVF of dry VEP material denoted by according to [13] is

$$\sigma_f = \sigma_{ef} \left\{ 1 - \frac{p_f}{p_E} \left[1 - D_1 \left(1 - D_f \right) \right] \right\} . \tag{25}$$

4. ANALYSIS OF POROUS CONCRETE SAMPLES

A large number of experiments have shown that the elastic properties of wet concrete are affected by the degree of saturation, and that the strength of saturated concrete decreases, while the static and dynamic moduli of saturated concrete increase, [26], [27]. Experimental data from [26] were obtained on concrete samples with different amounts of entrained air and different water-cement ratios. A total of 15 samples were analyzed, some with very similar data. Therefore, only eight samples shown in [13], whose data are sufficiently different, were selected for this analysis.

According to [26] the average modulus of elasticity of the dry sample with zero porosity is $E_{H,0} = 45{,}35 GPa$. Experimental results for eight selected samples are in detail analyzed in [13].

Assuming a linear change of modulus of elasticity with porosity in the interval [0, p_{max} = 0.508], where p_{max} is obtained for the sample No. 1 (35-00-L-2), we get the line shown in Figure 3, marked with black color. Figure 3 shows a comparison of the dimensionless moduli of elasticity obtained experimentally and by the RDA method. An excellent agreement of the results is observed.

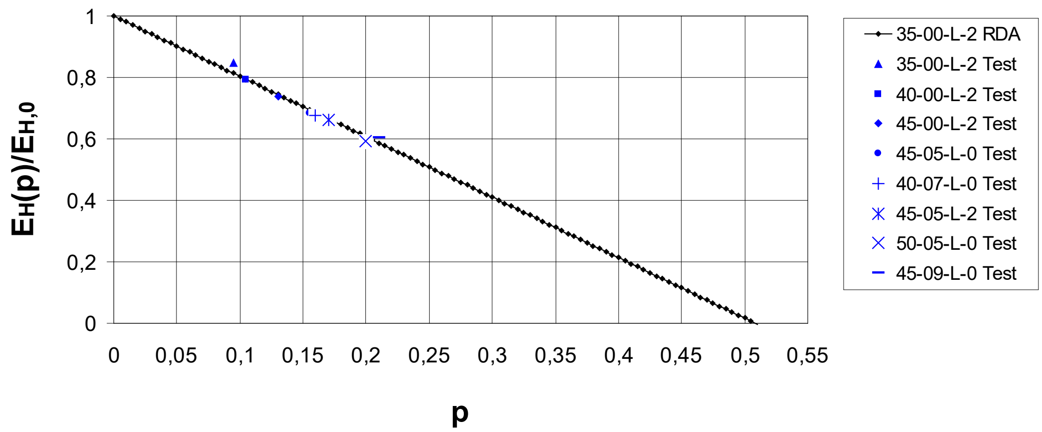

Figure 3. Comparisons of tested moduli of elasticity with functional dependence of modulus of elasticity versus porosity for sample No. 1 (35-00-L-2) according to RDA model

The calculated parameters by the RDA model associated with positive and negative values of Poisson's ratio are given in [13]. The functional dependence of the Poisson's ratio in relation to the porosity is shown in Figure 4 for sample No. 1 (35-00-L-2). The figure also shows a comparison of tested (μ) and numerically calculated (μ_1) values of Poisson's ratios that differ significantly.

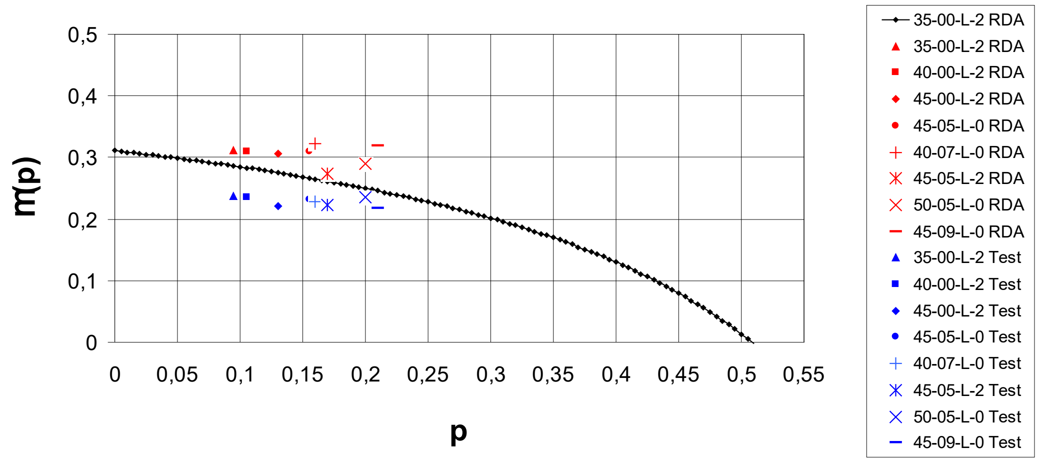

Figure 4. Comparison of tested and numerically calculated Poisson's ratios with functional dependence of Poisson's ratio versus porosity for sample No. 1 according to the RDA model

For all concrete samples except for sample No. 6 (45-05-L-2) an excellent agreement between the calculated and tested strengths is observed, [13]. Note that the calculated parameters were obtained using Poisson's ratios which are obtained from the P and S wave velocities.

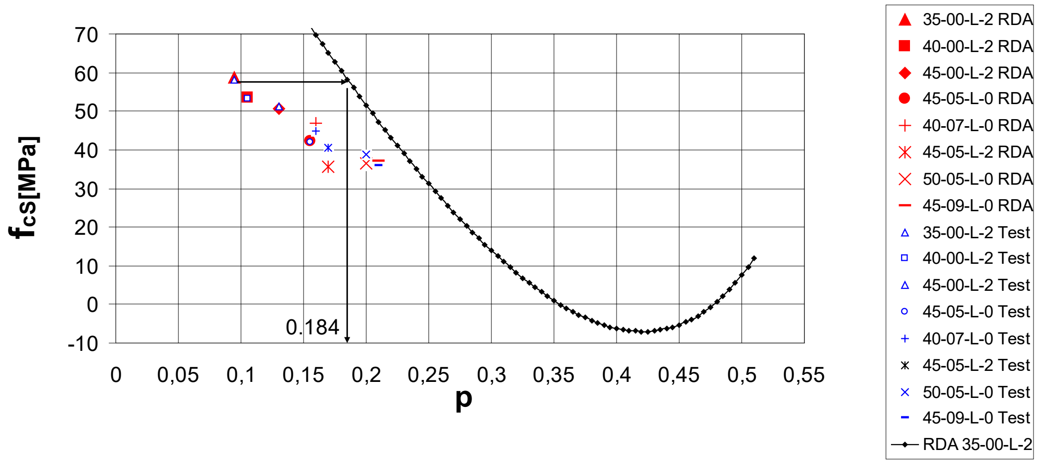

Figure 5. Comparisons of tested and calculated compressive strengths for established p_f, which control static strengths

The RDA method is based on a completely new concept of calculated VVF-s, based on the energy densities. The VVF-s control the static strengths, in contrast to all other models based on the measured porosities of unloaded samples described in detail in the work of [27]. Therefore, the measured porosity of sample 35-00-L-2 increase from 0.0944 to the value of 0.184. It can be argued that the difference of 0.0896 is the volume fraction of cracks.

It should be noted that the experimental compressive strengths f_{cS} were obtained for saturated samples only. The strengths of saturated sample are lower than the strengths of the dry samples. Therefore, strengths f_{cS} - not static strengths f_{US2} - are comparable to strengths σ_f.

The comparison of damage variables and dynamic strengths in [13] shows the validity of the proposed RDA model. Differences in damage variables are a consequence of the adopted spherical void shapes for calculating the variable D_{LD}. The differences between dynamic strengths f_{US1} and strengths σ_{min} controlled by minimum porosities is within reasonable limits.

5. ANALYSIS OF POROUS ROCK SAMPLES

Numerous versions of elasto-acoustic techniques have been developed to analyze the overall behavior of wave propagation in composite media. Theoretical models of composite materials have primarily been used for porous materials such as concrete, rock and ceramics, [27] and [28]. Among the different types of materials, rocks have an important place, due to their applications in various disciplines including the energy sector. In order to prove the validity of the proposed model, three different types of rocks were selected and analyzed: sandstone, granite and limestone.

The sandstone rock is presented as an author's research, [18]. The goal was to compare the calculation results with the measured values. The investigated rock is sandstone from the area of Bijeljina, which is located in the Republic of Srpska - Bosnia and Herzegovina.

Granite from HengYang region, China, was analyzed by Xiao et al. u [29], [30]. Based on experimental observations, the authors proposed a model of damage that can represent the whole process of damage due to fatigue.

Yasar and Erdogan in [31] analyzed carbonate rocks from several regions of Turkey. During sampling, unbedded rock types were selected to eliminate anisotropic effects on the measurements. Three different types of carbonate rocks were included in the research: dolomite, marble and limestone.

Figure 6 shows a comparison of the complete stress-strain curves for the analyzed rock samples obtained by the RDA model. The modulus of elasticity is the lowest for the limestone sample, while the highest for the granite.

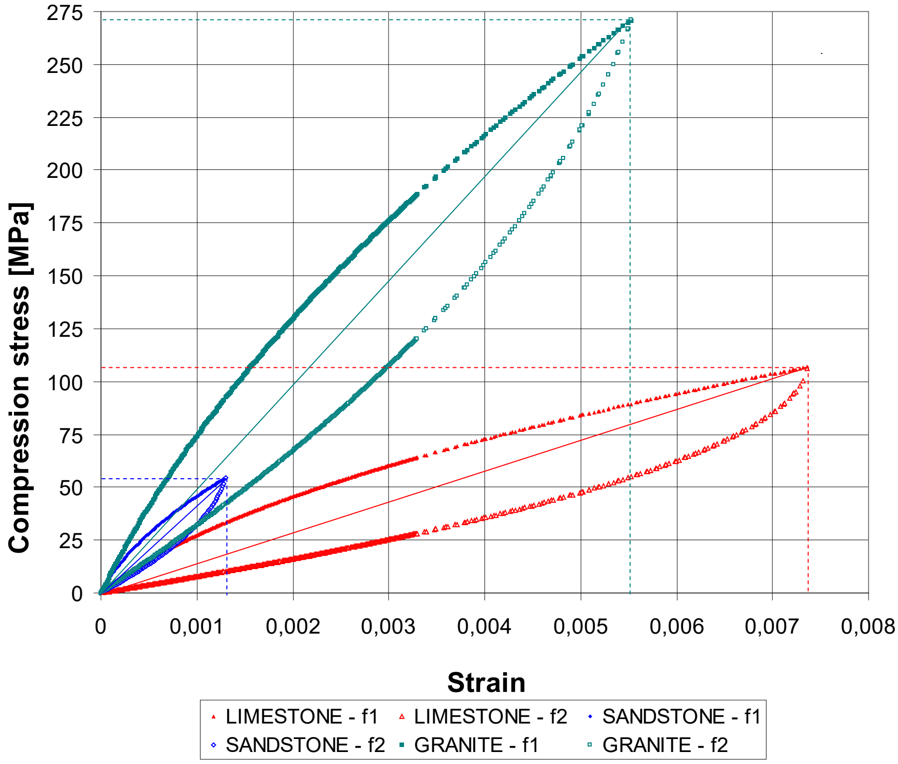

Figure 6. Dynamic stress-strain curves according to the RDA model for the analyzed rock samples

5.2. SANDSTONE ROCK SAMPLE

A cylindrical sample with a diameter of 73.5 mm was drilled from block B-1(I) (1.7 - 2.0 m) and cut to a length of 141.8 mm with a high-speed rotary saw. The end surfaces of the sample were ground with a grinder according to the standard. The measured density was 2526 kg/m3. The experiment was conducted on the PUN-DIT measuring equipment in the Material Testing Laboratory of the Technical Institute of Bijeljina. The complete stress-strain analysis was performed by [18] using the RDA method, whereby the UCS, as well as the dynamic f_{US1} and static f_{US2} strengths, were calculated considering only the measured velocities of P and S waves.
Table 1 shows the calculated energy densities and corresponding porosities. The last column shows the damage variable for the calculated porosity p_f. Based on the damage variable of 0.53 at zero porosity we can be concluded that it decreases to 0.42 due to porosity $p_f = 0.15$, which controls the static strength.

Table 1. RDA model parameters for the sandstone sample [18]

W_{el} [MJ/m^3]	W_{d1} [MJ/m^3]	W_{d2} [MJ/m^3]	p_{max}	p_E	p_f	D_f
0.035432	0.041678	0.026939	0.415972	0.176295	0.152368	0.415689

5.3. GRANITE ROCK SAMPLE

The FI-24 granite sample was cylindrical, 50 mm in diameter, and 100 mm in height. Experimental data for UCS and modulus of elasticity taken from Xiao et al. [29] were used in this paper. A complete stress-strain analysis was performed by Milašinović [18] using the RDA method, where dynamic f_{US1} and static f_{US2} strengths were calculated p_f. Table 2 shows the calculated energy densities and corresponding porosities. The last column shows the damage variable for calculated

p_f . Based on the damage variable of 0.47 at zero porosity can be concluded that it decreases to 0.36 due to the porosity $p_f = 0.13$.

Table 2. RDA model parameters for the granite sample [29]

W_{el} [MJ/m^3]	W_{d1} [MJ/m^3]	W_{d2} [MJ/m^3]	p_{max}	p_E	p_f	D_f
0.748141	0.86548	0.594703	0.361934	0.156842	0.133313	0.359524

5.4. LIMESTONE ROCK SAMPLE

Sound speed measurements were performed on five core samples with a diameter of 42 mm prepared in laboratory conditions. Conventionally, maximum, mean, and minimum velocities are found. The results of measured sound speeds and rock density (2430 kg/m^3), as well as empirically predicted Young's moduli and UCS of rocks are presented in [31]. Milašinović [18] performed a complete stress and deformation analysis of the selected sample of limestone, where the dynamic f_{US1} and static f_{US2} strengths were calculated. Table 3 shows the calculated energy densities and corresponding porosities. The last column shows the damage variable for the calculated porosity p_f which controls the static failure of the sample.

Table 3. RDA model parameters for the limestone sample, [31]

W_{el} [MJ/m^3]	W_{d1} [MJ/m^3]	W_{d2} [MJ/m^3]	p_{max}	p_E	p_f	D_f
0.390282	0.472888	0.26925	0.521772	0.211658	0.188698	0.526162

5.5. COMPARATIVE ANALYSIS OF POROUS DRY ROCK SAMPLES

The compressive strengths for the three analyzed rock samples are present in Table 4.

Table 4. Compressive strengths for the analyzed rock samples

Rock	E_H [MPa]	σ_{ef} [MPa]	UCS [MPa]	f_{US2} [MPa]	f_{test} [MPa]	σ_f [MPa]
Granite	49043	270.89	143.43	122.03	**114.75**	**110.03**
Limestone	14400	106.02	**38.7**	33.18	**-**	**39.94**
Sandstone	41831	54.45	25.65	**21.74**	**-**	**21.93**

The static strength f_{US2} agrees very well with the strength σ_f in the case of the sandstone sample with a proven VVF of $p_f = 0.15$. A possible reason for this is the fact that all the parameters of this sample as well as all the strengths were calculated using the measured velocities of P and S waves. The mass of the dry sample is determined by weighing, and the density by precise calculation of its volume. These results unequivocally confirm the correctness of the proposed RDA model.

For the granite sample, the difference between strength f_{US2} and strength σ_f is greater. However, in the work [29] authors reported that the sample had a maximum static strength of 114.75 MPa, which shows much better agreement with the 110 MPa strength calculated here. The modulus of elasticity was calculated from the stress-strain curve under static loading. The test was performed on an electro-hydraulic servo controlled rock testing machine RMT-150B, [30]. It is also important to point out that only the P-wave velocity is used to calculate the parameters of the RDA model in this paper. The density of the sample =2710 kg/m^3 is taken from the textbook [32] because the actual is not shown. Obviously, independent tests lead to differences in results, but they are within acceptable limits.

For the limestone rock sample, the difference between strength f_{US2} and strength σ_f is the largest. However, in the work [31] the authors stated that the two main parameters, modulus of elasticity and UCS, were empirically predicted. This is probably the reason why strength matches well with UCS rather than static strength f_{US2} .

Figure 7 shows the comparative results for the Poisson's ratios which show that the highest initial Poisson's ratio is for the limestone sample and the lowest for the granite sample.

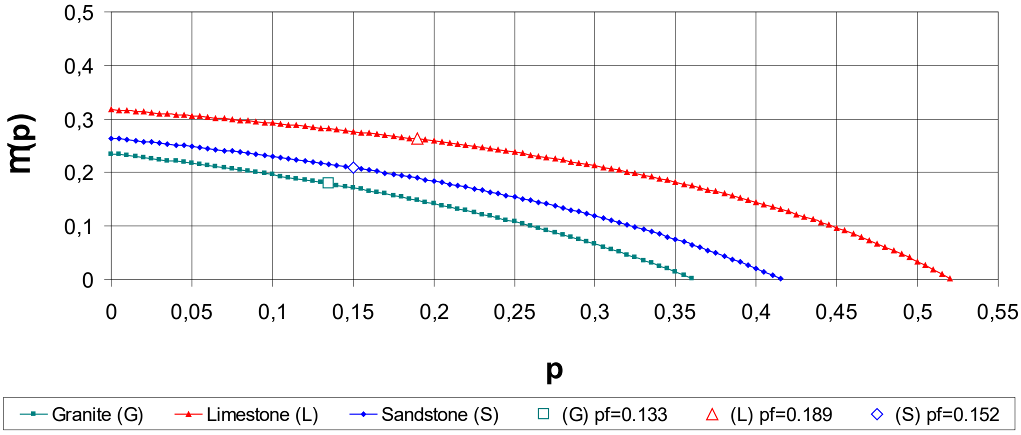

Figure 7. Poisson's ratios versus porosity for the analyzed rock samples

Figure 8 shows a significant decrease in strength with increasing porosity. However, although strength is a nonlinear function of porosity, in the range of measurable porosities an approximately linear decrease in strength with increasing porosity can be observed for all three analyzed samples. Although the porosities controlling the static strength are different, the strength drop to 0.4 from the effective stress is about the same.

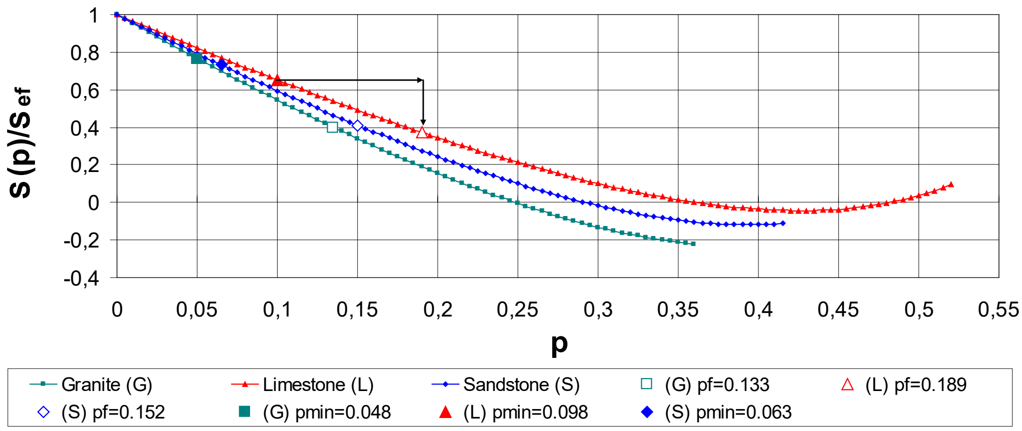

Figure 8. Dimensionless compressive strengths versus porosity for the analyzed rock samples

The results in this paper show that D_{LD} corresponds to reality only for p_{max} because in that case D_{LD} represents the damage variable D_1 from the RDA model, Table 5. Damage variables D_{LD} have slightly higher values due to the assumption of spherical voids that do not exist in the real materials. Table 5 shows comparisons of the dynamic strength f_{US1} with the strength σ_{min} controlled by the porosity p_{min}. Accordingly, the validity of the proposed RDA model is reconfirmed.

Table 5. Comparison of damage variables and dynamic strengths for the analyzed rock samples

Rock	D_1	p_{max}	$D_{LD} = p_{max}^{2/3}$	f_{US1} [MPa]	p_{min}	ρ_0 [kg/m^3]	σ_{min} [MPa]
Sandstone	**0.529**	0.416	**0.557**	**41.5**	0.063	2697	**40.2**
Granite	**0.471**	0.362	**0.508**	**213.1**	0.048	2847	**209.7**
Limestone	**0.635**	0.522	**0.648**	**76.3**	0.098	2695	**69.7**

Finally, based on the p_{min}, the initial density of rock sample at zero porosity $\rho_0 = \rho/1 - p_{min}$ can be determined, Table 5. The calculated initial densities correspond to the experimental ones, according to the textbook [32].

Table 6 shows dimensionless moduli of elasticity for the previously calculated porosities.

Table 6. Comparison of dimensionless moduli of elasticity for the analyzed rock samples

Rock	$E_{H,min}/E_{H,0}$	$E_{H,f}/E_{H,0}$	$E_{H,max}/E_{H,0}$
Sandstone rock sample	0.9199	0.8067	0.4711
Granite rock sample	0.9376	0.8271	0.5295
Limestone rock sample	0.8808	0.7701	0.365

Figure 9 shows dimensionless moduli of elasticity as a function of porosity for the analyzed rock samples.

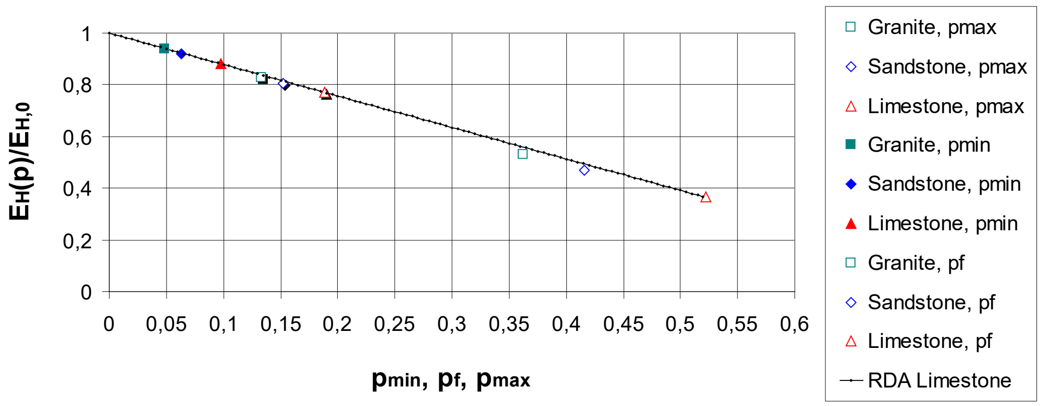

Figure 9. Dimensionless moduli of elasticity versus porosity for the analyzed rock samples

Comparison of the RDA law for modulus of elasticity as a function of porosity with experimental moduli obtained from P and S wave velocities shows excellent agreement of the results. The inclusion of damage variable in the law, shows that the modulus will not drop to zero even at maximum porosity. This fact in rock materials is real. If $D_1 = 1$, it is a break of the sample into two parts, which rarely happens.

6. CONCLUSIONS

The key result proposed in this paper refers to a new way of calculating porosities or VVF-s through energy densities. Results show that in all analyzed materials, VVF-s that control static strengths range from 0.14 to 0.25, which is in accordance with the research of [22] and [23]. The differences that appear in the calculated damage variables are due to the assumption of spherical voids in the Lemaitre and Dufailly [24] prediction that do not appear in actual damaged materials.

Yaman et al. [26], [27] found a valid model for predicting the modulus of elasticity of saturated concrete by comparing different methods, including micromechanical methods, experimental and semi-experimental methods, in which the Kuster-Toksoz [33] method was more effective than the others. The RDA method proposed in this paper gives excellent results for the analyzed hardened concretes analyzed by Yaman et al.

Of the three rock types analyzed in this paper, only the sandstone sample has fully defined RDA model parameters based on P and S wave velocities. The results show that the static strength agrees very well with the static strength obtained by the previously calculated porosity on the sample failure. This unequivocally confirms the correctness of the proposed model. For the granite sample, only the P-wave velocity was used, while the modulus of elasticity and UCS were taken from statically independent tests. This led to differences in the results, but they are within acceptable limits. Empirically estimated mechanical properties, including strength, were taken for the limestone sample. In this case, the strength obtained by the previously calculated porosity on the sample failure agrees satisfactorily with the UCS of the sample. Finally, the initial density for the analyzed rock samples at zero porosity is determined based on the porosity p_{min}.

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34
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REGIONALIZATION OF CATCHMENTS BASED ON SILHOUETTE WIDTHS FOR FLOOD RESPONSE ESTIMATION ACROSS SERBIA

Abstract

Regional analysis is often used for flood quantile estimation in ungauged catchments. The regionalization procedure has two phases: the formation of homogeneous regions and flood quantile estimation. The presented research results consider the first phase of the regional analysis for 41 catchments in Serbia. The catchment similarity attributes are catchment area and catchment mean elevation. The number of formed regions and the number of stations within the regions are determined by maximising the mean silhouette width of the region. Regions were first obtained by cluster analysis and then adjusted to comprise catchments with a positive silhouette width. For the three formed regions, homogeneity was checked by the Gini index - GI.

Keywords: regional analysis, Flood flow, Cluster analysis, silhouette width, Gini index

РЕГИОНАЛИЗАЦИЈА СЛИВОВА НА ОСНОВУ ШИРИНЕ СИЛУЕТЕ ЗА ОЦЈЕНУ ВЕЛИКИХ ВОДА НА ТЕРИТОРИЈИ СРБИЈЕ

Сажетак

Регионална анализа се често користи за оцјену великих вода у неизученим сливовима. Поступак регионализације има две етапе: формирање хомогених региона и оцјену квантила великих вода. Приказани резултати истраживања баве се првом фазом регионалне анализе за 41 слив на територији Србије. Атрибути сличности сливова су површина и средња надморска висина слива. Број формираних региона и број станица у регионима одређени су према услову највеће могуће ширине силуете региона. Региони су добијени испрва кластер анализом, а затим су подешени тако да све станице у регионима имају позитивну ширину силуете. За три формирана региона, хомогеност је провјерена Цини индексом - GI.

Кључне ријечи: регионална анализа, велике воде, кластер анализа, ширина силуете, GI

1. INTRODUCTION

Accurate flood estimation is important in civil engineering and construction to design the structures such as bridges, assess and mitigate potential risks to infrastructure and public safety. By properly estimating flood levels, resilient structures and infrastructure are designed, reducing the likelihood of damage and the need for costly repairs. Additionally, precise flood estimation enables informed decision-making regarding land use planning and development, ensuring that projects are located in areas less susceptible to flooding, ultimately enhancing community resilience.

In gauged catchments, flood estimation relies on available data from hydrological and meteorological gauging stations, enabling more precise assessments due to direct measurements of streamflow and rainfall. However, in ungauged catchments, flood estimation is more challenging as there is limited or no data, necessitating the use of indirect methods such as rainfall-runoff models or regional flood frequency analysis to approximate flood flows and from them, corresponding flood levels.

Although regional flood frequency analysis is typically employed in situations where limited or no direct data on flood events are available for a specific location or catchment, it is also used in gauged catchments for control of flood quantile estimation results or statistical properties of flood data series (e.g. skewness [1]), and when long data is available but the data record length is inappropriate compared to desired return period of flood quantiles [2]. In these situations, additional data must be incorporated, and it involves expanding temporal, spatial, and causal information to refine flood quantile estimation.

The primary focus of this paper revolves around spatial data transfer, particularly employing regionalization methods to formation of homogeneous regions. Spatial information expansion encompasses two main techniques: spatial regionalization and statistical regionalization. Spatial regionalization involves constructing envelope curves, specific runoff diagrams, or maps depicting quantiles or statistical parameters. Envelope curves and specific runoff diagrams illustrate high flows relative to catchment area or river network segments, and assist in validating estimated flood flows. Statistical regionalization procedures involve establishing dependencies between the parameters or quantiles of flood flows and the morphological and/or meteorological characteristics of the catchment. Key stages in statistical regionalization include identifying homogeneous regions and transferring information, particularly for estimating flood flows. Various methods for regionalization exist in the literature, differing mainly in their approach to these two critical stages.

Geographically adjacent regions are often presumed to exhibit similar hydrological processes and are thus treated as homogeneous areas for flood flow estimation, although this assumption may not always hold true [3]. To address this subjectivity, methods such as cluster analysis [4] or the Region of Influence (ROI) approach [5] are employed. In both cluster analyses and ROI, selecting attributes that reflect similarity among catchments is crucial. Typically, geomorphological characteristics are prioritized due to their accessibility [6], followed by hydro-meteorological properties [7] or the timing and distribution of peak flows [8], which offer more accurate and robust data.

Cluster analysis is commonly employed in flood regionalization due to its practicality [9], with Ward's algorithm (hierarchical approach) [10] or the k-means algorithm (partition approach) [11] being the most utilized methods. The hierarchical approach offers a dendrogram presentation of results, allowing for the determination of regions based on arbitrary distances or a specified number of cluster centers (CCs). Conversely, the partition approach requires predefining the number of CCs, often leading to dependency on initial assumptions and necessitating multiple runs of the algorithm. Despite the hierarchical approach's limitations regarding object migration between CCs, a hybrid cluster analysis has been proposed [4], combining both hierarchical and partition approaches to leverage their respective strengths.

In Bosnia and Herzegovina and Serbia, flood quantile estimation in ungauged catchments often relies on specific runoff diagrams or regressions linking flood quantiles with catchment area [12]. However, this approach has demonstrated notable tendencies for both underestimation and overestimation of flood quantiles, especially considering the assumption of homogeneous regions without validation [13]. Other techniques employed to enhance flood quantile estimation include extending gauged peak flow data using gauged water stage [14], assumed rating curves, and historical flood records [15]. Furthermore, comparative analyses involving statistical methods, empirical expressions, and geomorphological unit hydrographs such as the EBA4SUB model [16] have been considered. Regional analysis utilizing the cluster method was conducted for stations in Bosnia and Herzegovina, expanded to include stations from Serbia, highlighting the superiority of hierarchical (Ward's algorithm) over partition (k-means) clustering in flood quantile estimation [13].

In a recent research [17], an alternative hierarchical approach to region formation for flood quantile estimation was explored. The appropriateness of object assignment to a CC was evaluated using the silhouette width [18], while achieved mean silhouette width of a CC was used as a measure of optimal cluster number [19]. Regarding region formation, it is concluded in [17] that 1) the regions should be adjusted to comprise (hydrological gauging) stations with positive individual silhouette widths, and 2) the minimum number of stations in a region should be nine.

The aim of this paper is to investigate whether homogeneous flood estimation regions can be formed in Serbia with the minimum number of nine stations per region, based on silhouette widths. Additionally, it is examined if and how region adjustments influence selection of regional distribution function, i.e. information transfer function in each region.

The present work is partially based on the data and findings from the previous research [17]. The appropriateness of the silhouette-width-induced clustering is rated here using mean silhouette width as a measure of region compactness [18] and region homogeneity examination by the Gini Index (GI) [20], while preliminary detection of regional distribution function is done by L-moment plots.

2. METHODOLOGY

2.1. STUDY REGION AND DATA

The study region is situated in the southern part of the Danube River basin, in Serbia, and it is characterized by continental climate. The annual peak flow data were collected for 41 hydrological stations (HSs), with a catchment area up to 2054 km^2 (Figure 1).

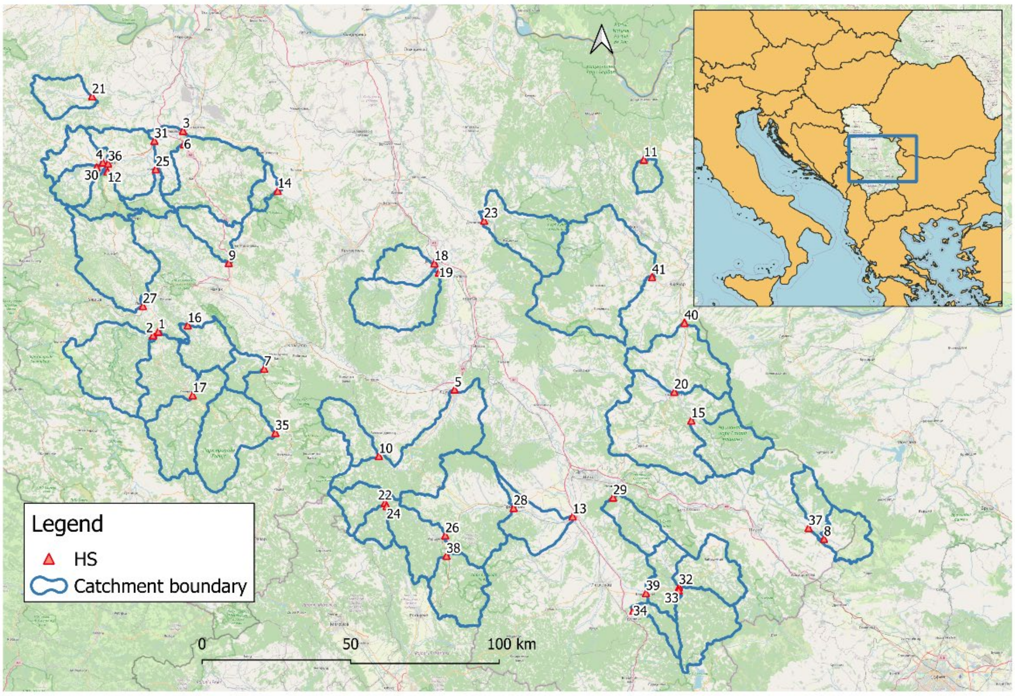

Figure 1. Study region, catchments and locations of hydrological gauge stations.

Statistical tests were conducted on peak flow datasets from 41 stations (Table 1) spanning the gauge period of 1948–2016, to assess their suitability for flood frequency analysis by statistical analysis of annual peak flows, focusing on stationarity, independence, and homogeneity in mean and variance [17]. In 12 stations, datasets were trimmed from the beginning of the gauge period until they met the criteria for statistical analysis, at the 5% significance level. The trimmed gauged peak flow data spanned from 1 to 22 years (Table 1). The datasets with gaps are left unaltered. On average, the datasets had a record length of 53 years.

The main catchment morphological attributes, such as catchment area (*A*), average slope (*Iavg*) and average elevation (*Havg*), have been determined from a 20 m resolution DEM [21].

Table 1. Annual peak flow data at stations: N-record length, Ntrimm-number of trimmed years in the data record, MAF- mean annual flood, LCv-L-coefficient of variation. Source [22].

Stat. no.	Station name	N	Ntrimm	MAF (m^3/s)	LCv (-)	A (km^2)	Iavg (%)	Havg (m asl)
1	Arilje	65		120.6	0.336	818	20.9	856
2	Arilje Rzav	49		100.1	0.258	583	25.4	870
3	Beli Brod	52	6	288.6	0.353	1833	19.83	373
4	Belo Polje	63		59.7	0.373	185	18.26	401
5	Bivolje	42	22	101.7	0.389	957	17.1	570
6	Bogovadja	59		99.3	0.328	697	14.1	314
7	Bogutovac	56		35.6	0.399	115	37.14	779
8	Brajicevci	54		40.0	0.352	227	21.7	1211
9	Brdjani	47		51.6	0.416	208	23.8	502
10	Brus	57		32.6	0.365	220	27.5	898
11	Crnajka	47	5	25.1	0.454	78	23.4	521
12	Degurici	55	3	44.1	0.356	159	29.8	673
13	Doljevac	58	5	135.5	0.350	2054	24.99	646
14	Donja Satornja	38	17	18.8	0.659	84	17.9	494
15	Donja Kamenica	61		44.2	0.408	360	36.62	812
16	Guca	54		71.2	0.341	235	22.2	576
17	Ivanjica	53		75.5	0.346	460	33.1	980
18	Jagodina	56		19.3	0.452	193	18.7	296
19	Jagodina Majur	53		73.3	0.502	427	21.35	390
20	Knjazevac	49	14	113.2	0.333	1260	26.2	659
21	Koceljeva	52	1	33.5	0.378	208	15.2	257
22	Magovo	42		30.1	0.430	180	33	1021
23	Man. Manasija	52		60.9	0.437	388	26.28	637
24	Mercez	45		19.6	0.425	112	44.7	1015
25	Pastric Mionica	58		50.4	0.550	108	28.27	530
26	Pepeljevac	46	20	130.4	0.336	987	26.1	800
27	Pozega	57		118.9	0.458	630	23.23	597
28	Prokuplje	42	20	151.4	0.367	1773	26.57	684
29	Radikine Bare	38	11	23.1	0.369	205	29	676
30	Sedlare	62		41.7	0.445	140	34.1	637
31	Slovac	59		187.9	0.297	995	20.1	443
32	Svodje Luznica	52		62.9	0.433	318	26.9	707
33	Svodje Vlasina	61		49.0	0.458	349	35.21	1066
34	Tupalovce	54		22.2	0.308	98	36.6	931
35	Usce Studenica	63		59.2	0.279	535	34.89	1130
36	Valjevo	59		85.8	0.378	340	12.96	510
37	Visocka.Rzana	42		69.9	0.314	403	32.23	1218
38	Visoka	55		71.2	0.422	370	28.9	740
39	Vlasotnice	57		147.3	0.400	972	28.7	865
40	Vratarnica	66		142.5	0.300	1765	25.72	614
41	Zajecar Gamzigrad	49	12	110.0	0.315	1167	19.83	528

2.2. METHODS

Regional analysis, regardless of employed methods, consists of two phases with 4 common steps:

- Phase 1:
  - Region (pooling region) formation,
  - Testing region homogeneity,
- Phase 2:
  - Information transfer function definition, and
  - Quantile estimation.

The focus of this research is in regional analysis phase 1, and in its results that influence the setup of the phase 2 for the Index-flood method, i.e. regional information transfer function.
The majority of calculations shown in the paper is performed in R package, ver 4.1.2.

2.2.1. REGION FORMATION

Within cluster analysis, catchments are assigned to regions via a hierarchical agglomerative process based on their morphological similarities. To prevent undue bias towards specific attributes, morphological characteristics should not display significant correlations [23]. Initially, each catchment forms its own cluster, with merging occurring progressively at each level of the clustering algorithm until a single region is formed. Ward's algorithm, chosen for its ability to create cohesive regions [4], is employed in this process.
The number of centers is selected according to the silhouette width, calculated as the ratio of the average distance of the object *i* from the others falling into the same center *j* and the maximum distance *d* from the objects of other centers [39]:

$$s_i^j = \frac{b_i^j - a_i^j}{\max\left(a_i^j, b_i^j\right)} \tag{1}$$

where s_i^j is the silhouette width of the object *i* from the cluster (center) *j*, a_i^j is the average distance between *i*-th vector in cluster C_j and other vectors in the same cluster, and b_i^j is the minimum average distance between *i*-th vector in cluster C_j and other vectors in the remaining clusters C_k (k = 1, ..., K, $k \neq j$):

$$a_i^j = \frac{1}{m_j - 1} \sum_{\substack{k=1 \\ k \neq i}}^{m_j} d\left(X_i^j, X_k^j\right), \qquad i = 1, \dots, m_j \tag{2}$$

$$b_i^j = \min_{\substack{n=1,\dots,K \\ n \neq j}} \left\{ \frac{1}{m_n} \sum_{\substack{k=1 \\ k \neq i}}^{m_n} d\left(X_i^j, X_k^j\right) \right\}, \quad i = 1, \dots, m_j \tag{3}$$

where $d\left(X_i^j, X_k^j\right)$ is the distance between objects X_i and X_k, m_j is the number of objects in cluster C_j, m_n is the number of objects in remaining clusters C_k, and K is the number of cluster centers.
The silhouette width, ranging from -1 to 1, indicates the compactness of a cluster, with values closer to 1 indicating greater cohesion and suitability for assignment to a center. The determination of the optimal number of centers is achieved by maximizing the mean silhouette width (MSW) of all objects in the cluster. However, an inherent challenge of this method arises from silhouette widths approaching zero or turning negative. In the latter case, negative values signify misplacement within a center, prompting adjustments to reassign objects to achieve positive silhouette widths. This iterative process involves checking and potentially relocating objects until all silhouette widths are positive, ensuring the validity of cluster assignments.

2.2.2. REGION HOMOGENEITY TESTING

Region homogeneity testing refers to assessing whether the characteristics or attributes of a particular catchment are statistically similar or different from those in surrounding ones in the cluster of catchments. In statistical regionalization, this testing implies determining a certain measure that describes deviations in distribution functions or statistical parameters. The most frequently used region homogeneity tests in hydrology are the parametric Hosking–Wallis (HW) test, and the Anderson–Darling (AD) bootstrap test, explained in detail in [17]. In this paper, Gini index (GI) is used as a measure of region homogeneity. The GI, originally designed as a measure in the field of economics (econometrics), is adopted by Raquena et al. [20] to measure region heterogeneity in regional hydrological frequency analysis, in the following form:

$$GI = \frac{\sum_{i=1}^{N}(2i-N-1)t_{i:n}}{N(N-1)\bar{t}} \tag{4}$$

where $t_{i:n}$ are the sample order statistics of L-coefficient of variation (usually labeled as t), $\bar{t}$ is their mean, N is number of stations in the region with data length n. This measure corresponds to the approach based on moments [24] where the coefficient of variation is used for defining homogeneous region when of 0 value and showing extremely heterogenous region when ≥ 0.4. However, the GI does not provide a critical value, but its specific values between 0 and 1 are interpreted depending on the context and the distribution being measured.

The data required for GI estimation (L-moments of each dataset) are tabulated in [17] Appendix A, while t, i.e. LCv is given in Table 1.

Regional L-moments t^R, t_3^R and t_4^R i.e. regional L-variation coefficient, L-skewness, and L-kurtosis respectively, are derived as average values, weighted by dataset size as:

$$t^R = LCv = \frac{\sum_{i=1}^{m_j} n_i t^{(i)}}{\sum_{i=1}^{m_j} n_i} \tag{5}$$

$$t_3^R = LCs = \frac{\sum_{i=1}^{m_j} n_i t_3^{(i)}}{\sum_{i=1}^{m_j} n_i} \tag{6}$$

$$t_4^R = LCk = \frac{\sum_{i=1}^{m_j} n_i t_4^{(i)}}{\sum_{i=1}^{m_j} n_i} \tag{7}$$

where i is station in region R of size m_j, n_i is i -th station's record length.

2.2.3. PRELIMINARY SELECTION OF REGIONAL DISTRIBUTION

To identify the appropriate distribution (or several candidates), plots of dimensionless L-moments proposed by Hosking [25] are used here. They show the relationship between *LCv* and *LCs* for two-parameter, i.e. *LCk* and *LCs* for three-parameter distributions (Figure 2). The closeness of the point representing L-moments of the studied dataset signifies an appropriate 2-parameter distribution when it is close to the marker in Figure 2, and/or 3-parameter distribution when close to the line. The red dot representing regional L-moments values in Figure 2 shows that the best distribution for a particular dataset would be 3-parameter generalized logistic distribution (GLO).

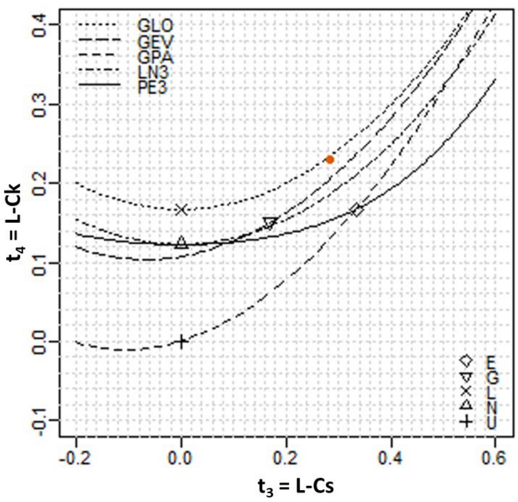

Figure 2. L-moments plot.

3. RESULTS

3.1. REGION FORMATION

In the formation of regions, catchment similarity attributes, clustering algorithm and number of centres are defined. The catchment morphological attributes that do not display significant correlations are found to be catchment area (*A*) and average catchment elevation (*Havg*). Therefore, input data for cluster analysis is Euclidean distance matrix (Figure 3), derived based on normalized values of *A* and *Havg*.

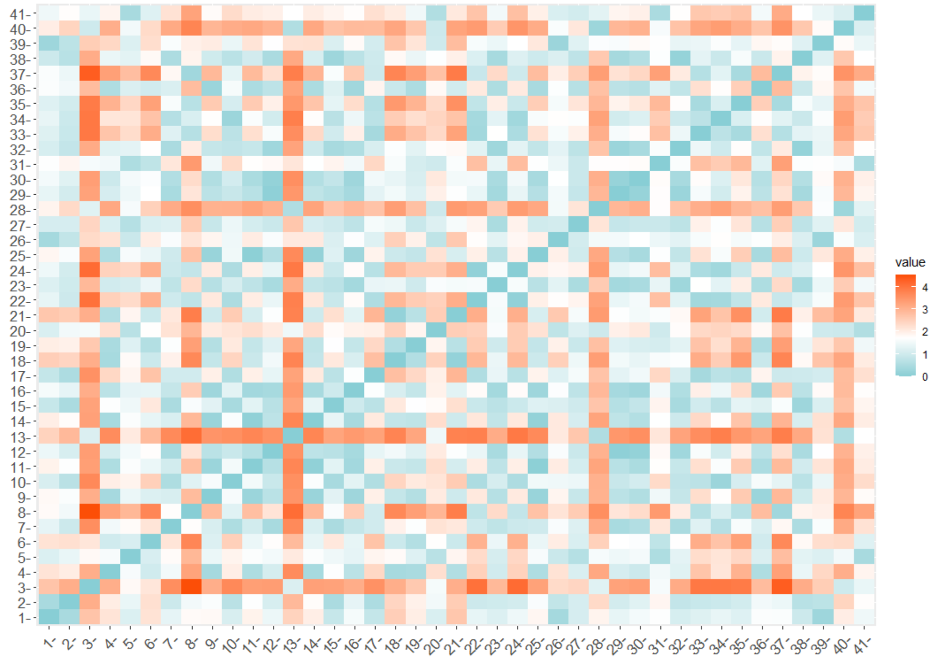

Figure 3. Catchment morphologic attributes distance matrix for catchment area (A) and average basin elevation (Havg)

The result of the cluster analysis performed by Ward's algorithm is presented in the dendrogram form (Figure 4).

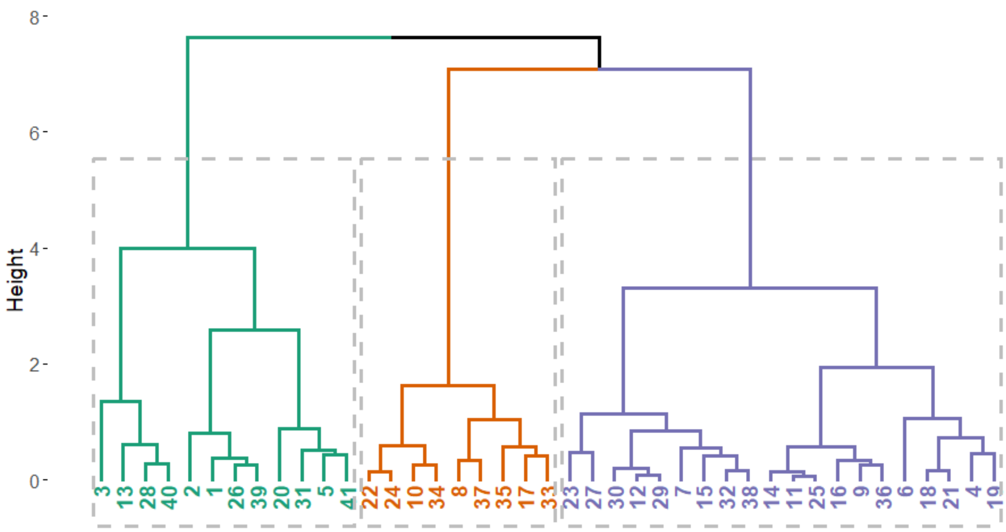

Figure 4. Cluster dendrogram based on Ward's clustering algorithm for 41 stations according to catchment similarity attributes, shown by their labels as in Table 1.

Based on the results of hierarchical grouping (dendrogram), regions are formed by choosing the number of centers. According to 23 measures available in *NbClust* function in R [26], 9 measures (the largest share of all measures) proposed 3 as the best number of clusters, and according to the 'majority rule', as defined in R package, that is the best number of CCs. Considering silhouette width measure alone, four, followed by three, is the best number of CCs (Table 2).

Table 2. Mean silhouette width (MSW) change with number of cluster centers (CC).

CCs	2	3	4	5	6	7	8	9	10
MSW	0.3663	**0.4484**	**0.4491**	0.4075	0.4332	0.4289	0.4097	0.4305	0.4254

When four CCs are considered according to MSW, there are 4, 8, 9 and 20 stations in the CCs respectively. Because the first two CCs hold less than 9 stations in the CC, which is set as a target in this paper, and MSWs for three CCs and four CCs are almost the same (0.4484 and 0.4491), the final number of CCs is set to three. The size of adopted three regions is 9, 12, and 19 stations (Figure 5).

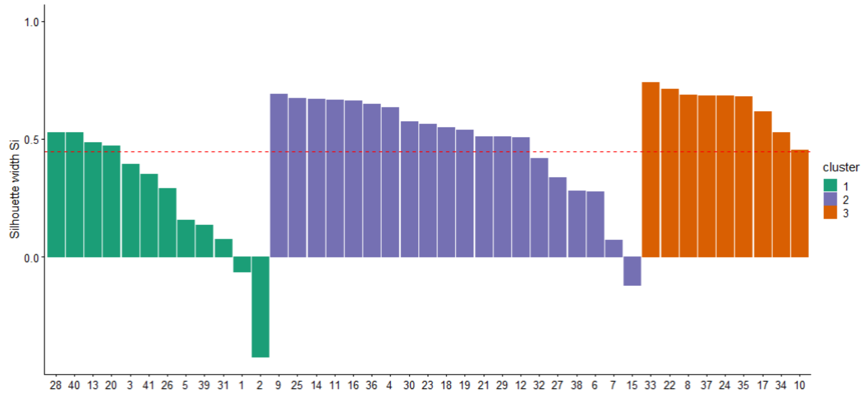

Figure 5. Cluster silhouette width plot for three adopted CCs

3.2. ADJUSTMENT OF REGIONS

The optimal number of CCs is achieved by maximizing the MSW of all objects in the cluster. Such clustering is labelled ORG hereinafter. Negative silhouette width of individual object (station) in the CC signify misplacement within a center, requiring adjustments to reassign object to another CC to achieve positive silhouette width. In Figure 6, it may be seen that three stations exhibit negative silhouette widths. The adjustment of CCs (regions) starts with the station of the largest negative silhouette width, station no. 2. Relocating one station to another CC changes the silhouette widths of all stations. It took 5 iterations to reach positive silhouette widths for all stations, forming adjusted regions (labelled ADJ). Five stations are moved to adj_CC3 (four from CC1 and one from CC2). Silhouette widths for original and adjusted regions are shown in Figure 6.

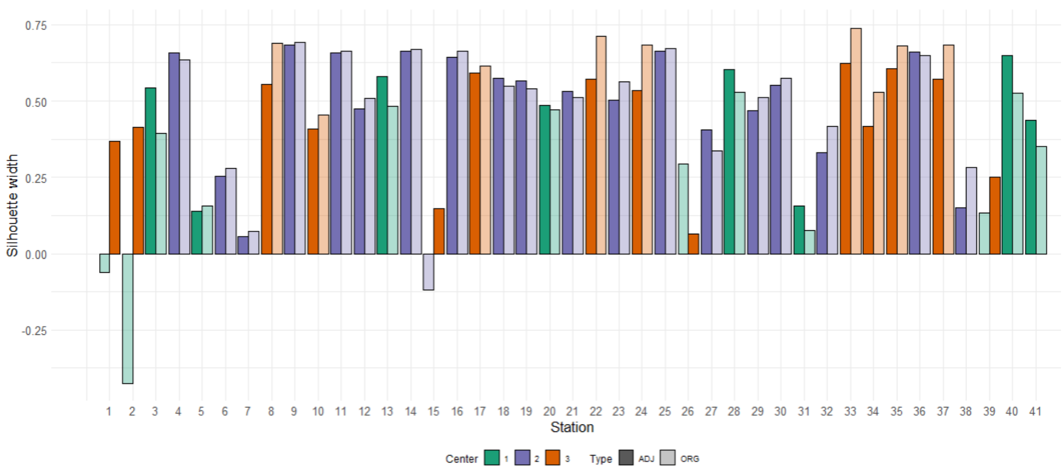

Figure 6. Single silhouette width per station in the original (transparent bar colour) and adjusted clusters (solid bar colour).

Table 3 shows that MSW is improved in adjusted CCs 1 and 2 compared to original, while the adjusted CC3 has turned from the highest MSW to the lowest one. On average, MSW of all stations is improved by the adjustments, compared to the original placement of stations in the CCs (Table 3, column ‘Overall’).

The change in morphological attributes across CCs in ADJ clustering compared to ORG is shown in Figure 7. Both methods (ORG and ADJ) pooled stations with larger basin area into CC1 (Figure 7 – left). A significant distinction between CC2 and CC3 (regions with smaller and medium catchment area) is in the average catchment altitudes, shown by a visible departure of CC3 from other clusters in both ORG and ADJ clustering (Figure 7 – right).

Table 3. Mean silhouette width achieved in each CC and in all stations. Number of stations (region size) is given in the brackets below the MSW value.

Method	CC1	CC2	CC3	Overall
ORG	0.244 (12)	0.484 (19)	0.643 (9)	0.448
ADJ	0.450 (8)	0.500 (18)	0.438 (14)	0.469

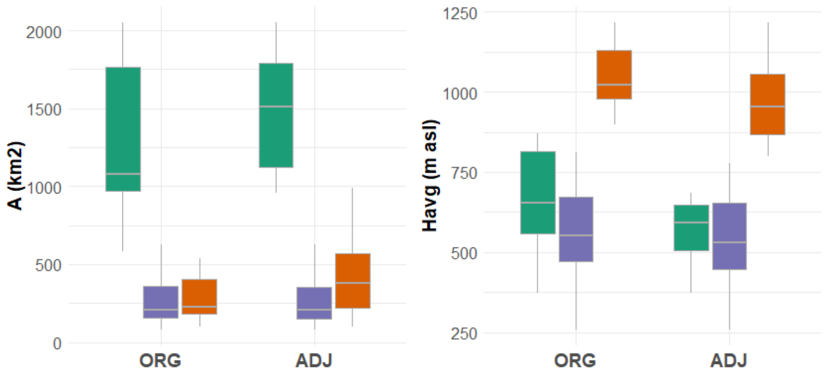

Figure 7. The boxplots of morphological attributes in the original and adjusted clusters mapped by the CC: CC1 – green, CC2 – purple, CC3 - orange.

The principal component (PC) plots in Figure 8, visualize the change of CC gravity centers location (in the first two PC dimensions) caused by ADJ clustering, as well as the change in shapes of the three CCs. It may be seen that CC3 significantly grew on the account of CC1 in ADJ clustering.

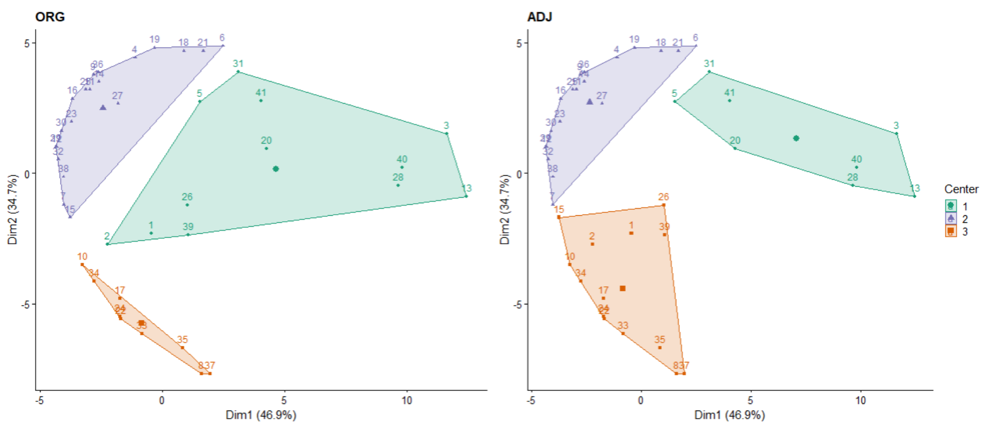

Figure 8. Principal component plots for the original (left) and adjusted (right) CCs.

3.3. REGION HOMOGENEITY

The GI values are shown in Table 4 for regions formed by cluster analysis by both ORG and ADJ approach. The comparison of the individual GI values among regions reflects varying degrees of inequality within a CC. In general, equality in CCs, hence homogeneity, is improved by ADJ clustering, although the starting GI values in ORG CCs were already low, considering the GI range between 0 and 1. The most homogeneous region measured by the GI comprises stations in CC1, then CC2, and finally CC3 in ORG clustering, while in ADJ clusters, CC1 remained more homogeneous compared to CC2 and CC3 that are equalized by the adjustment.

Table 4. Gini index achieved in each CC upon ORG and ADJ clustering

Method	CC1	CC2	CC3
ORG	0.070	0.100	0.101
ADJ	0.058	0.101	0.098

The regional *L*-moments t^R, t_3^R and t_4^R values estimated from flood flow (annual maxima) datasets according to equations (5), (6), and (7) in CCs are tabulated in Table 5. In CC1 and CC3 in both ORG and ADJ clusters, regional *L-Cv* is similar, while it is somewhat higher in CC2. The degree of variation within the clusters judged by *L-Cv* (Table 5) is different compared to GI in Table 4, where the least variation is found in CC1, then CC3 and the highest in CC2, regardless of the clustering method.

Table 5. Regional L-moments in CCs for ORG and ADJ clustering

Method	*L*-moment	CC1	CC2	CC3
ORG	$L\text{-}Cv = t^R$	0.3348	0.4245	0.3625
	$L\text{-}Cs = t_3^R$	0.2850	0.3971	0.4064
	$L\text{-}Ck = t_4^R$	0.2291	0.2723	0.3001
ADJ	$L\text{-}Cv = t^R$	0.3345	0.4256	0.3583
	$L\text{-}Cs = t_3^R$	0.2758	0.3956	0.3775
	$L\text{-}Ck = t_4^R$	0.2265	0.2677	0.2865

3.4. REGIONAL THEORETICAL DISTRIBUTION FUNCTION

The L-moments plot, representing an aid in the final selection of regional distribution function, is provided in Figure 9. Compared to Figure 2, a part that fits the estimated L-moments values is zoomed, to provide better insight into transition of ADJ CCs relative to ORG CCs. The data used to plot points describing location of CCs in this respect are given in Table 5.

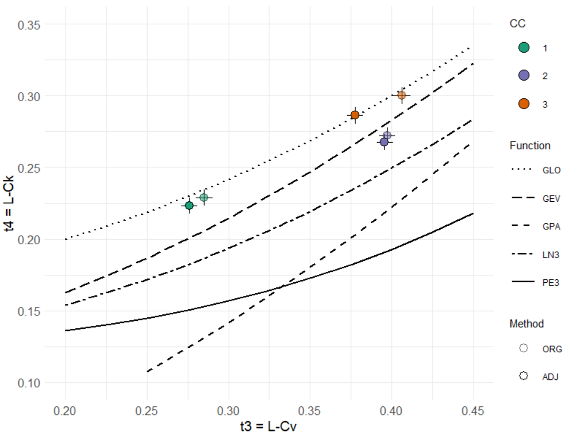

Figure 9. L-moments plot for the CCs of ORG (transparent marker) and ADJ (solid marker) clustering.

According to L-moments plot in Figure 9, the selection of regional distribution function is brought down to two: general logistic (GLO) and general extreme value (GEV) theoretical distribution. GLO is the best fit for CC1 and CC3, while GEV is the most suitable for CC2, and this holds for both ORG and ADJ clustering methods.

4. DISCUSSION

Following the aim of this research that is to investigate whether homogeneous flood estimation regions can be formed in Serbia with the minimum number of nine stations per region based on silhouette widths, it can be said that the main challenge in this research compared to others is the available number of catchments, which is 41. According to the silhouette width classes of compactness [18], the ones achieved here for the three regions in the original clustering belong to weak (≥ 0.26) to strong clustering class (≥ 0.51), which changed to weak clustering after the adjustment of regions (0.450, 0.500 and 0.438). Nevertheless, the achieved results seem better than for 3 regions obtained for regionalization of 245 catchments in Indiana, USA, where the maximum silhouette value of 0.406 is obtained employing Ward's algorithm [27], and also for 555 stations in Slovakia and Austria, divided into 3 regions by the k-means algorithm, where the maximum silhouette width below 0.5 was reached [28]. On the other hand, regionalization of 27 mountainous catchments in Utah, USA, resulted in larger silhouette width (maximum value about 0.65), applying Wards' over k-means clustering, that was reached for 2 centres [27] exhibiting a strong clustering structure. However, in one region there were only 2 catchments, which is not enough for further regionalization (phase 2) bearing in mind minimum number of stations in the region set in this research.

Silhouette width approach based on average within-cluster distance (equation (1)) combines two clustering criteria, compactness and separation, which, according to Lengyel and Botta-Dukát [29], implies that spherical cluster shapes are preferred over others. This can also be seen in the PC plot shown in Figure 8 of our research by the shape before (Figure 8a) and after the adjustment (Figure 8b), where an overall mean silhouette width is improved in ADJ compared to ORG clustering, reflecting in more balanced shapes of the regions showing three cluster centres. For the future research, a new method using generalized mean with flexible formula [29] is going to be tested, that permits the adjustment of sensitivity within the formula through one parameter, to delineate the significance attributed to connectedness and compactness. In this way, better scores can be obtained for clusters that are not perfectly spherical [29]. Due to specific issues in flood response regionalization, the generalized mean functionality can be used to tailor classifications according to the significance of connectedness relative to compactness.

Silhouette width and, as a consequence, the optimal number of cluster centres, depend on the clustering algorithm [27] [30], as well as selected similarity attributes. Using the same number of catchments for flood related regionalization, but without silhouette width as a criterion, 41 catchments in Iran were regionalized by 8 methods using 8 similarity attributes (7 morphological and 1 meteorological) [31]. Evaluation of methods and similarity attributes is performed in terms of homogeneity, accuracy of flood quantiles and region size. Ten best cases according to region homogeneity include catchment area and main stream slope, while ten best cases according to accuracy are obtained for the main stream slope. In the final regionalization ranking, 7 out of 10 include main stream slope, and 3 of 10 include catchment area. It is to be expected that the main stream slope is a function of the catchment slope, that is found significantly correlated with the mean altitude in our research. Implicitly, our selection of catchment area and average basin elevation as catchment similarity attributes is confirmed in [31].

The adjustments of regions performed in the paper according to silhouette widths, have led to regions with more compact, evenly distributed geomorphological attributes: catchment area and mean elevation (Figure 7). Such a distribution of geomorphological attributes shown by box plots across regions is precondition for reliable linear regression equations between geomorphological attributes and flood characteristics, intended for the second phase of regional analysis, i.e. index-flood method.

When it comes to region homogeneity, the lowest GI values are found in CC1 for both ORG and ADJ clustering methods, i.e. for regions consisting of large area catchments, while for CC2 and CC3, consisting of smaller area catchments in the study sample, GI is larger, pointing out to less homogeneous regions. The effect of adjustment of CC3 (adding 4 stations) contributed to slight reduction of GI. Merz and Blöschl [32] also found that by increasing catchment area the variation of *Cv* decreases (and consequently *LCv*), resulting in low GI. A large discrepancy in *Cv* is found in small catchments susceptible to flash floods, posing a challenge for establishing regression with the catchment area [32]. In general, it is considered that the regionalization of small catchments is a particularly difficult task partly due to the non-linear relationship between precipitation and runoff [33]. According to Raquena et al. results [20], it can be concluded that CC2 and CC3 are possibly homogeneous regions. The values of 0.1 of GI resemble to the range of 1 to 2 of *H1* in the Hosking and Wallis (HW) procedure, that gives inconclusive results regarding region homogeneity. Therefore, the final decision about adequacy of proposed regions is to be made according to flood quantile estimates, as in [17] and [31].

Additionally, it was found that adjustment of regions does not influence selection of distribution function according to L-moments plot i.e. information transfer function in each region, intended for index-flood method. It is worth noting that GLO (CC1, CC3) is recommended for regional distribution function in the UK for the index-flood procedure [34], while GEV (CC2) has shown as the best selection in majority of European countries [35] for at-site flood frequency analysis.

5. CONCLUSIONS

The flood information transfer from gauged to ungauged catchments based on geomorphological similarity implies the formation of homogeneous regions, for which cluster methods are often used. In this research, the regionalization of catchments using the hierarchical procedure by the Ward's algorithm and its adjustment is performed through silhouette width approach, with the evaluation of the region homogeneity using the Gini index. The study region comprised 41 catchments in Serbia, with the catchment area between 78 and 2054 km^2, and the average catchment elevation ranging from 257 to 1218 m a.s.l., as two catchment similarity attributes. In the first run of the clustering algorithm, three flood response estimation regions were formed with 9, 12 and 19 stations respectively, while after adjustment of regions according to silhouette widths, the regions comprised of 8, 18, and 14 stations.

The conclusions are as follows:

1. The intended number of stations in the flood response regions is achieved by original clustering, but with the adjustment, in one of the regions, there are 8 instead of 9 stations. This may not pose a problem in the index-flood procedure for flood quantile estimates, when establishing relationship between mean annual flood and catchment area. However, this has to be confirmed in further investigation.
2. The adjustment of regions according to silhouette widths had positive effects on the distribution of catchment morphological attributes within regions, compactness of regions, and generally on region homogeneity measure, the Gini Index. The adjustment had no influence on the theoretical probability distributions – general logistic and general extreme values, as candidates for regional transfer function compared to the original regions. These two functions are commonly used in at-site flood frequency analyses.
3. A significant improvement of the Gini index was noted in clusters that mainly consist of stations of larger catchment areas, while in regions with smaller catchment areas the value was slightly improved by the adjustments of regions.
4. The evaluation of flood response region homogeneity through Gini Index is simple and complements further regional analysis requirements through L-moments. Still, the space for inconclusiveness exists as in other known homogeneity tests applied in hydrology.

Further research will include performance-based evaluation i.e. the accuracy achieved in flood quantile estimation in the second regionalization phase, while including one meteorological catchment similarity attribute, and applying a new method using generalized mean instead of original method with mean silhouette width.

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35
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SOME PHYSICAL PROPERTIES OF LIGHTWEIGHT MORTARS WITH EXPANDED VERMICULITE

Abstract

Expanded vermiculite was added to the cement-lime mortar at 10%, 20% and 30%, which reduced the density of the hardened mortar (HM) without expanded vermiculite (EV) by an average of 8,3% for the HM with 10% EV, 14,7% for the HM with 20% EV and 24,2% for the HM with 30% EV. Compressive and flexural strength and static modulus of elasticity were investigated and the relationships between these properties were determined. The effect of the added amount of EV on: total porosity, air void content and capillary suction of HM according to SIA 262, Appendix A; capillary water absorption; gas permeability and air permeability; water permeability and internal freeze/thaw resistance up to 200 cycles was investigated and determined.

Keywords: lightweight cement-lime mortar, expanded vermiculite, physical properties of mortar

НЕКА ФИЗИЧКА СВОЈСТВА ЛАКИХ МАЛТЕРА СА ЕКСПАНДИРАНИМ ВЕРМИКУЛИТОМ

Сажетак

У цементно-кречни малтер је додат експандирани вермикулит са 10%, 20% и 30%, чиме је смањена густина очврслог малтера (ОМ) без експандираног вермикулита (ЕВ) у просјеку за 8,3% за ОМ са 10 % ЕВ, 14,7% за ОМ са 20% ЕВ и 24,2% за ОМ са 30% ЕВ. Истражена је чврстоћа на притисак и савијање и статички модул еластичности и утврђени су односи између ових својстава. Утицај додате количине ЕВ на: укупну порозност, садржај ваздушних шупљина и капиларно усисавање ОМ према СИА 262, Додатак А; капиларна апсорпција воде; пропустљивост гаса и пропустљивост ваздуха; испитана је и одређена водопропусност и унутрашња отпорност на смрзавање/одмрзавање до 200 циклуса.

Кључне ријечи: лаки цементно-кречни малтер, експандирани вермикулит, физичка својства

1. INTRODUCTION

In the framework of the project "Study of the production, placeability and characteristics of final filling and sealing mortars for the N2d disposal container" [1-4], investigations were carried out, the results of which served as a basis to determine the optimal mix proportion of the filling mortar and to optimize the technology for the preparation and placing of the mortars in the disposal container for low and intermediate level radioactive wastes.

The starting point are the results of the tests of the filling and sealing mortar developed in the framework of the project "Development of a prototype and certification of a disposal container for the disposal of low and intermediate level radioactive waste (LILW)" [5]. Based on the results of the gas permeability tests [6, 7], it was concluded that the gas permeability of this filling mortar is too low. The compressive strength of the mortar at 28 days is also considered to be too high (85,0 MPa on average).

Based on the findings of several foreign researchers, the use of cement-lime mortar would be preferable, as the presence of lime, which has a high pH, increases the binding capacity of radionuclides. The presence of lime in the filling mortar is also important to protect the metal drums from corrosion, as lime provides a sufficiently high alkalinity despite the release of CO_2 released by the anaerobic degradation of the stored (mainly organic) LILW. Cement-lime mortars show increased porosity, which is favorable in terms of increased gas permeability, but decreased compressive strength. Based on the calculation models of the container, the strength class of the filling mortar is sufficient C12/15.

Increased porosity and thus increased gas permeability of the aggregate mortar, as well as its ability to accumulate more gas, would be further achieved by the addition of porous (light) aggregate. The three types of lightweight aggregates mainly considered were: expanded clay, perlite and expanded vermiculite. As the use of perlite is suspected to be problematic in the long term [8], it was excluded from the study. In the following study, we consider expanded vermiculite, which has already been used at Nuclear Power Plant Krško for waste encapsulation.

2. SELECTION OF BASIC MATERIALS FOR THE PREPARATION OF MORTARS

The selection of the base materials was based on data and information from the literature, the container testing programme [9], our own experience from investigations of cement-lime mortars and the requirements of the project [10].

2.1. CEMENT

We used pure cement CEM I 42.5 N - SR 0, manufactured by Salonit Anhovo. This type of cement was chosen because it is more coarsely ground and therefore slower in reactions compared to CEM I 52,5 R and CEM I 42,5 N. This is important from the point of view of lowering the temperature of the mortar due to the hydration of the cement because the filling mortar must fill at least 2,6 m^3 in the container. Additionally, this cement ensures the sulphate resistance of the mortar, in case of aggression that could occur due to the possible formation of an aggressive medium during the degradation of the waste material.

2.2. LIME

The lime used was hydrated lime produced by InterCal Slovenija, Zagorje ob Savi. It is calcium hydroxide - $Ca(OH)_2$, containing $CaO > 92\%$, $MgO < 1,5\%$, $CO_2 < 4\%$, $SO_3 < 0,5\%$.

2.3. SUPERPLACTICIZER

In order to reduce the amount of water in the cement-lime mortar (to lower the w/c ratio and to reduce subsequent water extraction - bleeding), polycarboxylate-based superplasticizers were used.

2.4. CRUSHED LIMESTONE AGGREGATE AND STONE FLOUR

We used crushed limestone aggregate and, as part of preliminary trial mixing, stone flour from the Calcit Kamnik separation plant. The justification for the choice of limestone aggregate was given in the project "Study on the production, workability and characteristics of ready-mixed concrete for the secondary reinforced concrete lining of the silo of the LILW repository" [11]. In preliminary laboratory investigations, we looked for the optimum type of stone flour, particularly with regard to workability and bleeding of fresh mortar. The stone flours varied according to their granulometric composition: 0-120 μm (CalPlex VP), 0-70 μm (CalPlex 15) and 0-17,5 μm (CalPlex 5).

2.5. EXPANDED VERMICULITE

As mentioned in the introduction, based on the assessment of the long-term durability of lightweight aggregates in cement-lime mortar, we selected expanded vermiculite as potentially the most suitable. Expanded vermiculite was also used at Nuclear Power Plant Krško to encapsulate waste in drums. This use of expanded vermiculite has been eliminated because the vermiculite mixture occupies a large volume, so the amount of waste material in the barrel has been reduced. The increase in volume of the expanded vermiculite mortar shall not affect its use for filling the space between the drums (TTC) in the container, if such mortar fulfils all other criteria.

Since vermiculite contains 38 to 46 % w/w SiO_2, the question immediately arises whether an alkali-silicate reaction (ASR) can occur in the mortar. In the paper [8], the results of investigations show that there is no ASR potential in a cementitious composite with expanded vermiculite.

A similar conclusion was reached in the IRMA laboratory, where the potential alkali-silicate reactivity of expanded vermiculite was determined according to ASTM C1260-05a. The fractions of expanded vermiculite used were EXV0 (0,25-1mm), EXV1 (0,5-2.5mm) and EXV2 (1-4mm), produced by Vermit Group, Krško. Three combinations were investigated, varying the binder: (1) CEM I 52,5 R-SR from the Lafarge cement plant in Mannersdorf (Austria), (2) CEM I 42,5 N - SR 0 from the Salonit Anhovo cement plant, and (3) CEM I 42,5 N - SR 0 from the Salonit Anhovo cement plant and GIRK Kalun lime (lime/cement ratio = 1/2,65). For all three combinations, we measured practically no expansion after 16 days or 14 days of exposure to an alkaline environment.

3. PRELIMINARY INVESTIGATIONS - FINDING THE OPTIMUM MORTAR MIX PROPORTION

Preliminary investigations were carried out to find the optimal mix proportion of the filling mortar (FM) with respect to its rheological properties: workability (measured by the grout spreading method according to SIST EN 445:2008, section 4.3.2), segregability and bleeding, which were assessed visually.

To measure the spread, we use a cylinder (plastic tube) with an inner diameter of 39 mm and a height of 60 mm, standing on a smooth (glass) plate. Pour the mortar up to the top of the cylinder. After 30 s from the rising of the cylinder, measure the diameter of the spread in two mutually perpendicular directions (Figure 1).

Figure 1. Measurement of the diameter of the mortar spread.

The mortar was placed in 40 × 40 × 160 mm prism moulds, which were then cured according to SIST EN 1015-11:2020, Table 1: the day after preparation, the prisms were placed in polyethylene bags and stored for 7 days; after 7 days, they were removed from the bags and stored until the test in a chamber at 20°C (+3°C/-2°C) and 65%±5% relative humidity; when the mortar was tested at 3 and 7 days of age, the prisms were removed from the bags before the test.

Fresh mortar is considered suitable for filling disposal containers if the average spread according to SIST EN 445:2008, clause 4.3.2 is $PR_{per} \geq 120$ mm, with no segregation and bleeding observed by visual assessment.

Based on the calculation models carried out by the designer of the container, the compressive strength of the mortar is sufficient to meet the strength class C12/15.

The following tests were carried out to assess the applicability of the mortar:

- **in a fresh state:**
  - spread according to SIST EN 445:2008, clause 4.3.2;
  - visual assessment of segregation and bleeding;
- **in a hardened state:**
  - compressive strength according to SIST EN 1015-11:2020 converted to the compressive strength of a cube with an edge of 15 cm.

In addition, the following tests were carried out on selected mortars:

- **in a fresh state:**
  - air content according to SIST EN 1015-7:1999, pressure method;
  - water-cement ratio according to SIST 1026:2016, Appendix NC;
  - density according to SIST EN 1015-6:1999/A1:2007;
  - air and mortar temperature;
- **in a hardened state:**
  - density according to SIST EN 1015-10:2001/A1:2007.

Table 1 gives the mix proportions of all the filling mortars (FMs) from the preliminary investigations, together with an assessment of the applicability of each FM in relation to the results of the workability (spread) test of the fresh FMs, the visual assessment of segregation and bleeding of the fresh FMs, and the results of the compressive strength test of the hardened FMs.

Table 1. Mix proportions of all FMs from the preliminary investigations and assessment of applicability

set of FM mixtures	filling mortar designation	binding component		stone flour (μm)			superplasticizer				expanded vermiculite (mm)			crushed limestone (mm)		water	appropriate workability	segregation	bleeding	strength class C12/15	appropriate for application
		cement (% m/m)	lime (% m/m)	0-120	0-70	0-17,5	RC277	RC897	RC187	RC687	0,25-1	0,5-2,5	1-4	0-2	0-4						
1	»NIREX«, CalPlex VP	62	38		-	-	-	-	-	-	-	-	-	-	-		yes	no	yes	no	no
1	»NIREX«, CalPlex 15	62	38	-		-	-	-	-	-	-	-	-	-	-		yes	no	yes	no	no
1	»NIREX«, CalPlex 5	62	38	-	-		-	-	-	-	-	-	-	-	-		yes	no	yes	no	no
2	»NIREX«-mod, CalPlex VP	62	38		-	-		-	-	-	-	-	-	-	-		yes	no	yes	yes	no
2	»NIREX«-mod, CalPlex 15	62	38	-		-		-	-	-	-	-	-	-	-		yes	no	yes	yes	no
2	»NIREX«-mod, CalPlex 5	62	38	-	-			-	-	-	-	-	-	-	-		yes	no	yes	yes	no
3	FM-VER-1	62	38		-	-		-	-	-				-	-		no	no	no	yes	no
3	FM-VER-2	62	38		-	-		-	-	-				-	-		no	no	no	yes	no
3	FM-VER-2a	62	38		-	-		-	-	-				-	-		yes	no	no	no	no
3	FM-VER-2b	62	38		-	-		-	-	-				-	-		no	no	no	no	no
3	FM-VER-2c	62	38		-	-		-	-	-				-	-		yes	no	no	no	no
3	FM-VER-2d	62	38		-	-		-	-	-				-	-		yes	no	no	no	no
3	FM-VER-2e	62	38		-	-		-	-	-				-	-		no	no	no	no	no
3	FM-VER-2f	62	38		-	-		-	-	-				-	-		no	no	no	no	no
4	FM-VER-3	62	38		-	-		-	-	-				-			yes	no	no	no	no
4	FM-VER-3a	62	38		-	-		-	-	-				-			no	no	no	no	no
4	FM-VER-4	62	38		-	-	-		-	-				-			no	no	no	no	no
4	FM-VER-4a	62	38		-	-	-		-	-				-			yes	no	no	no	no
5	FM-VER-5	62	38	-	-	-	-		-	-		-	-	-			no	no	no	no	no
5	FM-VER-5a	62	38	-	-	-	-		-	-		-	-	-			no	no	no	no	no
5	FM-VER-5b	62	38	-	-	-	-		-	-		-	-	-			yes	yes	-	-	no
5	FM-VER-5c	62	38	-	-	-		-	-	-		-	-	-			yes	yes	no	no	no
5	FM-VER-6	62	38	-	-	-		-	-	-		-	-		-		yes	no	no	yes	yes
6	FM-VER-E-1-187	62	38	-	-	-	-	-		-	-	-	-		-		yes	yes	yes	yes	no
6	FM-VER-E-1-897	62	38	-	-	-	-		-	-	-	-	-		-		no	no	no	yes	no
6	FM-VER-E-1-687	62	38	-	-	-	-	-	-		-	-	-		-		yes	no	no	yes	yes
7	FM-0-EV	62	38	-	-	-	-	-	-		-	-	-		-		yes	no	no	yes	yes
7	FM-10-EV	62	38	-	-	-	-	-	-			-	-		-		yes	no	no	yes	yes
7	FM-20-EV	62	38	-	-	-	-	-	-			-	-		-		yes	no	no	yes	yes
7	FM-30-EV	62	38	-	-	-	-	-	-			-	-		-		yes	no	no	no	no

The mix proportions of FM set 7 were accepted as default for further laboratory tests.

4. LABORATORY INVESTIGATIONS OF SELECTED MORTARS

In the four selected FM mixtures (from set 7 in Table 1, designated FM-0-EV, FM-10-EV, FM-20-EV and FM-30-EV), we vary the volume fractions of the expanded vermiculite EXV0 (0,25-1 mm): 0, 10, 20 and 30 vol.%. The proportions of crushed limestone aggregate 0-2 mm shall be reduced accordingly. The proportions of cement CEM I 42,5 N SR0, lime and superplasticizer RC 687 remain the same. Water was added to each FM mix in such a quantity as to achieve a suitable workability of the fresh FM. Therefore, as the proportion of expanded vermiculite (EV) increased, more water had to be added, increasing the total water-cement ratio $(w/c)_{tot}$. In the mix proportions, we assume that the EV and the aggregate do not contain water. Therefore, we have also used dry EV and aggregate in the preparation of the FM.

4.1. INVESTIGATIONS OF FRESH MORTARS

4.1.1. TESTS ON FRESH MORTARS IN THE PREPARATION OF TEST SPECIMENS

The following tests and measurements were carried out in the preparation of the test specimens:

- air and mortar temperature;
- spread according to SIST EN 445:2008, clause 4.3.2;
- air content according to SIST EN 1015-7:1999 , pressure method;
- water-cement ratio $(w/c)_{tot}$ according to SIST 1026:2016, Appendix NC;
- density according to SIST EN 12350-6:2019.

The results of the creep measurements show that the workability of all FM was good immediately after mixing. The average values are 154 mm for FM-0-EV and FM-10-EV, 156 mm for FM-20-EV and 151 mm for FM-30-EV. After 30 minutes, workability decreases, but this varies considerably from mixture to mixture, even for mixtures of the same type of FM. Several factors influence the change in workability: the temperature of the air and mortar; the degree of humidity of the EV and aggregate, which affects their water absorption; and the precision of the measurements.

The air content increases slightly on average with increasing EV content for slightly higher dispersion results.

As EV increases, the density of fresh PM decreases (Figure 2).

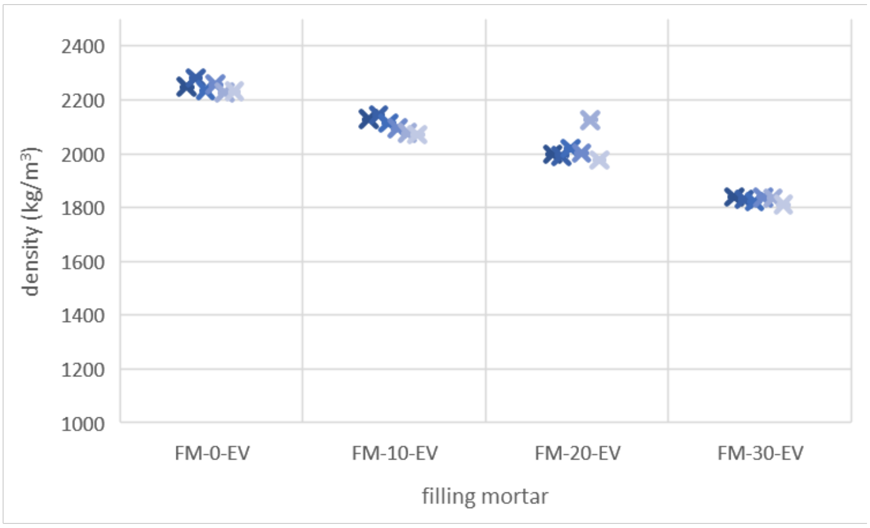

Figure 2. Results of the measurements of the density of fresh FM.

As the amount of EV was increased, more water had to be added, so for the same amount of cement in all FM mixtures, the total water-cement ratio $(w/c)_{tot}$ also increased.

4.1.2. INITIAL SETTING TIME OF FM

The penetration resistance is measured in the initial setting time test of FM. Measurements were carried out using a CT-421A concrete and mortar penetrometer according to the method given in ASTM C403/C403M -23. The mortar starts to set when it reaches a penetration resistance of 3,448 kPa (500 psi). As the amount of EV increased, more water was added and for the same amount of cement, the total water-cement ratio increases, so as the amount of EV increases, the FM initial setting time increases (Figure 3).

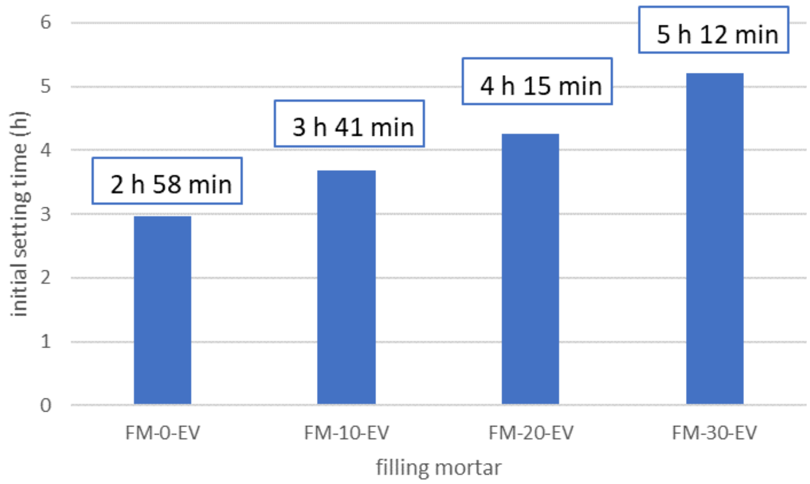

Figure 3. Initial setting time as a function of increasing amount of EV in the FM.

4.1.3. ADIABATIC THERMAL CHARACTERISTICS OF FM

The adiabatic thermal characteristics of the FM were measured in an ATC chamber (adiabatic calorimeter). The results of the measurements are given for each FM in Table 2: initial temperature T_i; maximum measured temperature $T_{max,meas}$; time at which the maximum temperature measured $t_{Tmax,meas}$; corrected maximum temperature $T_{max,corr}$; temperature increment ΔT.

Table 2. Initial temperature T_i; maximum measured temperature $T_{max,meas}$; time at which the maximum temperature measured $t_{Tmax,meas}$; corrected maximum temperature $T_{max,corr}$; temperature increment ΔT

parameters	FM-0-EV	FM-10-EV	FM-20-EV	FM-30-EV
Ti (°C)	21,57	26,49	19,58	21,62
$T_{max,meas.}$ (°C)	65,54	66,59	57,81	54,33
$t_{Tmax.meas}$ (day, h, min)	1d,14h,15m	1d,16h,05m	2d,2h,45m	2d,2u,15m
$T_{max,corr}$ (°C)	72,69	75,19	64,3	60,96
increase ΔT (°C)	51,12	48,7	44,7	39,34

As the amount of expanded vermiculite increases, the insulating capacity of the FM increases and therefore the temperature increment ΔT decreases.

4.1.4. SHRINKAGE OF FM DUE TO DRYING

FM shrinkage due to drying was measured according to DIN 4227 - Part 1, on 3 prisms of dimensions 10 × 10 × 50 cm, at a relative humidity of 65 (± 5)% and a temperature of +20 (± 4)°C. Additionally, shrinkage was measured on 3 prisms of identical dimensions, wrapped with PVC foil and stored under the same conditions. In this way, we want to simulate similar conditions to those that will be present in the FM placed in the disposal container.

Shrinkage due to drying of FM without protection is most intense for FM-30-EV and FM-20-EV, and much less intense for FM-0-EV and FM-10-EV (in Figure 4, the four curves below). This shrinkage is due to the water content, which is higher in FM with a higher amount of expanded vermiculite.

The reverse effect is obtained by partially preventing drying by wrapping the test specimens with foil (top four curves in Figure 4). We are talking about partial prevention because the foil is also permeable. In such a test, the evaporation of water from the FM is very slow and the intensity of shrinkage is correspondingly low. Unbound water remaining in the voids of the expanded vermiculite causes first a slight expansion of the grains. As this water slowly evaporates, shrinkage occurs, which is very small in the case of FM with a larger amount of expanded vermiculite, as can be seen in Figure 4 - the top two curves. This figure shows that PM-30-EV has not shrunk from its initial state after 188 days.

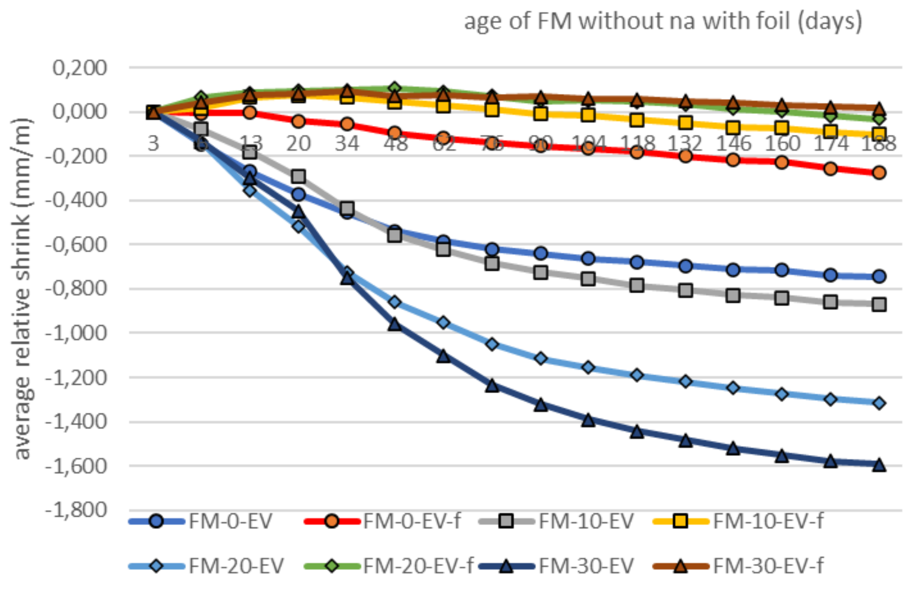

Figure 4. Shrinkage due to drying of FM without and with protection (with foil) as a function of the age of the FM.

4.2. INVESTIGATIONS OF HARDENED MORTARS

4.2.1. COMPRESSIVE AND FLEXURAL TENSILE STRENGTH AND DENSITY OF FM PRISMS 4 × 4 × 16 CM

The compressive and flexural tensile strengths and the density of FM were determined on 4 × 4 × 16 cm prisms according to SIST EN 1015-11:2020 and SIST EN 1015-10:2001/A1:2007 at 3, 7, 28, 56, 90 and 180 days of age.

Density

The average values of the results of the density tests as a function of age of the FM are given in Figure 5.

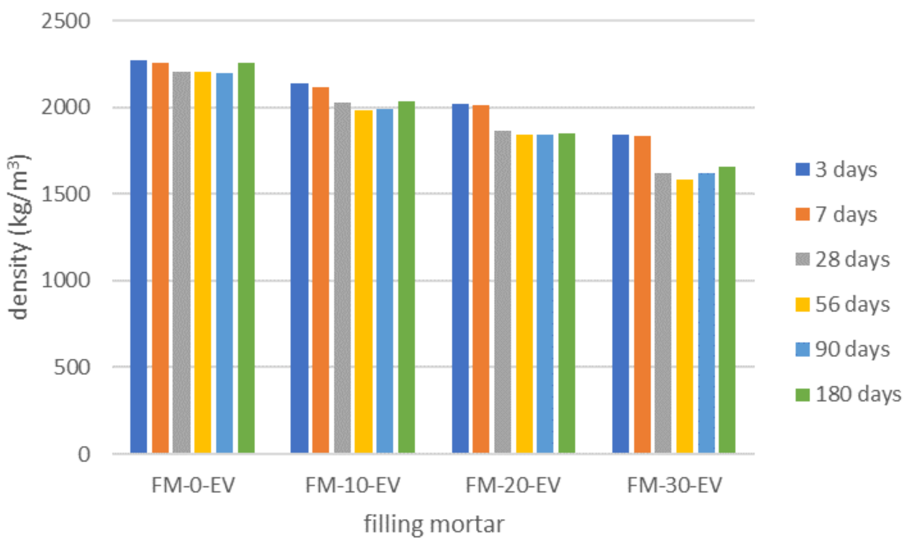

Figure 5. Average values of density test results as a function of FM age.

The density of FM decreases as the amount of expanded vermiculite increases. Compared to the density of FM-0-EV (ρ_0), the density of FM-10-EV (ρ_{10}) decreases on average by 8,3%, ρ_{20} (FM-20-EV) by 14,7% and ρ_{30} (FM-30-EV) by 24,2%.
After 7 days, the foil was unwrapped according to the standard and the test specimens were cured in a chamber at 20°C (+3°C/-2°C) and 65%±5% relative humidity until the test. This change in cure resulted in a decrease in the densities of all FM.

Compressive strength

The average values of the compressive strength test results, as a function of FM age, are given in Figure 6.

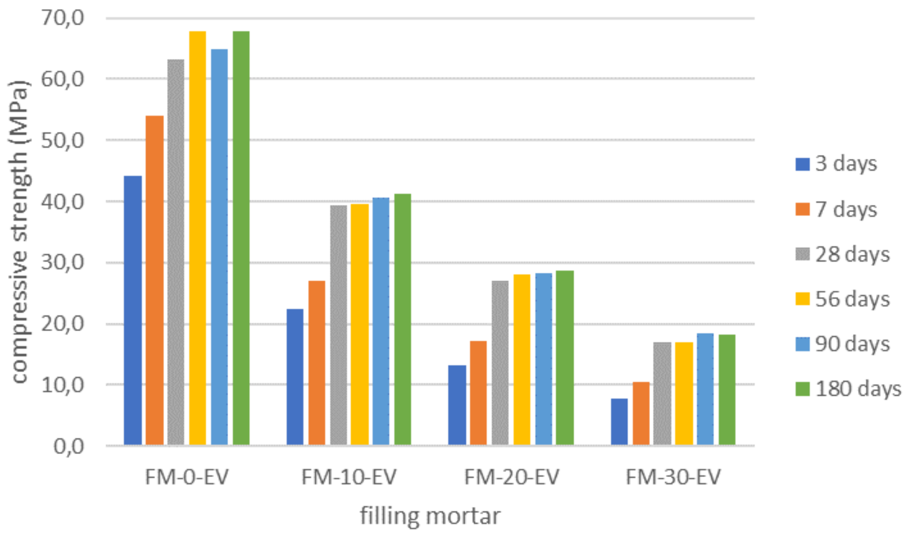

Figure 6. Average values of compressive strength test results as a function of FM age.

The compressive strength of all FM increases with age. Compared to the compressive strength of FM-0-EV (f_{c0}), the compressive strength of FM-10-EV (f_{c10}) decreases on average by 42,5%, f_{c20} (FM-20-EV) by 61,4% and f_{c30} (FM-30-EV) by 76,0%.
Up to the age of FM 7 days, FM with a higher amount of expanded vermiculite also contained a higher amount of water, resulting in lower compressive strengths. As mentioned above, after 7 days, the foil was unwrapped in accordance with the standard and the test specimens were cured until the test in a chamber with a temperature of 20°C (+3°C/-2°C) and a relative humidity of 65%±5%. This change in cure reduced the amount of water in the FM, thereby significantly increasing the compressive strength at FM age 28 days compared to the compressive strength at FM age 7 days (Figure 6). This relative increase is more pronounced in FM with expanded vermiculite (31,0% in FM-10-EV, 36,2% in FM-20-EV and 37,9% in FM-30-EV) compared to FM-0-EV, where it is only 14,5%.

Flexural tensile strength

The average values of the results of the flexural tensile strength tests, as a function of the age of the FM, are given in Figure 7. Compared to the flexural tensile strength of FM-0-EV (f_{f0}), the flexural tensile strength of FM-10-EV (f_{f10}) decreases on average by 18,4%, f_{f20} (FM-20-EV) by 356% and f_{f30} (FM-30-EV) by 47,0%.
The change in curing reduced the amount of water in the FM, thereby significantly increasing the flexural tensile strength at 28 days FM compared to the flexural tensile strength at 7 days FM (Figure 7). This relative increase is much more pronounced in FM with expanded vermiculite (18,7% in FM-10-EV, 30,8% in FM-20-EV and 37,7% in FM-30-EV) compared to FM-0-EV, where it is only 1,1%.

Relationship between flexural tensile strength and compressive strength

Figure 7 shows that for all FMs, the average flexural tensile strengths increase up to an FM age of 56 days and then decrease. However, Figure 6 shows that the average compressive strengths of all FMs increase up to 180 days of age. Figure 8 shows the progress of the flexural tensile strengths with respect to the increase in compressive strengths for each FM.

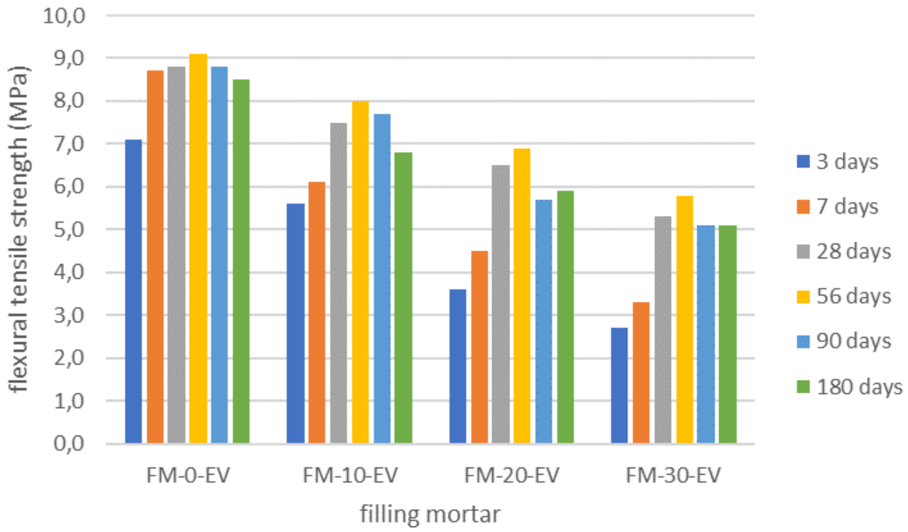

Figure 7. Mean values of flexural tensile strength test results as a function of FM age.

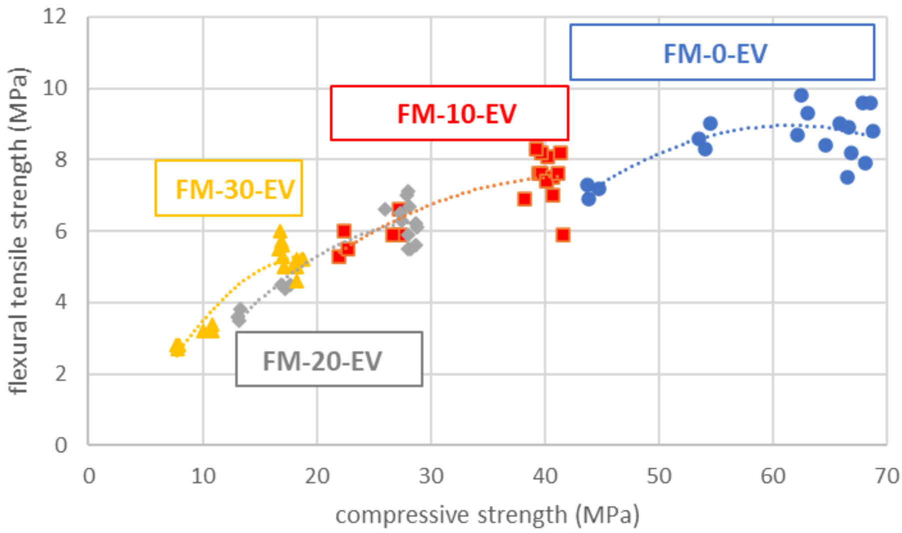

Figure 8. Progress of flexural tensile strengths versus increasing compressive strengths of FM.

Figure 8 shows that there is a trend towards decreasing flexural tensile strengths at higher compressive strengths. This is most evident in FM-0-EV, but much less so in all other FMs with expanded vermiculite. This means that FM becomes more brittle at higher compressive strengths, especially for FM-0-EV, which achieves much higher compressive strengths compared to the compressive strengths of FM with expanded vermiculite.

From the results obtained for the compressive and flexural tensile strengths of the FM, we can also calculate the ratio of the flexural tensile strength f_f to the compressive strength f_c: $f_f/f_c \times 100$ (Figure 9), which increases as the amount of expanded vermiculite in the FM increases.

4.2.2. COMPRESSIVE STRENGTH OF A CUBE WITH A 15 CM EDGE AND STATIC MODULUS OF ELASTICITY FM

The compressive strength was determined on a cube with an edge of 15 cm according to SIST EN 12390-3:2019 and the static modulus of elasticity on a prism of 10 × 10 × 40 cm according to DIN 1048, Part 5, section 7.5 at FM ages 3, 7, 28, 56, 90 and 180 days.

Compressive strength

The average values of the compressive strength test results as a function of FM age are given in Figure 10. The compressive strength of all FM increases with age. Compared to the compressive strength of FM-0-EV (f_{c0}), the compressive strength of FM-10-EV (f_{c10}) decreases on average by 48,9%, f_{c20} (FM-20-EV) by 65,3% and f_{c30} (FM-30-EV) by 78,4%.

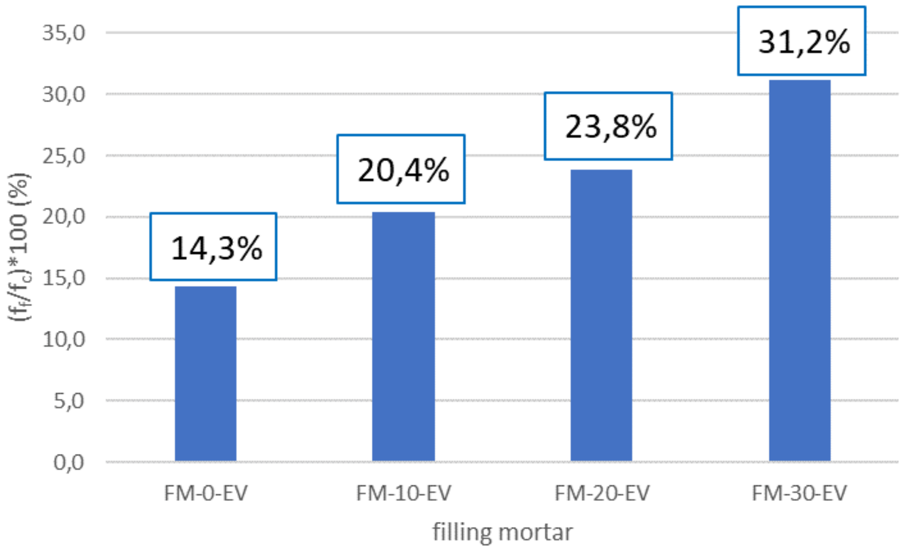

Figure 9. Proportions of the flexural tensile strength f_f with respect to the compressive strength f_c FM.

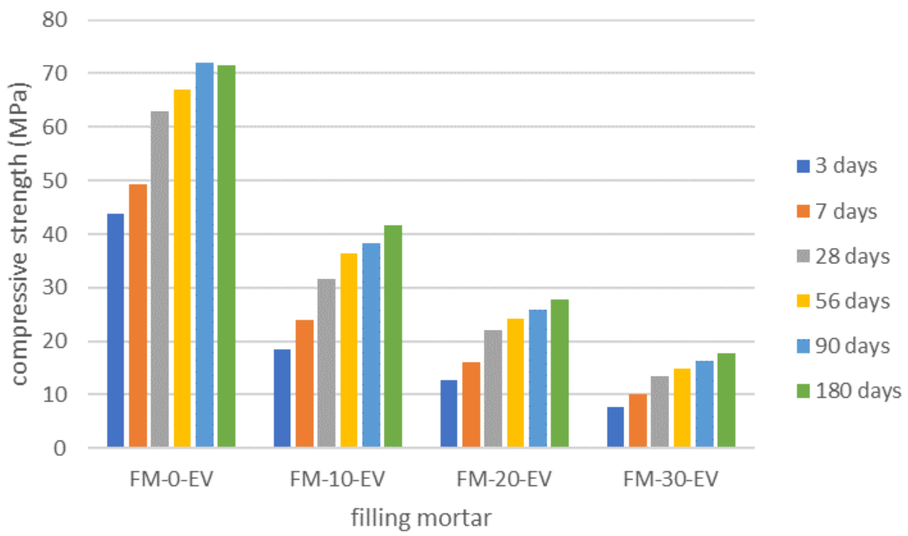

Figure 10. Average values of compressive strength test results as a function of FM age.

The effect of curing according to SIST EN 1015-11:2020, Table 1 on the increment of the compressive strength of FM cubes with a 15 cm edge is lower compared to the increment of the strength of FM cubes with a 4 cm edge (or 4 × 4 × 16 cm prism halves). The relative increase in compressive strength at FM 28 days compared to the compressive strength at FM 7 days is only slightly higher for FM with expanded vermiculite (24,6% for FM-10-EV, 27,6% for FM-20-EV, 24,6% for FM-30-EV) compared to FM-0-EV, where it is 20,2%.

In addition to FM-0-EV ($f_{cm,K15,28}$ = 62,9 MPa), FM-10-EV ($f_{cm,K15,28}$ = 31,7 MPa) also meets the criterion of the required strength class C12/15 at FM 28 days. The acceptance criterion for the initial compressive strength tests at FM 28 days is:

$$f_{cm,K15,28} \geq f_{ck} + 12,0 \text{ MPa} = 15,0 \text{ MPa} + 12,0 \text{ MPa} = 27,0 \text{ MPa}.$$

Ratio between the compressive strength of an FM cube with an edge of 15 cm and the compressive strength of an FM cube with an edge of 4 cm (or a prism half of 4 × 4 × 16 cm)

The correlations between the average compressive strength test results of an FM cube with 15 cm edge $f_{c,K15}$ and the average compressive strength test results of an FM cube with 4 cm edge $f_{c,K4}$ are given for each FM in Figure 11.

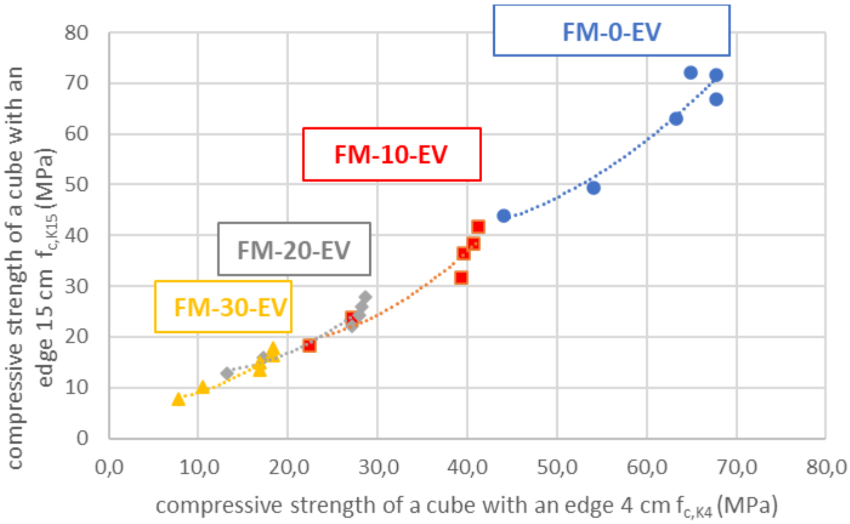

Figure 11. Correlation between $f_{c,K15}$ and $f_{c,K4}$ of individual PMs.

From the results of the compressive strength tests of the FM cubes with a 15 cm edge and the FM cubes with a 4 cm edge, calculate for each FM the ratio between $f_{c,K15}$ and $f_{c,K4}$:

- $f_{c,K15}/f_{c,K4}$ = 1,01 for FM-0-EV,
- $f_{c,K15}/f_{c,K4}$ = 0,90 for FM-10-EV,
- $f_{c,K15}/f_{c,K4}$ = 0,91 for FM-20-EV,
- $f_{c,K15}/f_{c,K4}$ = 0,92 for FM-30-EV.

Taking all the results of the FM compressive strength tests together gives the following average ratio:

- $f_{c,K15}/f_{c,K4}$ = 0,93 for all PMs together.

Static modulus of elasticity

The average values of the results of the static modulus of elasticity tests, as a function of the age of the FM, are given in Figure 12.

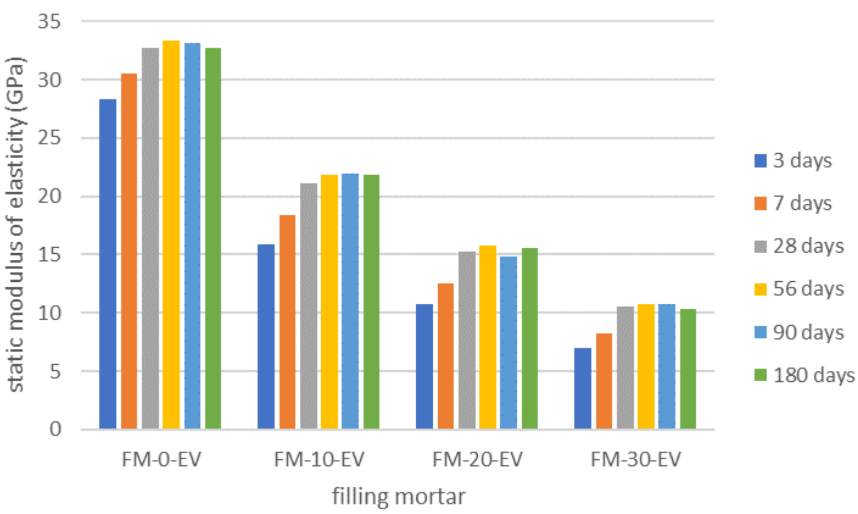

Figure 12. Average values of static modulus of elasticity test results vs. age of FM.

The elastic modulus of elasticity increases in all FM until the age of 28 days, after which the increase is moderate or almost stops until the age of 180 days. As compressive strength increases with FM age up to 180 days (Figure 10), this is also evident from the correlations between the average compressive strength and static modulus of elasticity test results. For intercomparison, all correlations are given together in Figure 13.

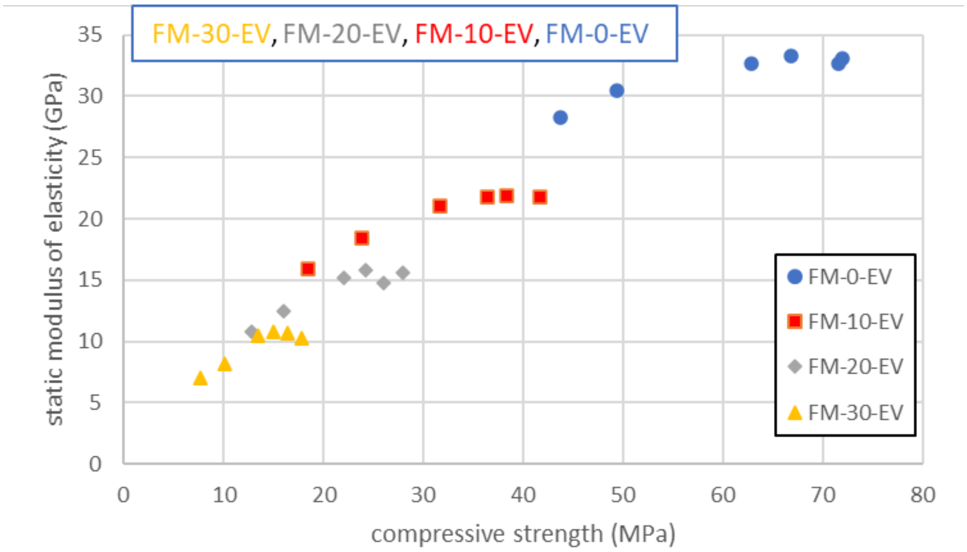

Figure 13. All correlations between compressive strength and static modulus of elasticity of FM together.

Compared to E_{stat0} (FM-0-EV), E_{stat10} (FM-10-EV) is on average 36,8% smaller, E_{stat20} (FM-20-EV) 55,8% smaller and E_{stat30} (FM-30-EV) 70,0% smaller.

4.2.3. TOTAL POROSITY, AIR PORE CONTENT AND CAPILLARY SUCTION OF FM ACCORDING TO SIA 262, APPENDIX A

Total porosity, air pore content and capillary suction of FM were determined according to SIA 262, Appendix A. The results are given in Table 3, together with a reference mortar from abroad.

Table 3. Total porosity, air pore content and capillary suction of FM.

filling mortar	average values		
	total porosity n (%)	air pore content L_p (%)	capillary suction q_w (g/(m^{2}h))
FM-0-EV	18,8	0,3	4,8
FM-10-EV	26,8	2,3	6,5
FM-20-EV	34,6	5,5	9,3
FM-30-EV	44,2	10,7	10,7
reference mortar	26,9	3,2	20,7

The total porosity and air pore content are given together in Figure 14, and the capillary suction is given in Figure 15.

As can be seen from Figure 14, the total porosity n and air pore content L_p of PM-10-EV are very similar to n and L_p of the reference filling mortar. However, it can be seen from Figure 15 that the capillary suction q_w of the FM-10-EV is much lower compared to the q_w of the reference FM. These results indicate the suitability of the FM-10-EV for its intended use.

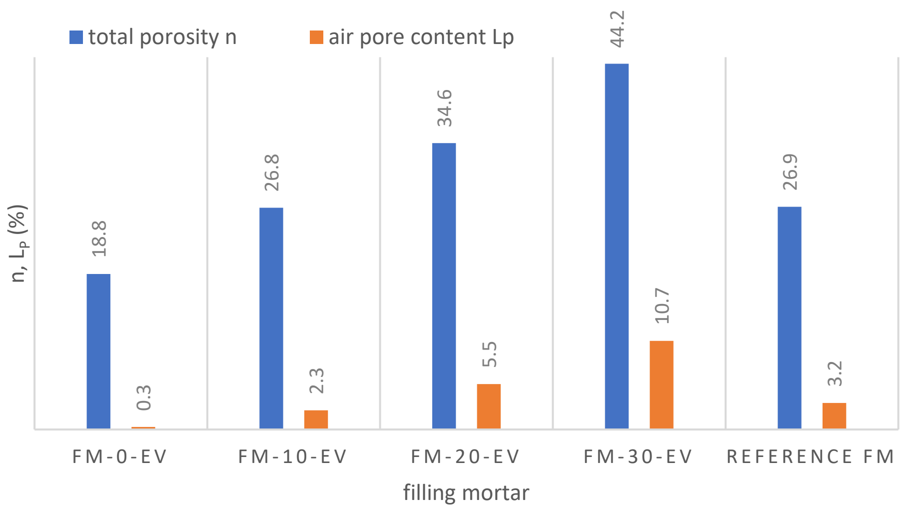

Figure 14. Total porosity n and air void content Lp.

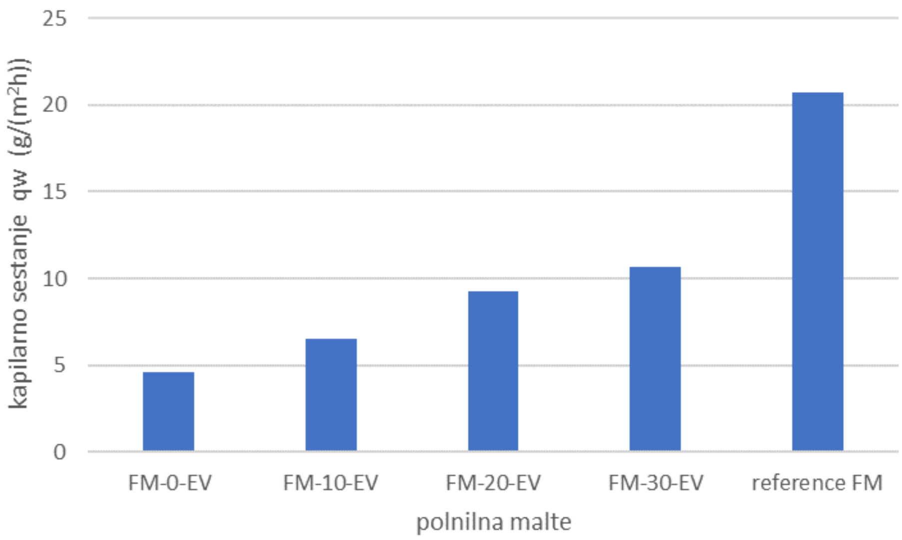

Figure 15. Capillary suction q_w.

4.2.4. CAPILLARY WATER-ABSORPTION

The capillary water-absorption of the FMs was investigated according to SIST EN 13057:2002. The average values of the sorption coefficients at FM ages 28, 90 and 180 days are given in Table 4 and Figure 16.

Table 4. Average sorption coefficient of FM.

age of FM (days)	average sorption coefficient ($kg/m^2\ h^{0,5}$)			
	FM-0-EV	FM-10-EV	FM-20-EV	FM-30-EV
28	0,72	1,31	1,99	2,36
90	0,56	1,12	1,98	2,31
180	0,67	1,18	1,99	2,34

Average sorption coefficients were determined for all FMs, which are less than the maximum permissible value of 2,50 $kg/m^2h^{0.5}$. The coefficient of sorption decreases only slightly with the age of FM. For FM-0-EV and FM-10-EV, the sorption coefficients are much lower compared to those of FM-20-EV and FM-30-EV.

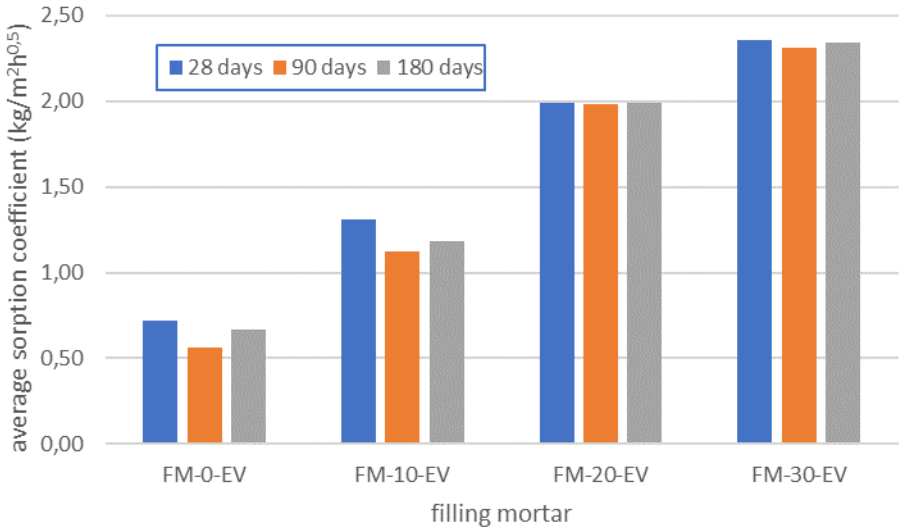

Figure 16. Average sorption coefficient depending on the age of the FM.

4.2.5. GAS PERMEABILITY

The gas permeability test was carried out in the CEMBUREAU permeameter in the laboratory of the University of Liège, Department of Architecture, Geology, Environment and Constructions. The cylinders tested were 150 mm in diameter and 50 mm high, drilled from cubes with a 20 cm edge. The test specimens are dried to a constant mass.
The following average values of intrinsic permeability k_{int} are obtained:

- $k_{int,avrg} = 2{,}80 \times 10^{-16}$ m^2 for FM-0-EV;
- $k_{int,avrg} = 4{,}21 \times 10^{-16}$ m^2 for FM-10-EV;
- $k_{int,avrg} = 6{,}21 \times 10^{-16}$ m^2 for FM-20-EV;
- $k_{int,avrg} = 1{,}18 \times 10^{-15}$ m^2 for FM-30-EV.

For the filling mortar used to fill the prototype containers at the Pomgrad ABI plant in Lipovci, we determined a much lower average intrinsic permeability:

- $k_{int,avrg} = 2{,}67 \times 10^{-17}$ m^2.

4.2.6. AIR PERMEABILITY

The air permeability of FM was measured in the ZAG laboratory on cubes with a 20 cm edge according to SIA 262/1:2019, Appendix E, at FM ages 28, 50, 90 and 180 days.
The following average values of the air permeability kT of 180-day-old FM are obtained:

- $kT_{avrg} = 0{,}043 \times 10^{-16}$ m^2 for FM-0-EV;
- $kT_{avrg} = 0{,}202 \times 10^{-16}$ m^2 for FM-10-EV;
- $kT_{avrg} = 0{,}525 \times 10^{-16}$ m^2 for FM-20-EV;
- $kT_{avrg} = 1{,}668 \times 10^{-16}$ m^2 for FM-30-EV.

The measured values show a lower permeability compared to the gas permeability measurements (paragraph 4.2.5) where the test specimens have been dried to a constant mass, which is not the case in the air permeability test.

4.2.7. WATER PERMEABILITY

The FM water permeability test in a triaxial cell at constant hydraulic gradient according to SIST EN ISO 17892-11:2019 was carried out in the ZAG laboratory.
The coefficient of water permeability at room temperature was calculated in the test:

- $k_T = 3{,}10 \times 10^{-14}$ m/s, for FM-10-EV;
- $k_T = 4{,}78 \times 10^{-13}$ m/s, for FM-20-EV.

By applying a temperature correction factor for a reference temperature of $T_{ref} = 10°C$, the water permeability coefficient at T = 10°C was calculated:

- $k_{10} = 2,24 \times 10^{-14}$ m/s, for FM-10-EV;
- $k_{10} = 3,45 \times 10^{-13}$ m/s, for FM-20-EV.

The results show that increasing the amount of expanded vermiculite in the FM from 10% to 20% increases the water permeability coefficient significantly.

4.2.8. INTRINSIC FREEZE/THAW RESISTANCE (IRFT-200)

The intrinsic freeze/thaw resistance of the FM to 200 freeze/thaw cycles (IRFT-200) was tested according to SIST 1026:2016, Appendix ND, at an FM age of 90 days.

Table 5 gives for each FM the average relative dynamic modulus of elasticity after 200 freeze/thaw cycles P_n and the minimum relative dynamic modulus of elasticity after 200 freeze/thaw cycles P_{min}.

Table 5. P_n and P_{min} after 200 freeze/thaw cycles.

average relative dynamic modulus of elasticity	FM-0-EV	FM-10-EV	FM-20-EV	FM-30-EV
P_n (%)	54	103,3	103,4	104,1
P_{min} (%)	27,7	103,1	102,9	103,0

Only FM-0-EV does not demonstrate intrinsic freeze/thaw resistance up to 200 cycles (IRFT-200) because $P_n < 75\%$ and $P_{min} < 65\%$. However, for all FM with expanded vermiculite, the dynamic modulus of elasticity increases after 200 cycles, indicating that no intrinsic freezing/thawing damage has occurred.

5. CONCLUSION

The addition of expanded vermiculite to lime-cement mortar reduces the fresh and hardened density of the lightweight mortar (FM). The reduction in density is in direct proportion to the increase in the amount of expanded vermiculite.

Increasing the amount of expanded vermiculite (EV) added has the effect of prolonging the initial setting time of the FM and reducing the temperature rise (ΔT) due to the hydration of the cement in the FM.

Shrinkage due to drying is most intense in FM with higher amounts of EV (30% and 20%), but much less in FM without EV and with lower amounts of EV (10%). This shrinkage is due to the water content, which is higher in FM with a higher amount of EV. The reversal effect is obtained by partially preventing drying by wrapping the test specimens with foil. In such a test, the evaporation of water from the FM is very slow and the intensity of shrinkage is correspondingly low. Unbound water remaining in the voids of the expanded vermiculite causes first a slight expansion of the grains and then, as this water slowly evaporates, shrinkage occurs, which is very slight in the case of FM with a larger amount of expanded vermiculite.

As the amount of EV increases, the compressive and flexural strengths of lightweight FM decrease. We found a trend towards decreasing flexural tensile strengths at higher compressive strengths. This is most evident for FM without EV, but much less so for all other FM with EV. This means that at higher compressive strengths the FMs become more brittle, especially FM-0-EV, which achieves much higher compressive strengths compared to those of the FMs with EV. From the results obtained for the compressive and flexural tensile strengths of the FM, we also calculated the percentage of the flexural tensile strength f_f with respect to the compressive strength f_c: $f_f/f_c \times 100$, which increases with increasing the amount of expanded vermiculite in the FM.

According to SIA 262, Appendix A, the total porosity n and air void content L_p of FM-10-EV are very similar to the n and L_p of the reference filling mortar. The capillary suction q_w of the FM-10-EV is much lower compared to the q_w of the reference FM. These results indicate the suitability of the FM-10-EV for its intended use.

All the results of the sorption coefficients determined by the capillary water-absorption test are less than the maximum permissible value, with the sorption coefficients of FM-0-EV and FM-10-EV being significantly lower compared to the sorption coefficients of FM-20-EV and FM-30-EV.

The average values of the intrinsic permeability k_{int} determined by the gas permeability test in the CEMBUREAU permeameter increase as the amount of EV in the FM increases and are higher than the k_{int} of the filling mortar used to fill the prototype containers. The measured air permeability values determined according to SIA 262/1:2019, Appendix E show a lower permeability compared to the gas permeability measurements (in the CEMBUREAU permeameter) where the test specimens were dried to a constant mass, which is not a coincidence in the air permeability test.

From the results of the water permeability test of the FM in a triaxial cell at constant hydraulic gradient, it is evident that the increase in the amount of EV in the FM from 10% to 20% results in a significant increase in the water permeability coefficient.

The results of the FM intrinsic freeze/thaw resistance test up to 200 freeze/thaw cycles (IRFT-200) show that only FM-0-EV does not exhibit intrinsic freeze/thaw resistance up to 200 cycles because the average relative dynamic modulus of elasticity is $P_n < 75\%$ and the minimum relative dynamic modulus of elasticity is $P_{min} < 65\%$. However, for all FM with expanded vermiculite, the dynamic modulus of elasticity increases after 200 cycles, indicating that no intrinsic freeze/thaw damage has occurred.

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36

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STRESS AND STRAIN ON STATE ROAD IB33 IN SERBIA

Abstract

In the pavement structure, stresses and deformations occur due to the effect of the environment and traffic load. The stresses that will occur mostly depend on the traffic load, the type of materials used, the modulus of elasticity of the materials used, the thickness of the layers... Due to the effect of the environment and traffic on the pavement, damage and the creation of permanent deformations, i.e. ruts, occur. If these damages are not repaired in time, the damage will develop even faster. In this paper, the traffic load on the road Požarevac - Veliko Gradište - Golubac was analyzed, the possible damage that may occur due to the effect of that load, as well as the method of maintaining that roadway in order to prevent major damage to the roadway structure.

Keywords: stress, strain, flexible pavement, traffic load, ruts, potholes

НАПОНИ И ДЕФОРМАЦИЈЕ НА ДРЖАВНОМ ПУТУ IБ33 У РЕПУБЛИЦИ СРБИЈИ

Сажетак

У коловозној конструкцији јављају се напони и деформације усљед дејства средине и саобраћајног оптерећења. Напони који ће се јавити највише зависе од сабраћајног оптерећења, врсте материјала, модула еластичности материјала, дебљине слојева... Усљед дејства средине и саобраћаја на коловоз, долази до оштећења и стварања трајних деформација (колотрага). Уколико се та оштећења не санирају на вријеме долази до њиховог бржег развоја. У овом раду је анализирано саобраћајно оптерећење на путном правцу Пожаревац – Велико Градиште – Голубац, могућа оштећења до којих може доћи усљед дејства саобраћаја као и методе одржавања тог коловоза како би се спријечила већа оштећења.

Кључне ријечи: напон, деформације, флексибилан коловоз, саобраћајно оптерећење, колотраг, ударна рупа

1. INTRODUCTION

Pavement structures are the most important part of our transportation infrastructure, serving as the most important and expensive part of our roads, highways, etc. While these surfaces may appear as simple layers of asphalt or concrete, they are subject to complex forces that affects their performance and durability. Understanding the concepts of stress and strain in pavement structures is essential for ensuring their durability, safety, and economic efficiency.

In this research, we will talk about the fundamental principles of stress and strain as they apply to pavement engineering. We will explore how various loads and environmental factors impact these structures and the importance of proper design and maintenance to prevent premature deterioration.

Before delving into the specifics of pavement engineering, it is crucial to define stress and strain.

Stress is a measure of the internal resistance within a material to deformation when subjected to an external force or load. In the context of pavement, stress is the force applied per unit area, usually expressed in units of Pascals (Pa) or pounds per square inch (psi) [1]. Understanding how stress is distributed within the layers of a pavement structure is essential for assessing its load-bearing capacity.

Strain is the measure of deformation experienced by a material in response to stress. It describes how much a material's shape changes when subjected to external forces. In pavement engineering, strain helps us understand how the layers of a pavement structure deform under the influence of traffic loads and environmental conditions [2].

2. THE SIGNIFICANCE OF STRESS AND STRAIN IN PAVEMENT

Stress and strain are very important in pavement engineering for several reasons [3]:

- Safety: Excessive stress or strain in a pavement structure can lead to cracks and surface deformations, which pose safety hazards for road users.
- Durability: The ability of a pavement to withstand repeated loading without deterioration depends on how stress and strain are distributed and managed.
- Economic Efficiency: Properly designed and maintained pavements with optimal stress and strain management can have longer service lives, reducing maintenance and rehabilitation costs.
- Environmental Impact: Pavement distress, such as rutting or cracking, can lead to increased fuel consumption and vehicle emissions. Minimizing these issues is essential for environmental sustainability.

In the subsequent sections, will be presented the types of stress and strain in pavement structures, how they are redistributed, and the factors that influence them. Also, will be discuss strategies for designing and maintaining pavements to mitigate stress and strain-related issues, ensuring safer and more resilient road networks.

The most important factors that influence on stress and strain values and distribution are:

- Traffic Load
- Environmental (temperature, freezing point etc.)
- Materials and thickness of layers in structure
- Condition of the pavement structure.

2.1. TRAFFIC LOAD

Flexible pavement structure is with an asphalt pavement cover and bearing layers of unbound natural or crushed stone aggregates, either partially or completely stabilized with a hydraulic binder. The load-bearing subbase layers have a significantly lower stiffness compared to the stabilized - bound ones and achieve an insignificant stress distribution on the foundation soil in the subgrade. The value of the stress depends mostly on the thickness of the bearing layers and not on the stiffness, it cannot differ significantly in the cases of Crushed stone Aggregate (CSA), and in this type of pavement structure it will depend mostly on the stiffness of the layer on which it is laid [4].

The passage of one traffic load causes damage of a different nature on pavement structures. Their subgrades, during each passage of the load, remember the permanent deformation as a function of the vertical stress to which it is subjected [5]. The accumulation of these deformations is transferred to the surface of the pavement and is depicted as a permanent deformation of the longitudinal and transverse profile. Such deformations are typical for pavements with unbound CSA, while in other cases the stresses on the pavement are of sufficiently moderate intensity that in normal cases permanent deformation remains on the pavement [4]. Figure 1 shows the behavior of the pavement structure under the influence of traffic load.

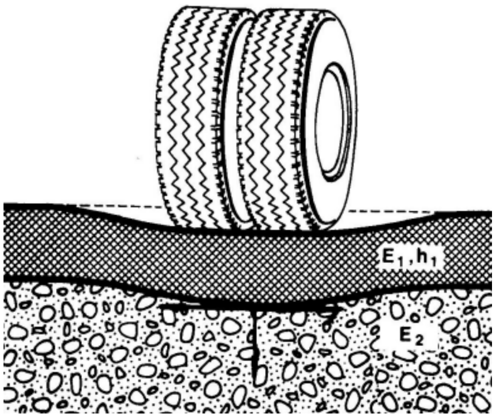


Figure 1. Scheme of mechanical behavior of flexible pavement structure under traffic load [6]

Figure 2 describes the vertical stresses, horizontal stresses and shear stresses in the bottom of the bound layers as well as the compressive and tensile stresses in the subbase layers and subgrade soils. This shows that the principal stresses σ1 and σ3 rotate before, under and after the wheel load. It is important to recognize there are compressive stresses in the bound layers in front of and behind the wheel load, while the stresses are strongly tensile under the wheel load [7].

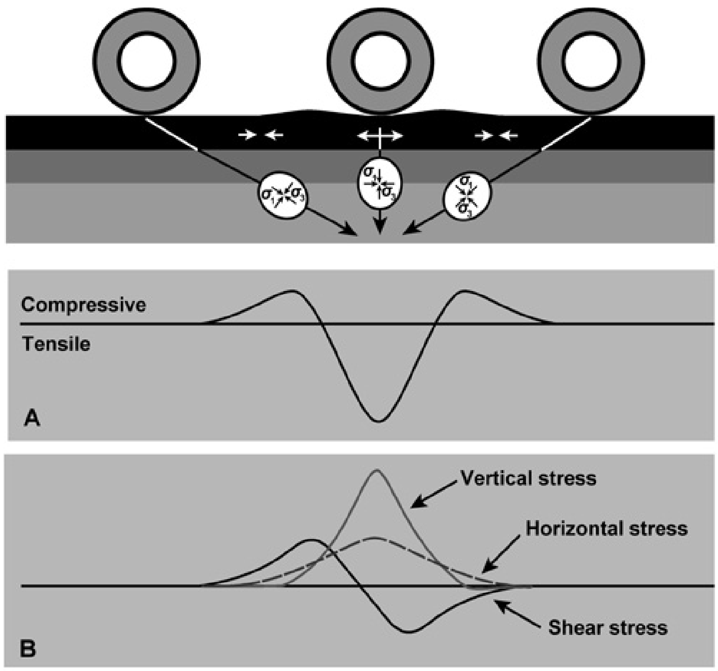


Figure 2. Strains (A) and Stresses (B) caused by a moving of tyre. Figure modified after Doré and Zubeck (2008) [6]

The tensile and compressive stresses induced on the pavement by heavy wheel loads decreases with increasing depth, also load duration, stress retention and stress area increases with increasing depth In order to take maximum advantage, pavement layers are usually arranged in order of descending load bearing capacity, with the highest load-bearing capacity material on the top and the lowest load-bearing capacity material at the bottom, as seen in flexible pavement [8].On figure 3 we can see stress on different layers in pavement structure.

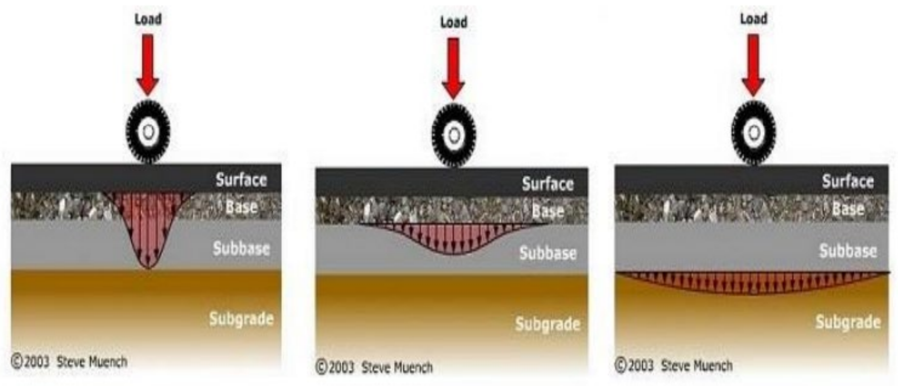


Figure 3. Typical Flexible Pavement and Load Distributions [9]

2.2. ENVIRONMENTAL

Since different layers of the pavement structure are heated differently, temperature is one of the most important factors that affect changes in stress and deformation of pavement structures, and high and low temperatures cause impacts in the pavement. In addition to temperature and solar radiation, wind also affects pavement structures. These environmental influences are different for each location, so they have different effects in different locations.

Temperature affects the mechanical and rheological properties of all materials in the pavement structure, with the greatest impact on asphalt layers. Asphalt is a material that has highly elastic characteristics at high temperatures, and highly plastic characteristics at low temperatures. The behavior of asphalt can be represented by certain rheological models that are made up of differently connected Newtonian and Hooke elements (dampers and springs) (Figure 4). At high temperatures, Newton's elements come into greater expression, i.e. flow, and at low temperatures Hooke's elements, i.e. plasticity [10].

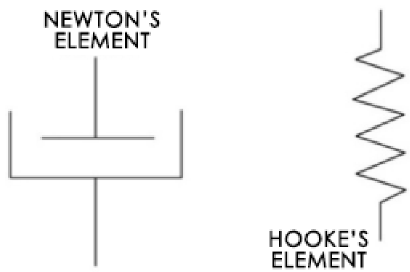


Figure 4. Basic rheological models of asphalt behavior [10]

A big problem occurs in the winter months when the water freezes in the layers that are sensitive to frost (subbase, subgrade), ice lens forms, which causes the pavement to rise in those places and cracks appear.

Fractures in flexible structure caused by thermal effects are a problem, both in climatic areas with low temperatures, and in climatic zones where large variations in daily temperatures are noticeable [11]. Due to the effect of low temperatures, thermal stresses are equalized with the tensile strength of the materials from which the pavement is made. In this way, the bonds within the bitumen itself and the bonds between the bitumen and the aggregates break - the structure breaks [12]. Figure 5 shows the fracture temperatures.

In the case of flexible pavement structures, the influence of temperature manifests itself in two ways, through:

- extremely high dependence of the modulus of rigidity - elasticity on temperature, i.e. variable load capacity during different seasons;
- extremely small dependence of the pavement structures (temperature stresses) on temperature changes [12].

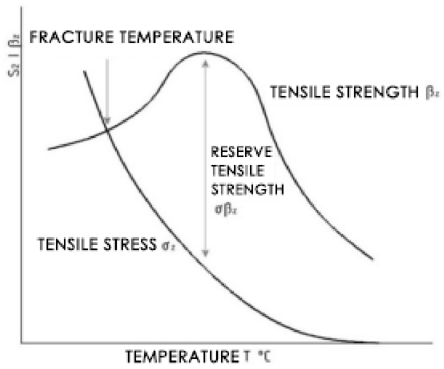


Figure 5. Determination of tensile strength as a function of temperature [11]

2.3. MATERIALS AND THICKNESS OF LAYERS IN STRUCTURE

All the technical properties of mineral stone materials, hydraulic and hydrocarbon binders, and the type and quality of the material in the subgrade affect the damage to the pavement during exploitation. How an asphalt material will behave under the influence of traffic load depends primarily on its three fundamental mechanical properties: stiffness, resistance to fatigue under repeated tensile stresses from bending and resistance to the occurrence of permanent deformations [12].

2.4. CONDITION OF THE PAVEMENT STRUCTURE

The current pavement condition as well as its maintenance also have a significant impact on the stresses and deformations in the pavement. Namely, if the roadway structure is not properly maintained, potholes and bumps are created, if they are not repaired under the influence of a wheel that hits a pothole or bump, even greater stresses are created in the roadway than in a structure in which there is no damage. Roadex Network shows how bumps can affect pavement. The magnitude of stresses and strains is also affected by how smooth and even the road surface is. This is due to the fact that uneven bumps can cause impact loads to the pavement due to the suspension system of trucks. Because of this the stresses and strains after a bump can be substantially higher than the corresponding values on the normal surface, what we can see on Figure 6. This may cause a faster deterioration of the pavement due to water from the top of the wet base course pumping up through the pavement [7]. They also showed that with a traffic speed of 80-100 km/h, one bump has an effect on the pavement for almost 200 m.

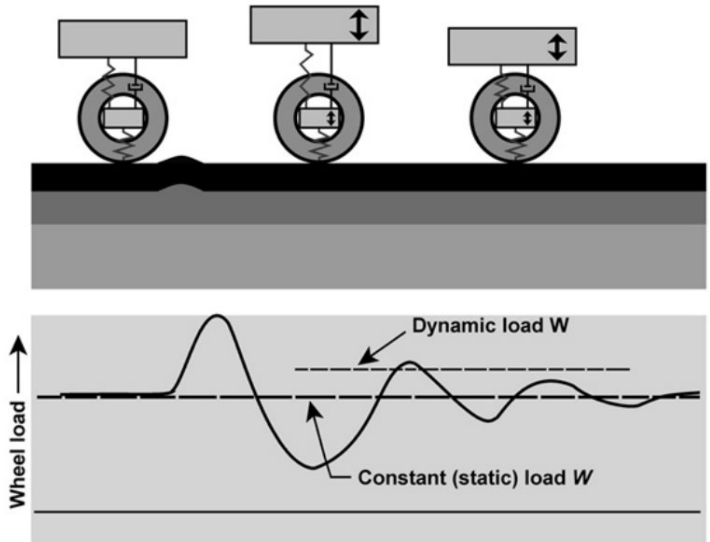
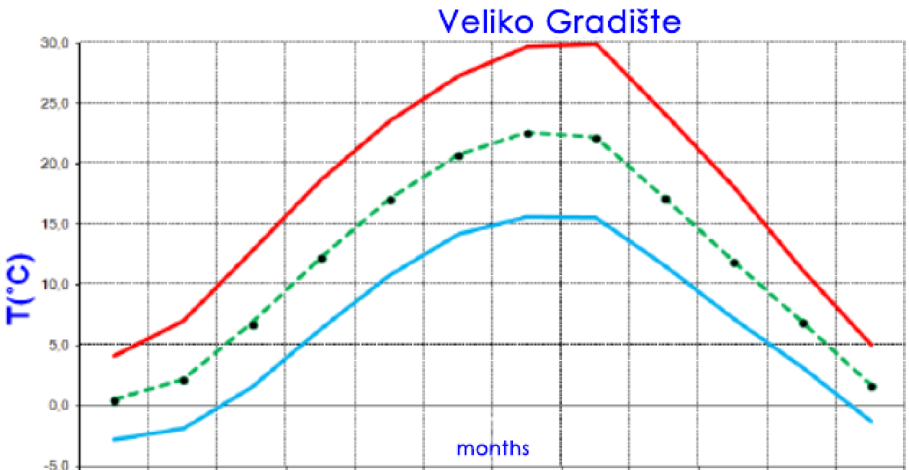


Figure 6. The effect of an uneven bump and how it loads the pavement after the bump. The oscillating load levels after the event can be much higher than the constant (theoretical) load. Figure modified after Doré and Zubeck (2008)[7]

3. STRAIN AND STRESS IN PAVEMENT ON STATE ROAD IB33

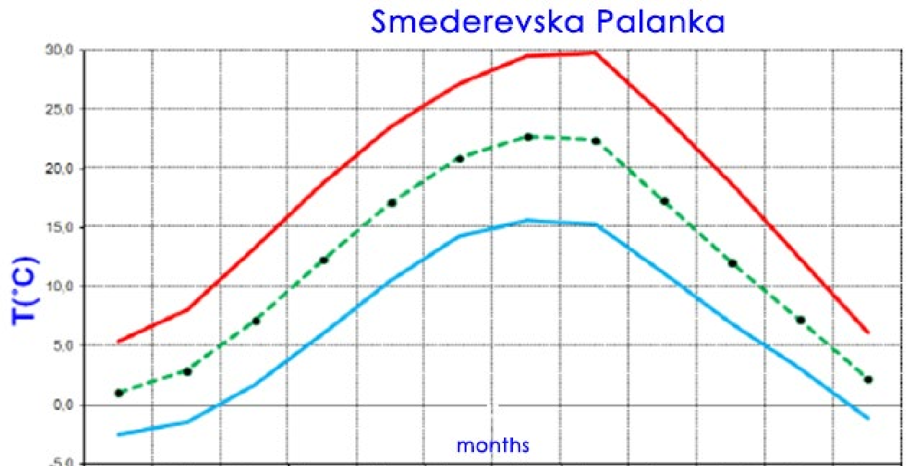
In this review we analyzed stress and strain on state road IB33 from toll plaza Pozarevac to Pozarevac (km 0+000- km 13+184). This location is in Central Serbia near locations Veliko Gradište, Velika Plana, Smederevo, Smederevska Palanka and Belgrade. This road is important because it is connection to important tourist attractions and it is one of connection between Serbia and Romania. In that part of Serbia live around 300.000 people and it is important to control stain and stress on that road, to keep road in good conation.

The mean value of the annual sum of precipitation for Veliko Gradiste is 669.8mm and for Smederevska Palanka is 669.5mm. In figure 7 and 8 we can see temperature by months in Veliko Gradiste and Smederevska Palanka. This parameters are important for pavement design, to know for witch weather conditions we are designing pavement structure.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T maximum	4,1	7,0	12,8	18,7	23,5	27,3	29,7	29,9	24,2	18,1	11,3	5,0
T minimally	-2,8	-1,9	1,5	6,3	10,8	14,2	15,6	15,5	11,6	7,2	3,2	-1,3
T average	0,5	2,2	6,8	12,3	17,1	20,8	22,6	22,2	17,2	11,9	6,9	1,7

Figure 7. Mean monthly temperatures for the synoptic station Veliko Gradiste (1991-2020) [14]



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T maximum	5,3	8,0	13,3	18,8	23,5	27,2	29,5	29,8	24,5	18,7	12,4	6,1
T minimally	-2,6	-1,5	1,7	6,0	10,5	14,3	15,6	15,3	11,2	6,8	3,1	-1,2
T average	1,0	2,9	7,1	12,3	17,1	20,9	22,7	22,4	17,3	12,0	7,2	2,2

Figure 8. Mean monthly temperatures for the synoptic station Smederevska Palanka (1991-2020) [14]

In figure 9 we can see frost index for Belgrade for season 2011/2012. This parameter we are using to know frost line and which material we need to use for pavement structure and for subgrade.

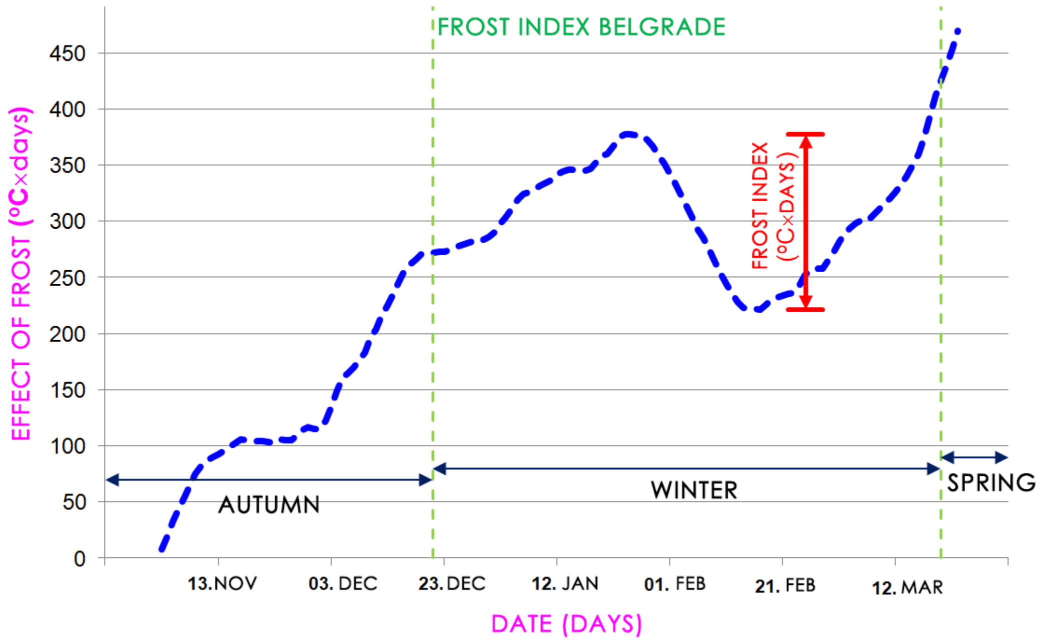


Figure 9. Graphic display of frost index calculations for the weather station Belgrade (season 2011/2012)[14]

The equivalent traffic load was calculated for the project period of 20 years. In accordance with standards SRPS U.C4.010 and SRPS U.C4.015 traffic load is expressed in equivalent standard axles of 82 kN. Traffic analysis was performed based on traffic forecasts for the period from 2025 to 2044. , input data for this analysis we get from Preliminary design (Highway institute) and from PE „Roads of Serbia". In table 1 we can see traffic forecast [15]. In that table we can see annual average daily traffic (AADT) by years, also there are number of each type of vehicle by year. There we have bus (BUS) , light truck (LT), medium truck (MT) , heavy truck (HT) and semi-trailer truck (TT).

Table 1. Traffic forecast from toll plaza Pozarevac to Pozarevac (bypass)

Year	AADT	BUS	LT	MT	HT	TT
2025	2123	277	390	456	301	699
2026	2185	279	403	471	311	720
2027	2246	283	415	486	321	740
2028	2307	286	429	501	330	761
2029	2370	290	442	517	340	781
2030	2429	293	454	531	351	802
2031	2490	295	467	546	361	822
2032	2552	299	480	561	370	843
2033	2612	302	492	576	380	863
2034	2674	305	505	591	390	884
2035	2735	310	519	607	395	905
2036	2792	313	532	621	401	924
2037	2853	318	546	637	407	945
2038	2911	322	558	653	413	965
2039	2973	327	572	669	419	985
2040	3031	331	585	684	425	1006
2041	3091	335	599	700	431	1026
2042	3150	339	612	716	437	1046
2043	3208	344	623	730	442	1066
2044	3267	348	639	746	448	1087

The equivalent traffic load for this part of state road IB33 is 15 518 025 equivalent standard axles of 82 kN and for pavement design we take number of 16 000 000 equivalent standard axles.

According to design pavement structure was with 50cm subbase of crushed stone aggregate (30 cm 0/63mm Ev2 ≥ 140 MPa and 20 cm 0/31,5mm Ev2 ≥ 180 MPa),14cm in two layer of binder course (7cm with BIT50/70 and 7cm with Pmb 45/80-65) and 4cm surface course of SMA11s, on figure 14 we can see typical cross section of pavement structure. In table 2 we can see modulus of elasticity and Poisson's coefficient of all materials in this pavement structure.

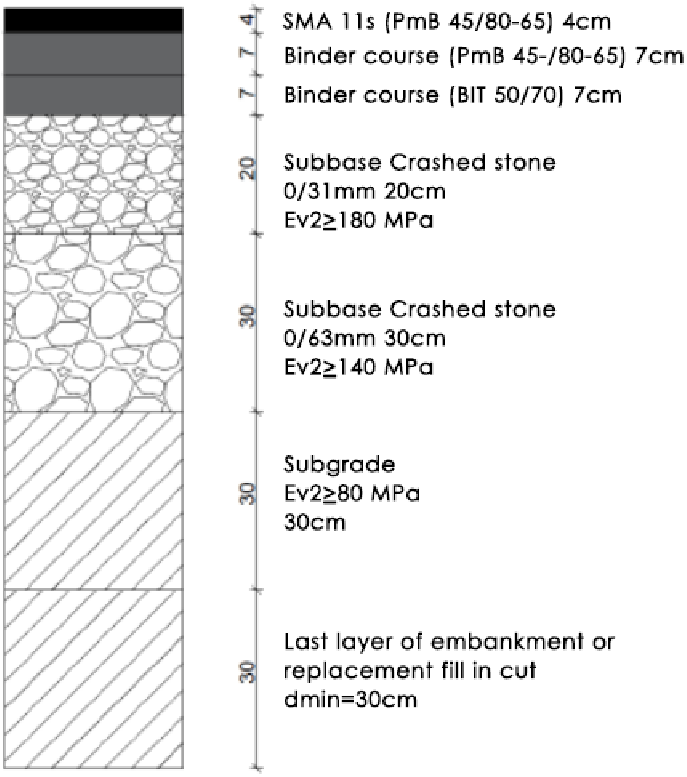


Figure 10. Typical cross section of pavement structure [14]

Table 2. Material characteristics in pavement structure

d (cm)	Layer	E (MPa)	ν
4	SMA11s	3600	0.35
7	Binder course (PmB 45/80-65)	4800	0.35
7	Binder course (BIT 50/70)	5340	0.35
20	Subbase Crushed stone 0/31mm	500	0.40
30	Subbase Crushed stone 0/63mm	230	0.40
	Subgrade	80	0.40

In BISAR 3.0 Shell's software is calculated stress and deformation on this road with this pavement structure under calculated traffic load for this road, below is software output data. The program calculates the eigen values and eigen vectors of the stress and strain tensors, the principal stresses and strains and the corresponding principal directions. The maximum and minimum principal values represent the maximum and minimum normal stresses and strains.

BISAR 3.0 - Block Report

Pozarevac - Golubac

0+000 - 13+184

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0.040	3.600E+03	0.35
2	0.070	4.800E+03	0.35
3	0.070	5.340E+03	0.35
4	0.200	5.000E+02	0.40
5	0.300	2.300E+02	0.40
6		8.000E+01	0.40

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	2.000E+01	5.774E-01	0.000E+00	0.000E+00	1.050E-01	0.000E+00	-1.575E-01	0.000E+00
2	2.000E+01	5.774E-01	0.000E+00	0.000E+00	1.050E-01	0.000E+00	1.575E-01	0.000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0.000E+00	0.000E+00	4.000E-02	-2.828E-01	-3.164E-01	-2.662E-02	-4.520E+01	-5.782E+01	5.087E+01	0.000E+00	0.000E+00	2.658E+02
2	1	0.000E+00	-1.575E-01	4.000E-02	-4.782E-01	-4.403E-01	-5.392E-01	-3.760E+01	-2.341E+01	-6.046E+01	0.000E+00	5.489E+00	2.660E+02
3	2	0.000E+00	0.000E+00	1.100E-01	2.461E-02	-7.628E-02	-9.317E-02	1.748E+01	-1.089E+01	-1.564E+01	0.000E+00	0.000E+00	2.670E+02
4	2	0.000E+00	-1.575E-01	1.100E-01	-3.884E-03	-2.471E-02	-2.801E-01	2.141E+01	1.556E+01	-5.626E+01	0.000E+00	-5.345E-01	2.623E+02
5	3	0.000E+00	0.000E+00	1.800E-01	5.390E-01	3.126E-01	-7.867E-02	8.561E+01	2.836E+01	-7.055E+01	0.000E+00	0.000E+00	2.640E+02
6	3	0.000E+00	-1.575E-01	1.800E-01	5.841E-01	4.724E-01	-8.814E-02	8.419E+01	5.597E+01	-8.575E+01	0.000E+00	-6.737E+00	2.579E+02
7	4	0.000E+00	0.000E+00	3.800E-01	4.312E-02	3.684E-02	-3.370E-02	8.374E+01	6.615E+01	-1.314E+02	0.000E+00	0.000E+00	2.372E+02
8	4	0.000E+00	-1.575E-01	3.800E-01	4.029E-02	3.327E-02	-3.115E-02	7.887E+01	5.924E+01	-1.211E+02	0.000E+00	-1.009E+01	2.314E+02
9	6	0.000E+00	0.000E+00	6.800E-01	7.197E-04	3.988E-04	-1.296E-02	7.178E+01	6.616E+01	-1.675E+02	0.000E+00	0.000E+00	1.984E+02
10	6	0.000E+00	-1.575E-01	6.800E-01	6.767E-04	1.650E-04	-1.237E-02	6.948E+01	6.053E+01	-1.588E+02	0.000E+00	-1.012E+01	1.952E+02

As we can see in this report all deformation are satisfactory under calculated traffic load. This traffic load did not make any fracture in pavement structure. The maximum values of strain on bottom of asphalt layer depends of modulus of elasticity, volume if bitumen percentage of bottom asphalt layer and traffic load. The maximum value of strain on top of subgrade depends on traffic load and confidence level (here it is 95%). Here strain on bottom of asphalt layer is 85,6 μm and allowed value is 100 μm, and for top of subgrade value is 168 μm and allowed values is 269 μm .This pavement must have good maintenance plan to keep the strains and stresses that way. In table 3 is one of variant of maintenance strategy for this road, with which we can keep the strains and stresses like in BISAR report.

Table 3. Variant of maintenance of this road for next 20 years

Driving lane (% of subject area)	
Year of exploitation	Maintenance method
2	15% filling cracks
4	50% filling cracks
6	100% filling cracks
8	20% replacement of the wear layer 4cm
10	100% scraping 11cm
10	100% new binder course 7cm
10	100% new wear layer 4cm
12	15% filling cracks
14	50% filling cracks
14	20% replacement of the wear layer 4cm
16	100% filling cracks
18	20% replacement of the wear layer 4cm
20	100% new binder course 7cm
20	100% replacement of the wear layer 4cm

4. CONCLUSION

This study has examined the stress and strain characteristics of pavement materials depends of various conditions. The findings have provided valuable insights into the factors affecting pavement performance and durability. We have demonstrated that proper pavement design and maintenance strategies are crucial to mitigate the adverse effects of stress and strain, ultimately enhancing the safety and longevity of road infrastructure. In this study we analyzed strains and stress on state road IB33 form toll plaza Pozarevac to Pozarevac under predicted traffic load for next 20 years. We did that in BISAR 3.0 software and in report we got that all stresses and strains in this pavement structure under predicted traffic load are satisfactory, but we must have good maintenance plan if we want to keep that state in pavement structure for next years.

Future research should focus on conducting field experiments to validate these findings and further explore the complexities of pavement behavior. The significance of this research lies in its potential to improve the resilience and sustainability of our transportation networks, ensuring safer and more cost-effective infrastructure for the future.

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37
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TORSIONAL IRREGULATITY PROVISIONS FOR BUILDINGS IN MODERN CODES

Abstract

It has been observed that in earthquake-affected areas, structures with a configuration classified as torsionally irregular are more prone to damage than regular structures. Modern seismic provisions have introduced criteria for determining if the structure is torsionally sensitive and guidelines for designing them. Eurocode 8 prescribes criterion which is based on characteristics of natural vibrations of building while in most of the other regulations criterion is based on comparison of maximum and average story drift. The assessment and comparison of provisions for torsionally irregularity is performed on 18 structures. Six layouts of structure were created by varying the position of structural elements in order to create different levels of torsional irregularity. Because of the different approach in the classification of building regarding torsional irregularity it is noted that there are conflicting results in different regulations.

Keywords: Torsional irregularity, Eurocode 8, Asce 7-16

ОДРЕДБЕ У МОДЕРНИМ ПРОПИСИМА ЗА ТОРЗИОНО НЕРЕГУЛАРНЕ ОБЈЕКТЕ

Сажетак

Уочено је да су у подручјима погођеним земљотресом, конструкције са конфигурацијом класификованом као торзионо неправилне склоније оштећењу од регуларних конструкција. Кроз савремене сеизмичке прописе су уведени критеријуми за утврђивање да ли је конструкција осјетљива на торзију и смјернице за њихово пројектовање. Еврокод 8 прописује критеријум који се заснива на карактеристикама природних вибрација зграде, док се у већини осталих прописа критеријум заснива на поређењу максималног и просјечног релативног спратног помјерања. Упоређење одредби прописа за торзионо нерегуларне конструкције извршено је на 18 конструкција. Промјеном положаја конструктивних елемената у циљу стварања различитих нивоа торзионе неправилности креирано је шест основа конструкције. Због различитог приступа у класификацији грађевина у погледу торзионе неправилности, закључено је да се добијају опречни резултати према различитим прописима.

Кључне ријечи: торзиона нерегуларност, Еврокод 8, АСЦЕ 7-16

1. INTRODUCTION

Structural systems of buildings are conditioned with architectural requests regarding shape and function. These requests result with structural systems that have grouping of high stiffness elements (walls, concrete cores) close to the center of the building in plan, while flexible elements (or secondary seismic elements for gravity loads) are located on the perimeter of the building layout, or on only one side of structure. These structures are likely to exhibit severe rotational displacements about a vertical axis of reference under horizontal seismic excitation, which impose increased stress and deformation demands on structural members lying close to the perimeter of the building [1]. For plan irregular structures coupling between translation and torsion produces uneven displacements in structural elements. If this coupling is strong enough, than torsional sensitivity, an undesired phenomenon may take place, [2].

2. TORSIONAL IRREGULARITY PROVISIONS IN MODERN CODES

Torsional irregularity was the subject of research at a large number of scientific research institutions in the region and beyond. Although this problem has been researched for more than 60 years, the design of irregular buildings for earthquake action is still an open area of research, and the treatment in modern regulations differs significantly. Modern seismic provisions have introduced criteria for determining if the structure is torsionally sensitive and guidelines for designing them. US and European regulations prescribe different approaches. While Eurocode 8-EC8 [4], presents analytical criteria that is based on dynamic characteristics of structure, the other modern codes adopted criteria based on drifts as a result of analysis. The difference in approaches can lead to classifying the same structure differently.

If structure is classified as torsionally sensitive, it implies limited structural nonlinear behavior, so the design codes prescribe different "penalties" related to seismic analysis to be performed and behavior factor to be adopted.

For torsionally irregular structures Eurocode 8 prescribes use of reduced behavior factor, use od 3D model and at least modal analysis as structural investigation method. On the other hand, US code ASCE 7-16, [6], defines two levels of torsional irregularity, torsional irregularity and extreme torsional irregularity, with different "penalties" for structural analysis. Structures with extreme irregularity are not allowed in certain zones with extreme seismic activity, and for buildings of public interest (public institutions, industrial structures, etc.)

2.1. TORSIONAL IRREGULARITY IN EUROCODE 8

Eurocode 8 gives set of basic principles of conceptual design where it is stated that besides lateral resistance and stiffness, building structures should possess adequate torsional resistance and stiffness to limit the development of torsional motions. In this respect, arrangements in which the main elements resisting the seismic action are distributed close to the periphery of the building present clear advantages. EC8 classifies structures as "regular" and "non-regular" separately in plan and elevation according to certain structural regularity criteria. It is noted that behaviour of irregular structures to strong ground motions cannot be predicted with the same confidence as for regular structures. For this reason EC8 introduces stringent requirements for irregular structures regarding FE structural model to be adopted, seismic method of analysis to be applied and the reduction of behaviour factor value.

A series of structural regularity conditions in plan are prescribed in clause 4.2.3.2 of EC8.

The qualitative structural regularity conditions in plan are following:

(i) In plan slenderness,

$$\lambda = L_{\max} / L_{\min} \leq 4 \tag{1}$$

- Plan irregularity is checked on each level and along each main direction of the structure, the structural eccentricity has to match,

$$e_{oX} \leq 0.3 r_X \quad (2$$

$$e_{oY} \leq 0.3 r_y \tag{3}$$

where:

e_{oX}, e_{oY}, - are the distances between the centre of stiffness (or shear centre) and the centre of mass, measured along the X and Y directions, respectively, normal to the direction of analysis considered;
r_X, r_Y - are the torsional radii with respect to the centre of stiffness given by the square root of the ratio of the torsional stiffness to the lateral stiffness in the Y and X directions, respectively;

- Torsional irregularity or torsional sensitivity criterion has to be checked for each story and for each direction of computation. If this criterion is not met than structure is classified as torsionally sensitive (torsionally flexible in EC8):

$$r_x \geq l_S \tag{4}$$

$$r_y \geq l_S \tag{5}$$

where:
l_S - is the radius of gyration of the floor mass in-plan given by the square root of the ratio of the polar moment of inertia of the floor mass in-plan with respect to the centre of mass of the floor over the floor mass;
The criterion of torsional irregularity (iii) given by European regulations (Eurocode 8) is based on the characteristics of natural vibrations (i.e. stiffness and mass) of the building. The subject criterion for a single-story building is satisfied when translational natural period along a principal axis is longer than the rotational natural period (the structure is not torsionally sensitive) [3]. This criterion for multi-story buildings is not explicitly defined, but the procedure for checking this criterion is at the level of recommendations for certain types of structures. It is not clearly defined whether it is necessary to satisfy the criterion for each floor or whether the average value needs to be analysed [5].
If the structure is classified as torsionally irregular than behavior factor is to be reduced for up to 50%.

2.2. TORSIONAL IRREGULARITY IN ASCE 7-16 – US CODES

Code ASCE 7-16 prescribes three levels of torsional irregularity in accordance with the following index:

$$\alpha = \frac{\Delta_{max}}{\Delta_{average}} \tag{6}$$

Where:
Δ_{max} – maximum drift on the corresponing story i
Δ_{avg} – average drift on the corresponing story i
Torsional irregularity criterion is graphically presented in figure 1.

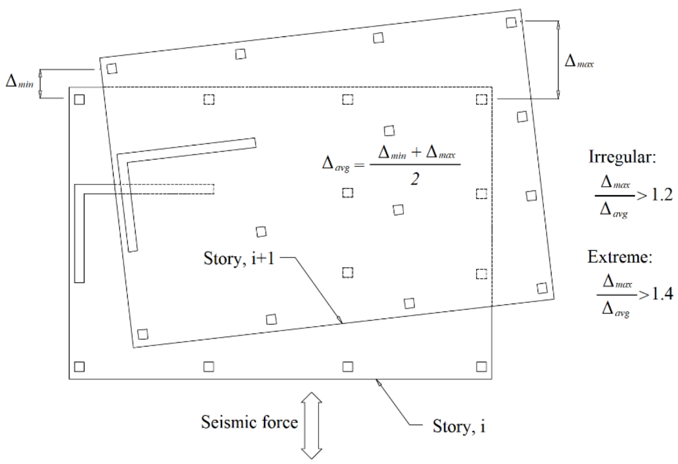

Figure 1. Torsional irregularity criterion ASCE 7-16

Torsional irregularity is defined in the following levels:
(i) Structure is not torsionally irregular if α<1,2;
(ii) Structure is torsionally irregular if 1,2 ≤ α ≤ 1,4 and

(iii) Structure is extremelly torsionally irregular if α>1,4.

Accidental torsion is taken into account by shifting the centre of mass of each floor by 5% of the building dimension, perpendicular to the seismic excitation.

For structure s that are torsionally irregular accidental torsion is to be magnified with amplification factor:

$$A_x = \frac{\Delta max}{1.2 * \Delta_{avg}}, \dots 1.0 < A_x < 3.0 \tag{6}$$

In addition, if the building has extreme torsional irregularity, the moments resulting from accidental torsion of the building should be amplified by 30%.

3. CASE STUDY

In order to perform an analysis of code provisions for torsional irregularity for buildings, an analysis of 18 buildings was performed. Six characteristic layouts of the building (figure 2, figure 3) with different levels of torsional irregularity were analyzed with different number of storeys (6, 9 and 12 storeys).

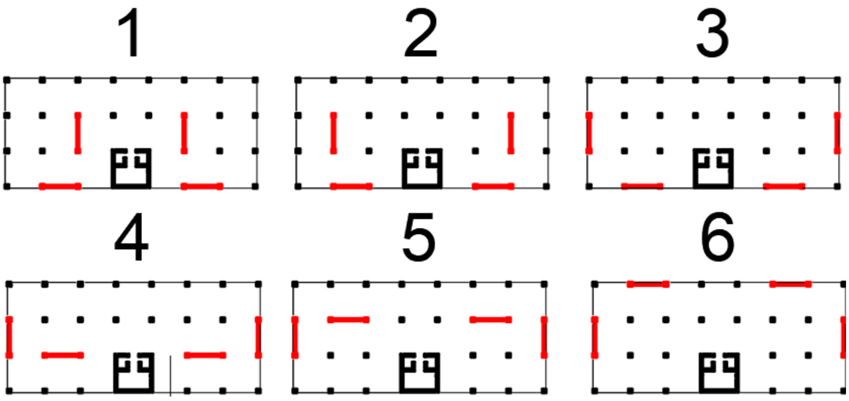

Figure 2. Layout of structure type 1 to 6

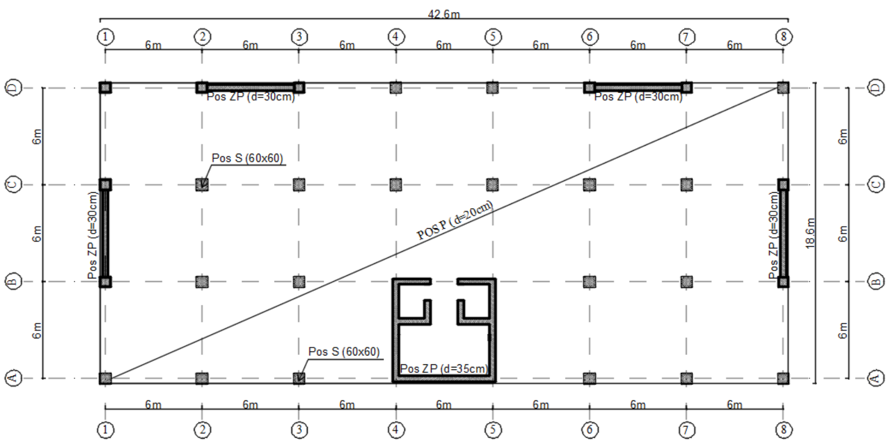

Figure 3. Layout of structure type 6

All layouts of buildings were configured to have the same number and dimensions of vertical structural elements, and different level of torsional irregularity was achieved by variation of the position of elements. For the system for lateral loads wall system with concrete core was adopted. The floor height of the ground floor is 4.5m, and the other floors are 3.2m. The layout of the building is rectangular with dimensions of 42.6 m x 18.6 m (building is not slender). The grid in both directions is 6m. The roof is flat and impassable. The slabs were designed as reinforced concrete flat slabs with a thickness of d = 20 cm directly supported by columns and walls. Columns were designed with dimensions b/d = 60/60 cm only for gravity load, so they are classified as secondary seismic elements in accordance with EC8. The thickness of the walls of the stair core and wall elements is 30 cm.

3.2. MODAL ANALYSIS RESULTS

Modal analysis was performed for 18 structures. The first natural period was coupled translation in X direction and rotation where translation was dominant. Second natural period was uncoupled translation in Y direction. Third natural period is coupled rotation and translation in X direction where rotation is dominant. The results obtained for first three natural periods are given in table 1. Analysing the results, it can be concluded that with the change in the level of torsional irregularity, the value first natural period increased, while the second and third natural period do not change significantly. It can be concluded that the change in the first natural period is more significant in buildings with less floors, and that this ratio decreases with the increase in the number of storeys. The difference in first natural period for a building with 6 storeys is 81%, 9 storeys 55%, while for 12 storeys it is 39%. The modal mass of the 1st natural period decreases and for the 3rd increases with increased level of irregularity.

Table 1. Values of first three natural period for analyzed structures

No	**6 SP 1**	**6 SP 2**	**6 SP 3**	**6 SP 4**	**6 SP 5**	**6 SP 6**
1	1,0528	0,8647	0,7415	0,6909	0,6307	0,5816
2	0,5029	0,5027	0,5036	0,5030	0,5028	0,5056
3	0,4145	0,4018	0,3849	0,4013	0,4144	0,4208
No	**9 SP 1**	**9 SP 2**	**9 SP 3**	**9 SP 4**	**9 SP 5**	**9 SP 6**
1	1,7291	1,5096	1,3570	1,2748	1,1807	1,1099
2	0,9783	0,9798	0,9837	0,9804	0,9805	0,9884
3	0,7592	0,7349	0,7078	0,7309	0,7501	0,7593
No	**12 SP 1**	**12 SP 2**	**12 SP 3**	**12 SP 4**	**12 SP 5**	**12 SP 6**
1	2,4741	2,2390	2,0823	1,9684	1,8471	1,7704
2	1,6105	1,6153	1,6258	1,6169	1,6171	1,6342
3	1,1927	1,1502	1,1089	1,1371	1,1616	1,1715

3.3. TORSIONAL IRREGULARITY CHECK IN ACCORDANCE WITH EUROCODE 8

In plan regularity check was performed in accordance with two analytical criterions given in EC8. Calculation of criterions for structure of 6 storeys with configuration 1 is given in the table 2. In the table 3 overall results of in plan regularity check for all analysed structures is presented.

Table 2. Regularity check for structure with 6 storeys and configuration 1 (SP1)

Story	e_{ox} [m]	e_{oy} [m]	r_x [m]	r_y [m]	l_s [m]	$e_{ox}<=0.3r_x$	$e_{oy}<=0.3r_y$	$r_x>l_s$	$r_y>l_s$
6	0,0	8,65	7,97	14,78	13,11	Yes	No	No	Yes
5	0,0	8,35	7,78	14,49	13,08	Yes	No	No	Yes
4	0,0	8,15	7,50	14,14	13,08	Yes	No	No	Yes
3	0,0	7,84	7,17	13,65	13,08	Yes	No	No	Yes
2	0,0	7,39	6,89	13,02	13,08	Yes	No	No	No
1	0,0	6,54	6,73	12,03	13,09	Yes	No	No	No

Table 3. Results of regularity check for all 18 structures EC8

SP 6 - 6	SP 6 - 5	SP 6 - 4	SP 6 - 3	SP 6 - 2	SP 6 - 1
Yes	**No**	**No**	**No**	**No**	**No**
SP 9 - 6	SP 9 - 5	SP 9 - 4	SP 9 - 3	SP 9 - 2	SP 9 - 1
Yes	**No**	**No**	**No**	**No**	**No**
SP 12 - 6	SP 12 - 5	SP 12 - 4	SP 12 - 3	SP 12 - 2	SP 12 - 1
Yes	**No**	**No**	**No**	**No**	**No**

3.4. TORSIONAL IRREGULARITY CHECK IN ACCORDANCE WITH ASCE 7-16

In plan regularity check was performed in accordance with analytical criterion given in ASCE 7/16. Calculation of regularity criterions for structure of 9 storeys with configuration 6 and 1 is given in the tables 4 and 5.

In the table 6 overall results of torsional regularity check and eccentricity amplification factor values for all analysed structures is presented in accordance with the ASCE 7-16.

Table 4. Regularity check for structure with 9 storeys and configuration SP6

	storey displacement		Storey drift		δmax/ δavg	Regularity check	Ax - amplification faktor	Ekcentricity %	Extreme irregularity
	Max (mm)	Min (mm)	Max (δmax mm)	Avg (δavg mm)					
st 9	58,47	40,3	8,1	6,885	1,176	Regular	1	0,05	Regular
st 8	50,37	34,63	8,14	6,905	1,179	Regular	1	0,05	Regular
st 7	42,23	28,96	8,02	6,8	1,179	Regular	1	0,05	Regular
st 6	34,21	23,38	7,76	6,565	1,182	Regular	1	0,05	Regular
st 5	26,45	18,01	7,27	6,14	1,184	Regular	1	0,05	Regular
st 4	19,18	13	6,55	5,52	1,187	Regular	1	0,05	Regular
st 3	12,63	8,51	5,54	4,66	1,189	Regular	1	0,05	Regular
st 2	7,09	4,73	4,19	3,52	1,190	Regular	1	0,05	Regular
st 1	2,9	1,88	2,9	2,39	1,213	Irregular	1,022	0,051	Regular

Table 5. Regularity check for structure with 9 storeys and configuration SP1

	storey displacement		Storey drift		δmax/ δavg	Regularity check	Ax - amplification faktor	Ekcentricity %	Extreme torsional irregularity
	Max (mm)	Min (mm)	Max (δmax mm)	Avg (δavg mm)					
st 9	70,89	26,88	9,06	6,765	1,339	Irregular	1,246	0,062	Regular
st 8	61,83	22,41	9,25	6,8	1,360	Irregular	1,285	0,064	Regular
st 7	52,58	18,06	9,3	6,71	1,386	Irregular	1,334	0,067	Regular
st 6	43,28	13,94	9,18	6,47	1,419	Irregular	1,398	0,070	Irregular
st 5	34,1	10,18	8,85	6,07	1,458	Irregular	1,476	0,074	Irregular
st 4	25,25	6,89	8,2	5,465	1,500	Irregular	1,563	0,078	Irregular
st 3	17,05	4,16	7,18	4,63	1,551	Irregular	1,670	0,084	Irregular
st 2	9,87	2,08	5,69	3,53	1,612	Irregular	1,804	0,090	Irregular
st 1	4,18	0,71	4,18	2,445	1,710	Irregular	2,030	0,101	Irregular

Table 6. Results of regularity check for all 18 structures ASCE 7-16

	ASCE 7/16			
	Torsionally irregular	Amplification factor of accidental eccentricity	Extreme torsional irregularity	Increase of seismic forces
6 sp 1	YES	2,32	YES	30%
6 sp 2	YES	1,49	YES	30%
6 sp 3	YES	1,42	YES	30%
6 sp 4	YES	1,38	YES	30%
6 sp 5	YES	1,32	NO	0%
6 sp 6	YES	1,27	NO	0%
9 sp 1	YES	2,02	YES	30%
9 sp 2	YES	1,38	YES	30%
9 sp 3	YES	1,27	NO	0%
9 sp 4	YES	1,24	NO	0%
9 sp 5	YES	1,22	NO	0%
9 sp 6	YES	1,18	NO	0%
12 sp 1	YES	1,71	YES	30%
12 sp 2	YES	1,46	YES	30%
12 sp 3	YES	1,30	NO	0%
12 sp 4	YES	1,26	NO	0%
12 sp 5	YES	1,19	NO	0%
12 sp 6	YES	1,13	NO	0%

4. COMPARISON OF RESULTS

In the table 7 overall comparison of results of torsional regularity check in accordance with EC8 and ASCE 7-16 is given.

Table 7. Comparison of regularity check in accordance with EC8 and ASCE 7-16

	ASCE 7/16		EC 8
	Torsionally irregular	Extreme torsional irregularity	Torsionally irregular
6 sp 1	YES	YES	YES
6 sp 2	YES	YES	YES
6 sp 3	YES	YES	YES
6 sp 4	YES	YES	YES
6 sp 5	YES	NO	YES
6 sp 6	YES	NO	NO
9 sp 1	YES	YES	YES
9 sp 2	YES	YES	YES
9 sp 3	YES	NO	YES
9 sp 4	YES	NO	YES
9 sp 5	YES	NO	YES
9 sp 6	YES	NO	NO
12 sp 1	YES	YES	YES
12 sp 2	YES	YES	YES
12 sp 3	YES	NO	YES
12 sp 4	YES	NO	YES
12 sp 5	YES	NO	YES
12 sp 6	YES	NO	NO

Analysed buildings can be classified as regular of irregular dependent of code that we are applying. Also, EC8 prescribes increase of seismic forces of 65% while ASCE 7-16 prescribes increase of 30% of extreme torsional irregularity and increase of accidental eccentricity tor torsional irregularity.

5. CONCLUDING REMARKS

From the performed study following conclusions can be made:
- Criterion for torsional irregularity in EC8 and ASCE 7/16 is significantly different. Criterion defined in EC8 presents analytical criteria that is based on dynamic characteristics of structure, while ASCE 7-16 code has criteria based on drifts. This can lead in classifying same structure as torsionally regular or irregular.
- By classifying structure as torsionally sensitive in accordance with EC8 reduced behaviour factor must be applied, which significantly increases total seismic forces to be applied on structure (up to 100%) equally imposed on all elements not only elements on perimeter of structure. On the other hand, ASCE 7-16 prescribes increase of accidental eccentricity up to 300% for torsionally irregular structures and increase of seismic forces for 30% .

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38
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STEPGRAD
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ZOLLINGER LAMELLA VAULT OF EXISTING TIMBER HANGARS IN ŠIBENIK (CASE STUDY) – INITIAL CONDITION ASSESSMENT AND PRELIMINARY ANALYSIS OF GLOBAL STRUCTURAL FEATURES

Abstract

A preliminary condition assessment using non-destructive testing methods for determining material quality, has been carried out on three adjacent wooden hangars near Šibenik with the aim of exploring the possibilities of their repurposing. Through visual inspection and detailed geometric measurements, it has been verified that their unique structure embodies the original Zollinger lamella vault system in which the joint typology is decisive for both, the overarching structural analysis and the execution of the structure. In this paper, the results of conducted investigation, including the developed detailed geometric model are presented, and guidelines for future comprehensive research focusing on the influence of joint stiffness on global structural features are discussed, as well.

Keywords: timber, Zollinger lamella vault, on-site testing, results, guidelines for further analysis

ЗОЛИНГЕР МРЕЖАСТИ СВОД ДРВЕНИХ ХАНГАРА У ШИБЕНКУ (СТУДИЈА СЛУЧАЈА) – ПОЧЕТНА ОЦЈЕНА СТАЊА И ПРЕЛИМИНАРНА АНАЛИЗА КАРАКТЕРИСТИКА КОНСТРУКЦИЈЕ

Сажетак

За групу од три сусједна дрвена хангара код Шибеника извршена је прелиминарна процјена стања примјеном неразорhiх тестова за одређивање квалитета материјала, како би се испитале могућности њихове пренамјене. На основу визуелног прегледа и детаљних геометријских мјерења је потврђено да јединствена конструкција јест оригинални Золингеров ламелни свод у коме је типологија споја кључна како за цјелокупну анализу конструкције тако и за њено извођење. У овом раду су приказани резултати спроведених истраживања, укључујући израду детаљног геометријског модела и дискутоване су смјернице за будућа детаљна истраживања, са фокусом на утицај крутости спојева на глобалне карактеристике конструкције.

Кључне ријечи: Золингер дрвени свод, теренскi тестови, резултати, смјернице за анализу

1. INTRODUCTION

This work is the result of preliminary investigation work carried out on three hangars with the aim of condition assessment of the structural timber elements. Although there are five hangars of the same structure at this site only three hangars (Figure 1), are planned to be repurposed as an educational facility dedicated to undersea biodiversity and integrated into the continuation of the project „Tourism Valorisation of the St Anthony's Channel“. The hangars are located in Minerska Cove (in suburb of Šibenik), directly opposite the St Nicholas’ Fortress, which was inscribed on the UNESCO World Heritage List in 2017. Until the 1990s, the hangars were part of a large military complex of the former army, and since then they have been abandoned and heavily devastated. Although there is no project documentation or other evidence of the real age of the buildings, it is possible that they were built during the Second World War for the needs of German military units and served as ammunition warehouses even then.

Figure 1. Three adjacent hangars (left) located in Minerska Cove (right) [1, 2]

Figure 2. Timber hangars – typological characteristics of diamond grid structure [1, 2]

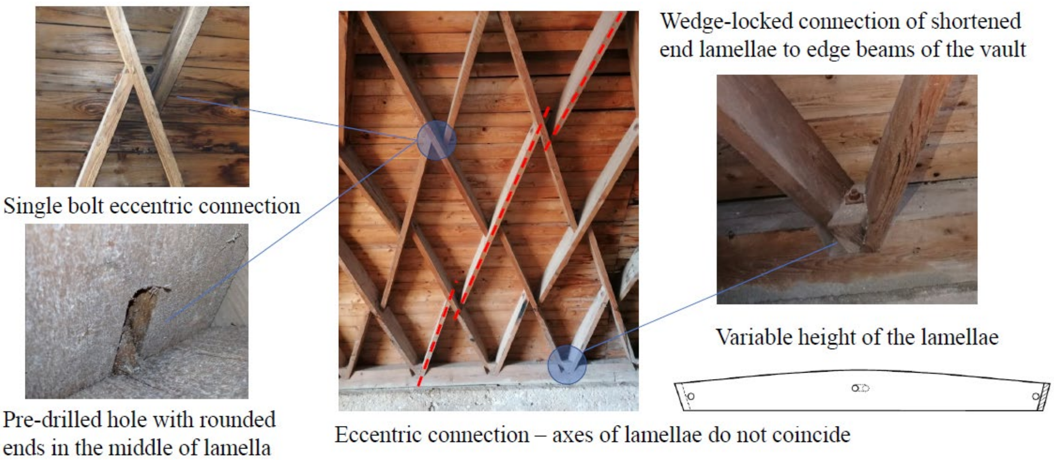
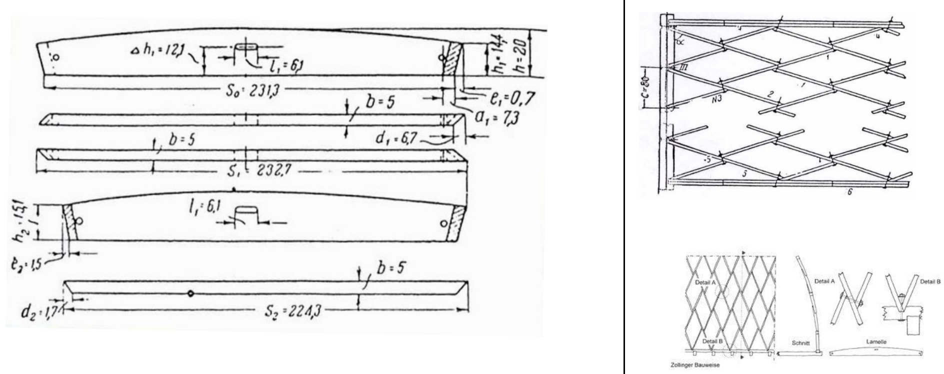


Figure 3. Lamellae and joints – similarity with Zollinger lamellar vault system [1, 2]

It is evident that the structures of all three hangars (Figures 2 and 3) embody the original Zollinger lamellar vault system patented in the 1920s (Figure 4). Faced with crisis in residential construction at the time, Friedrich Reinhart Baltasar Zollinger (appointed Town Building Advisor at Meresburg, Germany in 1918) developed the "Zollbau" method for flats and houses, based on the use of precast concrete panels and a timber sawing low form of gothic arched roof using "Zollbau Lamellen Dach" – system that he patented in 1921 [3, 4]. This work led him to develop the lamellar system for large spans (schools, churches and large halls), which he patented in 1923 and which became widely used for arched roofs in Europe and America. The basic idea of the structure comprised of a network of intersecting helices of thin planks (lamellae) of varying lengths forming diamond-shaped cells with bolted joints at their intersection [3, 5], as shown in Figure 4.



Lamella's shaping depends on the geometry of vault and joint

Vault floor plan and details

Figure 4. Original Zollinger system of lamellar vault [6]

The conducted preliminary investigation work and the resulting report on the current state and timber members quality are the usual starting points for further actions - a detailed condition assessment of the existing structure as a basis for proposals for renovation measures or removal and replacement with a new one (Figure 5). As the analysed hangars are not under the protection as heritage objects, but the architectural value of their structure is recognised, the replacement option implies a facsimile of a similar typology that meets the current requirements for mechanical resistance and stability as well as fire resistance. Other necessary structural interventions must include the connection of the hangars to an external corridor and the integration of installations and equipment that meet reuse requirements. The investigation work included a visual inspection, detailed geometric measurements of the hangars and the structural elements available for inspection, and the implementation of non-destructive tests to determine the condition and quality of the timber lamellae.

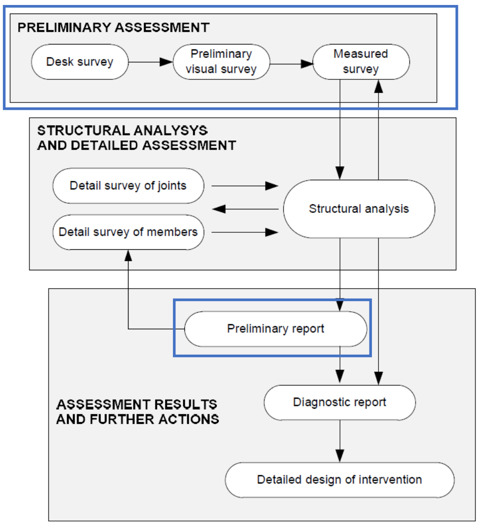


Figure 5. Different assessment phases and accompanying actions

This paper presents the results of the research work and the continuation of the research, which were prompted by the uniqueness of the structure's typology. A geometric model of the lamellar vault was created as the basis for the structural analysis and condition assessment of the existing structure. Since the type of joint - the eccentric bolt connection - is decisive for the evaluation of its behaviour, laboratory tests were also carried out to a limited extent on samples with approximately the same timber quality, connection geometry and bolts in order to check the suitability of the test settings and to gain an insight into the connection failure. A discussion of the preliminary laboratory test results is also part of this paper.

2. PRELIMINARY ASSESSMENT RESULTS

Investigation work on the hangars was carried out according to the valid regulations and standards as well as the existing guidelines for timber structures [7, 8, 9]. The activities did not include a global condition assessment of the structures nor proposals for interventions, and the prepared report will be a precursor to the preliminary design project for reuse (the structures are not architectural heritage) [2]. Only the condition of the structural elements was assessed and qualitative recommendations for further actions were given (Figure 5). The lack of project documentation was compensated by preparing a building blueprint (Figure 6). Although numerous and various methods and techniques are available on the market for the condition assessment of existing timber structures [10], the initial step is to select the appropriate methods for a specific case study (taking into account the parameters of the cost-benefit analysis). The final step is the implementation of the measured and estimated data into a model for structural analysis. The prepared preliminary report is therefore based on a visual inspection and detection of the botanical species and an inspection with the following measurements: geometry of the structure and structural elements, timber moisture content and dynamic modulus of elasticity. The selection of reference measurement points was based on a visual assessment – in each hangar, the elements with suspected and/or occurred significant degradations and available for inspection were selected (equipment for inspecting higher parts of the structure that would ensure the safety of the examiner was not available).

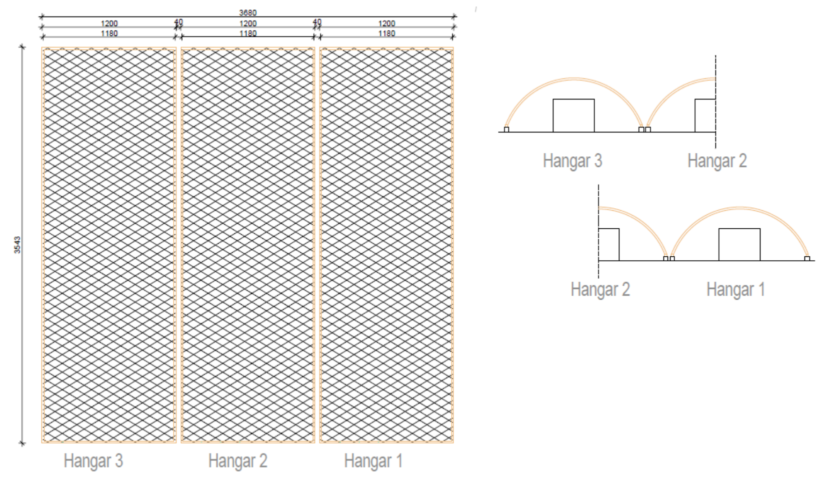


Figure 6. Timber hangars – floor plan and gables (view from sea side) [2]

2.2. VISUAL INSPECTION AND GEOMETRIC MEASUREMENT

A visual inspection confirmed the obvious consequences of years of neglect of the hangar. Apart from the fact that the covering made of curved asbestos-cement panels is not acceptable for any current use, localised damage to the covering (gaps in the areas of the panel joints) and the bitumen pasteboard has led to deterioration of the timber formwork and the visible consequences of its long-term wetting on significant areas of the vaults. Localised structural degradation of the edge base beams, which are anchored in low concrete walls, is also evident, particularly at the gables where the ends of the beams are protruding. Structural damage is also visible at the rarely accessible parts of the edge arches (they are two-part, bolted together from the lamellae and hidden by gable walls made of masonry blocks). The consequences of exposure to moisture are also visible on the timber lamellae of the vaults, with the discoloration (greying due to surface erosion) being more pronounced in the zones where they have also been exposed to the sun (the hangars have been without doors for years). Along the gables on the south-west side of Hangar 2 (the area at the base of the vault, along the gutter towards Hangar 3), the covering panels were completely destroyed, and the inevitable rotting zones of the timber structure were also detected there (lamellae, edge beams and arches). No significant mechanically induced damage to the lamellae were observed, although it does occur occasionally, albeit in negligible numbers. It can also be seen that some (e.g. along the entire length of one side of Hangar 3, the lower part of the vault) were caused by the removal (probably by pulling) of something when leaving the hangar. The consequences of the "work" of the connections are also visible in some areas – although the ends of the holes in the lamellae are rounded, damage around the holes was observed on a smaller number of lamellae in the lower sections of the vaults, regularly combined with degradation of the material due to wetting (areas with gaps between the covering boards). Longitudinal cracks on the connected lamellae (extending from the joint) are also observed. The lamellae are made of larch wood and are generally in good condition despite visible signs of ageing (the timber has hardened and undergone all rheological changes without significant dimensional changes) and aesthetic damage (discoloration). All anchors, bolts and washers have completely corroded. Results of the survey are shown on Figures 7, 8 and 9.

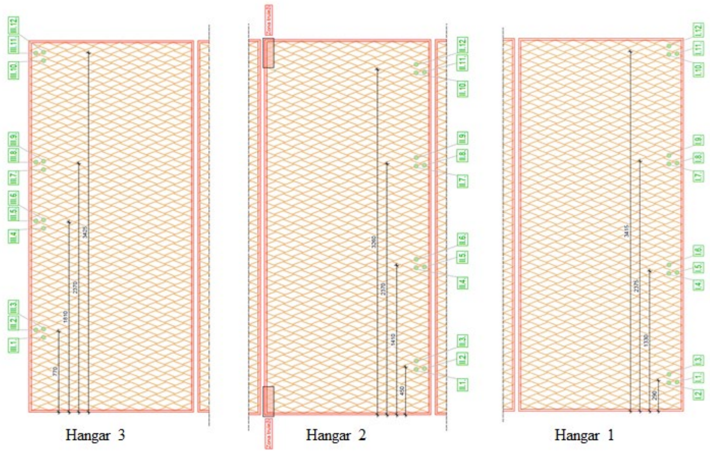
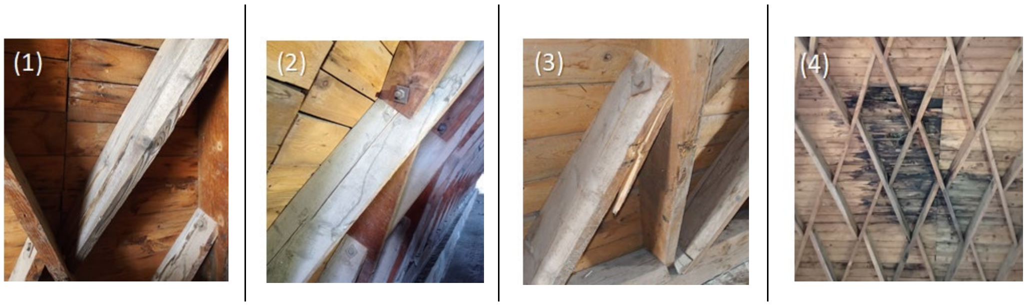


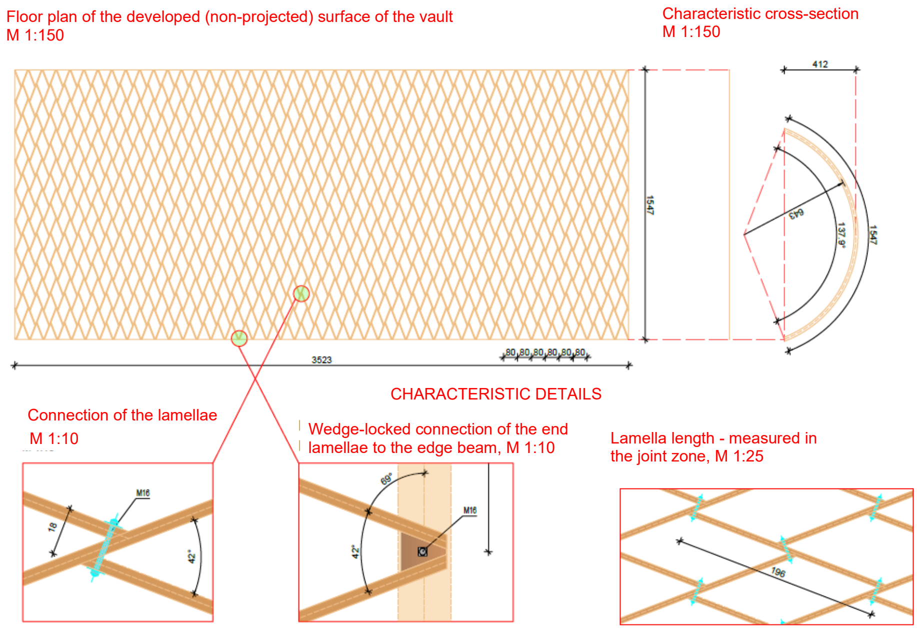
Figure 7. Probe positions and location of detected decay (dry rot) in Hangar 2 [2]



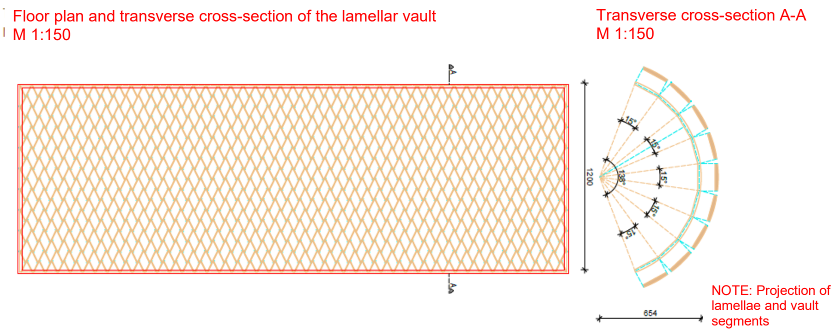
(1) Knots, grain irregularities, grey stains, (2) cracks, (3) mech. damages, (4) decay of the covering boards.

(5) Anchor corrosion and a piece of decayed edge beam (Hangar 2, zone of the northern gable), (6) damage in the vicinity of a hole (mechanical, but possible combined with decay – gap between covering planks is visible, (7) overall decay of timber (Hangar 2, zone of southern gable); Measured dimensions of lamellae (50 mm, width vary from 145 up to 225 mm), bolts and anchors diameter (M16).

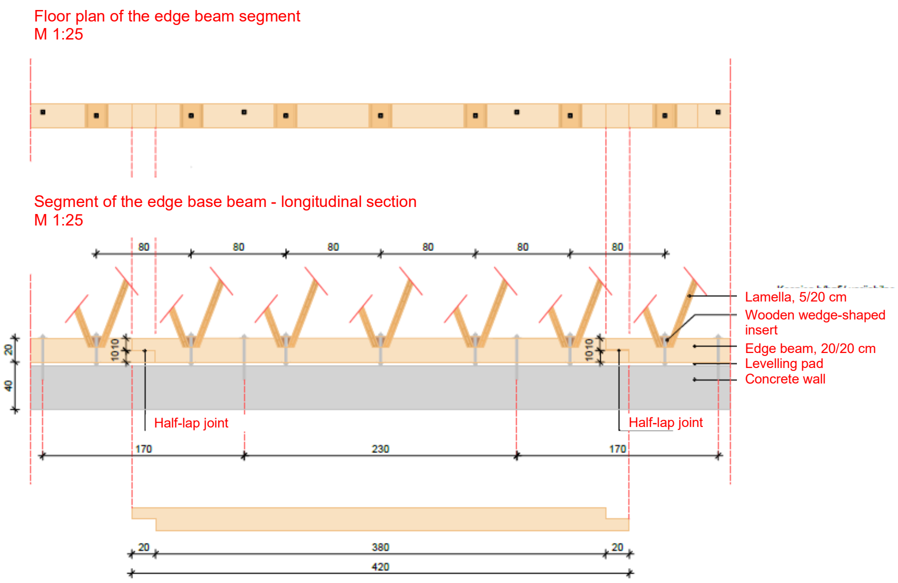
Figure 8. Observed damage types (brief overview) and measured dimensions [2]



Floor plan dimensions (diamond grid), height of the structure and essential geometric measured parameters



Projections: floor plan (grid: 44 x 0,8 m) and cross-section of the vault (division into 9 segments)



Edge beams – joining of adjacent segments in the queue and arrangement of anchoring in concrete wall

Figure 9. Drawings resulted from measured survey [2]

2.3. NDT SURVEY

The determination of load duration class and the service class according to the EN 1995-1-1:2004 standard [11] is based on the visual inspection of the timber structure and the measurement of the moisture content in the material. Together with the classification of the material into strength classes, in this way the necessary assumptions for the implementation of structural analysis are fulfilled. The following non-destructive tests (NDT) of the lamellae were carried out at the selected probe positions, which are shown in Figure 7. The probe positions included four characteristic areas in each hangar (two near the gables and two in the center), namely those for which the visual inspection indicated qualitatively different structural conditions. The measured average room temperature was 8.5°C and the relative humidity was 45.3%.

- Hygrometric test (using Brookhuis FMC / FME Moisture Meter for timber elements) – the purpose is to assess the influence of the moisture content of wood on its technical properties (the potential for the presence of rot) and to apply the results in the procedure of classification of lumber according to strength.
- Ultrasound test (using CBS-CBT SylvaTest TRIO portable ultrasonic device) – with indirect longitudinal test (dynamic MoE measurement), the lamellae were examined along parts of the length (outside joints zones and at the lower edge, at the same positions as for moisture content measurements), and with radial test, the presence of local rot was checked.

In the indirect longitudinal test, the paired probes were placed on the surface of the lamella (at a slight angle to the grains, much less than 30°). The probes are connected directly to the measuring devices with a cable required to transmit the electrical signal. In the measurement settings, the device was set to measure the speed of the signal, which then transmitted a low-frequency wave of 22 kHz to measure the maximum value of the energy of these waves. In this way, the speed of the signal propagation is related to the dynamic modulus of elasticity (MoE), while the attenuation of the signal energy is related to the characteristics of the material with which it is directly correlated (grain direction, lumps in wood, degradation zones in wood, etc.) [12, 13].

(1) Probe position labels,
(2) Ultrasound indirect longitudinal test,
(3) Ultrasound radial test,
(4) Moisture content measurements,
(5) Rot inspection

Figure 10. Material properties determination – ND tests and used devices [1, 2]

2.3.2. RESULTS OF NDT SURVEY

Based on the conducted hygrometric tests on the equilibrium moisture content of wood, which varies between 12.4% and 13.8% for Hangar 1, between 12.0% and 14.8% for Hangar 2, and between 12.4% to 13.4 % for Hangar 3 (depending on the probe position, where three measurement were made for each probe) it can be concluded that the average measured values are 13.2% for Hangar 1 and Hangar 3, and 12.9% for Hangar 2. As the equilibrium moisture content in the wood does not exceed 20%, it may be considered that the existing structure meets the requirements for service class

2. In Table 1, average results of the indirect longitudinal ultrasonic measurement are presented for Hangar 1, obtained for four characteristic probe groups (each group contains three probes).

Table 1. Average measured values and obtained results for four characteristic groups

Hangar 1 Groups	Sylvatest-Trio / stress wave NDT				Sylvius software – results			
	L	t_i	v_i	Peak energy	v	$E_{dyn,0}$	MoR	Assigned strength class
	(mm)	(μs)	(μs/m)	(mV)	(μs/m)	(MPa)	(MPa)	
I-1	1450	278	2599	18	5216	12892	35	C27
	730	137	2658	27	5315	13391	37	C30
I-2	1440	259	2776	25	5560	14624	42	C35
I-3	1380	241	2857	78	5726	15461	45	C40
I-4	1430	249	2864	35	5743	15546	46	C40
Used symbols: L – measured length; t_i – time of flight; v_i – measured speed; v – calculated speed (considering influence of measured moisture content), $E_{dyn,0}$ – dynamic modulus of elasticity (MoE, parallel to grains), MoR – modulus of rupture Note: Sylvius is an in-field data acquisition software for Sylvatest-Trio measurements (see also Figure 10)								

For the indirect longitudinal stress wave test (using Time of Flight ND technique), the acquisition software provides data on the dynamic modulus of elasticity and the estimated bending strength on the basis of the data on the measured moisture content and peak energy as well as the botanical type of wood (larch) and assigns a strength class. The average measured values of the dynamic modulus of elasticity $E_{dyn,0}$ are: 14.70 GPa (Hangar 1), 14.63 GPa (Hangar 2) and 15.38 GPa (Hangar 3). The values of the static modulus of elasticity, $E_{0,mean}$ were preliminarily estimated as 10% of the reduced $E_{dyn,0}$ value and assigned to strength classes. The mean density values, ρ_{mean}, calculated from the dynamic modulus of elasticity and the squared values of the wave speeds (v) correspond to the assigned strength classes according to EN 338:2016 [14]. Table 2 lists the calculated values of the material properties for the hangars and the assigned strength classes.

Table 2. Mean values for material properties and assigned strength classes

Hangar 1			Hangar 2			Hangar 3		
$E_{0,mean}$	ρ_{mean}	Strength class	$E_{0,mean}$	ρ_{mean}	Strength class	$E_{0,mean}$	ρ_{mean}	Strength class
(GPa)	(kg/m^3)		(GPa)	(kg/m^3)		(GPa)	(kg/m^3)	
Average mean values								
13.23	472.4	C35	13.19	472.5	C35	13.83	470.1	C35
Corrected mean values (standardized to equilibrium moisture content, MC = 12%)								
13.17	472.5	C35	12.86	472.7	C30	13.69	470.5	C35

2.4. DISCUSSION ON CONDUCTED INITIAL ASSESMENT AND CONCLUSIONS

On the basis of the conducted preliminary investigation work and the obtained results, it is clear that further measures can only be taken in two directions: to carry out a detailed condition assessment of the structure with a proposal for restoration measures, or to remove and replace it with a facsimile of similar typology and geometry. From the point of view of today's safety and usage requirements, as well as the requirements for reuse, the existing structure has obvious deficiencies:

- Connections with a single fastener are not considered load-bearing, and the connection made with a single bolt (note that they are all corroded) can have a very negative impact on the load-bearing capacity and flexibility of the entire structure (especially in the case of replacing existing solid gables with softer structures).
- The thickness of the lamellae (50 mm) is potentially questionable from the point of view of fire resistance (any increase in the thickness of the lamellae necessarily changes the geometry of the mesh and the way the lamellae are connected together).

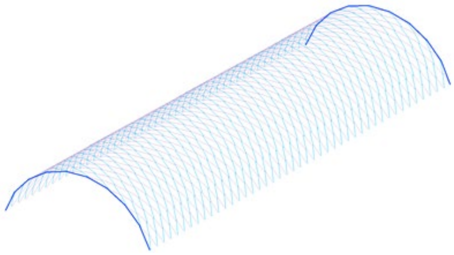
In the context of planning any renovation, a cost-benefit analysis (including the time) is certainly a key decision parameter, and a detailed assessment of the structure with the implementation of a static analysis with built-in geometric parameters and material properties must precede the proposal of any procedure. Although a detailed assessment of the structure was not planned at this stage (nor possible considering future architectural interventions related to repurposing), the attractiveness of the structure and the fact that it is still "standing" despite the identified defects, age and neglect, encouraged us to continue the research.

3. RESEARCH CONTINUATION AND PRELIMINARY RESULTS

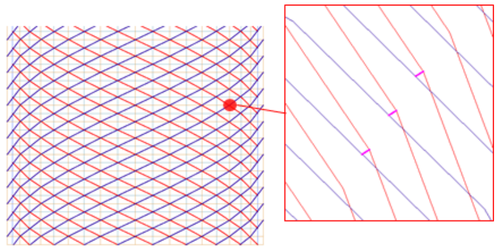
An additional reason is that over the last decade scientific and professional interest in grid timber structures has increased, as can be seen from the published works [15, 16, 17, 18]. The motivation for continuing this research also lies in the fact that the typology of the connection influences the geometry of the lamellae and the entire vault as well as the way it is executed. At the same time, the failure mechanisms of this type of connection have been studied little or not at all, although it is basically innovative and guarantees a simple and fast execution of the structure.

3.1. GEOMETRIC MODEL OF EXISTING STRUCTURE

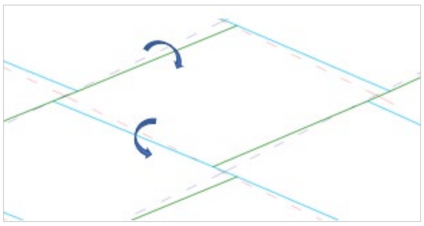
Although the shape of the vault exhibits a relatively simple geometric form, beneath it lies a diamond grid constituted by numerous straight elements with complex geometric relations. As the vault contains nine lamellas per arch, the curves are more flowing and the lamellas themselves look elegant and lithe. Structure geometry can also be considered as an assembly composed of two sets of oppositely oriented arches (Figure 11.1) that can be justified by insight into distribution of internal forces along the lamellae. Arches of each group appear iteratively at regular intervals along the longer side of the building ensuring global structural stability by mutually supporting each other. Furthermore, each arch consists of several individual elements (lamellae) whose axes do not coincide which is essential to enable a single bolt connection. Adjacent lamellae are connected at the intersection of two arches. The connection between the two lamellae does not occur at the same position as the connection between oppositely directed lamella elements; but passes through the centre of opposite lamella. An alternate position of connections is achieved by varying the length of the first lamellae in the group – one group of arches begins with a full-length lamella while the opposing arch starts with a half-length lamella. A favourable consequence of such a configuration is that the connection between lamellae, which could be regarded as a "weak point" of the structure, is supported by a relatively rigid point ensured by the lamellae from the opposite direction. Individual arch therefore follows a segment of the spatial curve – cylindrical helix (Figure 11.2), providing the uniform length of all internal lamellae. Furthermore, to enable an eccentric connection of the elements, each lamella is rotated around its vertical axis at its midpoint (Figure 11.3) [15]. Such spatial configuration also necessitates specially shaped element ends, which must be cut at specific angles to obtain compatible inclination. The exact geometry within the connection area has been extensively explored in the literature [19] as well as the curvature of the lamella upper edge which is necessary to obtain a final smooth surface of a barrel vault. Before recreating the existing structure geometry, a few key geometric parameters have to be accurately measured, as it is shown on Figures 6, 7 and 9. There is a strict mathematical correlation between such parameters and measurement inaccuracy that could lead to an incorrect model with variable lamella length or angles.

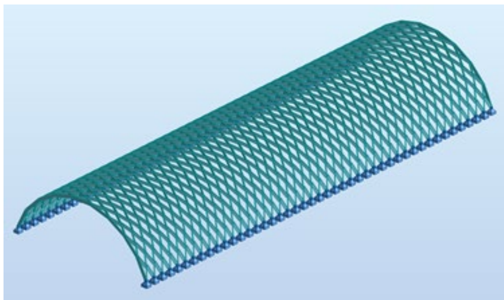


1. Reconstructed geometry of Hangars



2. Imaginary axes (lines that connect supports) around which real elements rotate)





3. ECCENTRIC CONNECTION AND LAMELLAE ROTATION (LEFT) 4. INITIAL GEOMETRIC MODEL (RIGHT)

Figure 11. Reconstructed geometry of Hangars and created initial geometric model

3.2. INITIAL EXPERIMENTAL RESEARCH ON JOINT STIFFNESS

Two sets of Zollinger connections, each containing 8 samples, were planned to be experimentally investigated at the Laboratory for Structures at the Faculty of Civil Engineering, University of Rijeka. Connections were constructed of spruce lumber and consisted of two 0.5 m long lamellae having cross-sectional dimensions 50/150 mm and one 1.0 m long lamella having cross-sectional dimensions 50/220 mm. Lamellae were connected with a threaded rod/M16 bolt and steel square washers. The first phase of testing was planned to be conducted on the set containing specimens made of brand-new timber, whereas the second phase was planned to be conducted on the set containing specimens made of old spruce planks previously used for another purpose (lumber without structurally unacceptable dimensional and other anomalies). The ends of the shorter lamellae were cut at an inclined angle of 45°, while the geometry and the position of the holes for the bolt correspond to the original configuration (Figure 4). It was planned to investigate four samples with covering boards and four samples without boards in every test group. Spruce boards with cross-sectional dimensions 24/150 mm and a length of 1.0 m were intended to be nailed to lamellae as such conditions represent the actual structure state. Visual investigation and ND tests were conducted on timber material to determine the mechanical properties (Figure 12). The density obtained from the measured dimensions and mass varies in the range 455.5 – 482.7 kg/m^3 for the new lumber and 449.9 – 475.3 kg/m^3 for the old one. Dynamic Modulus of Elasticity was defined within the range 14.8 – 16.45 GPa for the new lumber and 13.7 – 16.6 GPa for the old one. Finally, strength classes were assigned to the investigated lumber: C35 – C45 for the new one and C30 – C40 for the old one. It was concluded that strength classes, together with other material properties, correspond to the timber material of investigated Hangars.

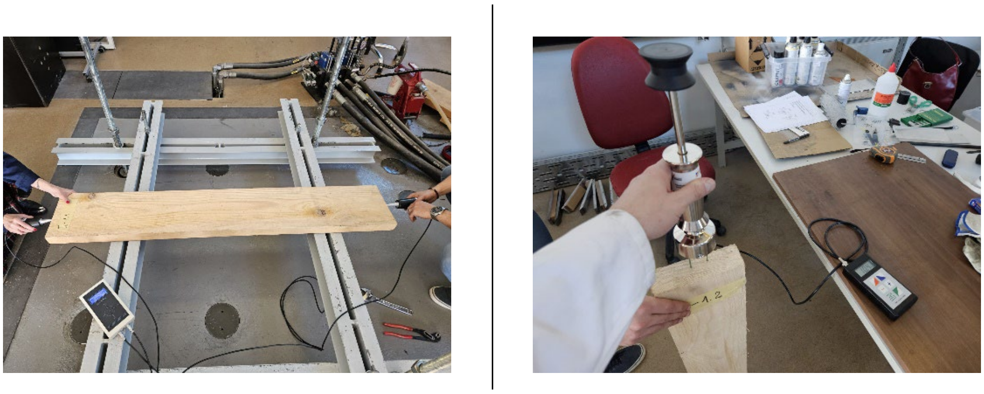


Figure 12. Material properties determination – planks used for manufacturing specimens

Although the comprehensive destructive laboratory tests of the Zollinger connection were planned, only a preliminary test conducted on two additional samples is shown in this paper. During the following detailed testing, displacements will be measured using LVDT at positions critical for understanding behaviour and determining the stiffness of the connection, while the displacement field will be also measured using digital photogrammetry. The purposes of the preliminary testing are defined as follows: to determine the suitability of the test setups, to reassess assumptions about force transfer among the lamellae and connection behaviour, and to examine failure mechanisms. The preliminary testing of additional samples was conducted within a steel frame with the frame sides composed of double-welded UNP profiles, whereas the frame elements were connected by bolts. Furthermore, the frame was secured to the reaction floor using threaded rods with a diameter of 32 mm. Force was applied via a cylinder press using a manual pump with a capacity of 100 kN (type RC 101), as it is shown on Figure 13. During the testing of preliminary samples, deformation of the steel frame was observed, which occurred due to an underestimated connection capacity. Therefore, in the continuation of the planned experimental research, it will be necessary to reconsider the test setup and equipment.

The failure force was assumed based on an experiment available in the literature, where the samples were scaled (1:2) [18]. The underestimated capacity suggests nonlinear and complex relationships between the dimensions of the components in the connection and the failure force. The connection failure occurred during a repeated attempt, and the failure pattern resembles the damage observed in the structure (Figure 8) – crushing around the hole combined with shear failure and a longitudinal cracking extending from the hole (Figure 14).

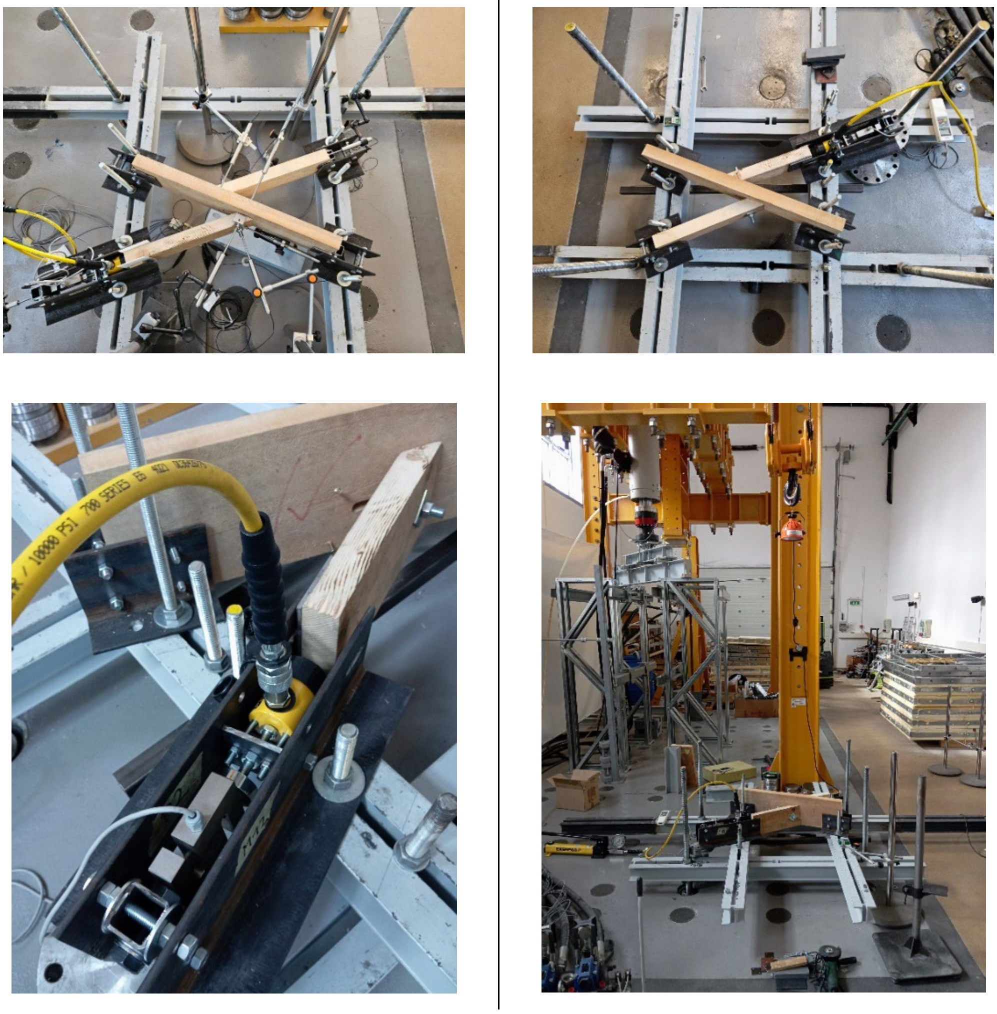


Figure 13. Setup of preliminary destructive test and equipment

Figure 14. Observed types of failures

4. FINAL DISCUSSION AND CONCLUSIONS

The global objective of sustainable development has been greatly directed toward the preservation of existing structures. Therefore, condition assessment and reconstruction of existing timber structures have been gaining importance in recent times. In this paper, some of the non-destructive and semi-destructive methods frequently used for timber structures are pointed out as promising methods for a quantitative description of the current condition of timber members and as a prerequisite for any further action and for conducting a detailed condition assessment of the structure. The results and conclusions derived from the preliminary condition assessment of wooden material of Hangars are presented and discussed in chapter 2.3, and guidelines for further research are given. They are focused on implementation of all key parameters - geometry of the structure and structural members and material properties, as well. Considering the uniqueness of the architecture and structural features of structures which were investigated in this case study, special attention was given to its geometry and joint typology. Prepared preliminary geometric model is presented and discussed, as well as the results of conducted experimental research on joint stiffness. The expected objectives of the experimental research, which is planned to be continued on a larger scale, are to provide better understanding of the failure mechanisms of the connection, to determine the stiffness properties of the connection and to incorporate them appropriately into the structural model, and to examine whether the covering planks (an integral part of the original vault typology) has an influence on the stiffness of the structure and how it can be simulated in the model.

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39
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OPTIMIZATION OF PURLINS CROSS-SECTION EXPOSED TO FIRE

Abstract

In practice, consideration of fire protection for structural elements mainly occurs after the adopted dimensions of sections. However, this procedure leads to not the most cost-effective solution in general. To find the optimal solution, it is necessary to apply one of the optimization methods. The presented optimization of purlins RHS cross-section is performed with nonlinear programming available in widely used program Excel. The objective function is defined as producing the purlin at a minimal price, considering the price of steel, work, and fire-resistant paint. Limits are introduced to ensure the cross-section satisfies the ultimate limit state for permanent and transient load situations, as well as in case of fire. Besides the ultimate limit states, the limits are defined for serviceability limit states and for cross-sectional geometry. Optimization analysis for different ISO 834 fire durations is followed by a result comparison. It provides an overview of cross-sectional parameters that most influence the bearing capacity in case of fire. It is concluded that by increasing the exposure time to fire, the optimal solution becomes a section with a smaller perimeter, larger surface area, and a thicker layer of fire-resistant coating.

Keywords: fire safety analysis, ISO 834, optimization, nonlinear programming

ОПТИМИЗАЦИЈА ПОПРЕЧНОГ ПРЕСЈЕКА РОЖЊАЧЕ ИЗЛОЖЕНЕ ПОЖАРУ

Сажетак

Разматрање заштите од пожара конструктивних елемената у пракси углавном долази након усвојених димензија пресјека. Међутим то у већини случајева није најисплативије рјешење. Да би се пронашло оптимално рјешење, потребно је примијенити неку од метода оптимизације. Приказана је оптимизација RHS попречног пресјека рожњаче употребом нелинеарног програмирања. Функција циља је дефинисана тако да се добије најмања цијена рожњаче, узимајући у обзир цијену челика, рада и противпожарног премаза. Ограничења су постављена тако да осигурају испуњење носивости при сталним и повременим прорачунским ситуацијама, као и при дејству пожара. Поред услова носивости, постављена су ограничења за гранично стање употребљивости и за геометрију попречног пресјека. Након извршених прорачуна, резултати за различито трајање стандардног ISO 834 пожара су упоређени. Поређење резултата оптимизације нам даје увид у карактеристике пресјека које највише утичу на пораст његове носивости при дејству пожара. На основу резултата анализе, закључено је да повећавајући вријеме изложености пожару, оптимално рјешење постаје пресјек који има мањи обим, а већу површину и дебљи слој противпожарног премаза.

Кључне ријечи: противпожарна анализа, ISO 834, оптимизација, нелинеарно програмирање

1. INTRODUCTION

In structure dimensioning, in most cases, the bearing capacities in permanent, transient, and seismic situations are considered. Meanwhile, the bearing capacity in a fire situation is given less importance. It is usually, in the case of steel structures, provided with fire-resisting materials [1]. In the case that necessary bearing capacity cannot be achieved by the chosen material, a cross-section with higher performances will be chosen [2, 3, 4].

To get the optimal cross-section, it is necessary to consider the bearing capacity in fire design situations in the process of dimensioning. To show the possibilities of an optimization algorithm applied to a structure that is exposed to fire, a brief review of previous studies follows. The study by Bendetti et al. [5] shows the optimization algorithm for steel I-section columns with and without fire-resistant coating. An optimization of steel moment frames is presented in a paper by Jarman et al. [6]. Hopkih et al [7] optimized the cross-section of a steel beam. The increase in constraints that must be satisfied during design, makes the optimization problem significantly more complex. An example is shown in a work by Albero et al. [8], who, in the process of finding the optimal solution, varied the size and shape of openings in hollow prestressed concrete slabs exposed to fire. A paper by Cauteren et al. [9] analyses the optimization of hybrid concrete-timber trusses. Besides the bearing capacity and serviceability in permanent and transient situations, bearing capacity in case of fire was analyzed, as well as their impact on the environment. Thai et al. [10] optimized a cross-section of composite CLT and concrete slabs, introducing the human-induced vibration check into the analysis, besides the usual constraints.

Previous studies, such as the work by Bendetti et al. [5] simplify the thermal analysis by disregarding the variation of material properties with temperature. Some studies present an optimization algorithm is not available in publicly available software [8, 9].

This paper shows a solution to an optimization problem, solved in Excel – widely used program from Microsoft, for a purlin of steel haul protected with a fire-resistant coating, which, with minor adjustments, can be used for other structural elements.

2. DESCRIPTION OF THE STRUCTURE AND ACTING LOADS NTRODUCTION

The considered hall structure is formed with main bearing frames at an intermediate distance of 5 m. The intermediate distances of purlins, which are bridging this span, are 2.5 m. Purlins static system is a continuous beam. The middle span will be analyzed. An insulated panel with 80 mm thickness is adopted as the roof cover. The roof slope is 6°, which classifies this roof as a duo pitch for wind and snow load analysis. The commonly applied rectangular hollow section (RHS) is adopted for the purlin (Figure 1).

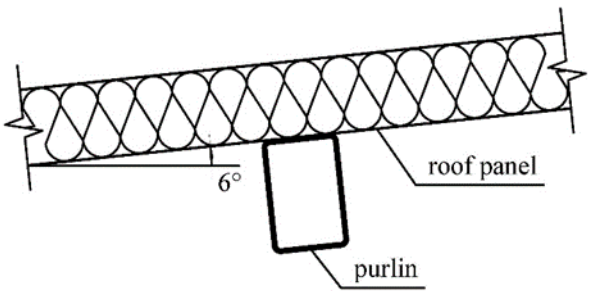

Figure 1. Analyzed purlin

The purlin is protected from heating with fire-resisting paint, that, when exposed to elevated temperatures, expands and forms an insulating layer around the structure. Taking into account that the insulated panels are placed on the top side of the purlin, that side of the cross-section is considered protected from heating.

The purlins are, besides their self-weight and panel weight, loaded with snow and wind. The following values are obtained from the load analysis:

- panels weight........................0.12 kN/m^2
- installations...........................0.30 kN/m^2
- snow......................................0.80 kN/m^2

- wind (pressure).....................0.30 kN/m^2
- wind (suction)......................-0.60 kN/m^2

Purlin self-weight is considered with its accurate value during optimization analysis.

3. CONSTRAINS

The conditions that must be fulfilled in optimization analysis are called constraints since they prevent the objective functions from having smaller or greater value. Depending on the nature of the constraint, it can be written in the form of an equality or an inequality relation.

Constraints that must be fulfilled in this analysis are the bearing capacity in permanent and transient situations, the serviceability limit state, the bearing capacity in a fire situation, and additional geometrical constraints.

3.1. BEARING CAPACITY IN PERMANENT AND TRANSIENT SITUATIONS

Before checking section bearing capacity, it is necessary to perform its classification according to SRPS EN 1993-1-1 [11]. Depending on the cross-sectional class, calculation can be performed by plasticity or elasticity theory. The bearing capacity of sections with classes 1 and 2 can be determined by the plasticity theory, while for sections with classes 3 and 4, the elasticity theory is applied. The bearing capacity of the cross-section of class 4 is performed with the effective cross-section.

The bearing capacity criterion in case of fire is very restrictive for the cross-sections with class 4. For that reason, these sections are not considered optimal, and therefore, are excluded from the study.

3.1.1. BEARING CAPACITY DETERMINATION BY PLASTICITY THEORY

When plasticity theory is used, the bearing capacity check is performed following SRPS EN 1993-1-1. The shear bearing capacity is checked per section 6.2.6 for both directions in the following way:

$$\frac{V_{Ed,\mathrm{y}}}{V_{\mathrm{pl,y,Rd}}} \leq 1.0 \tag{1}$$

$$\frac{V_{Ed,\mathrm{z}}}{V_{\mathrm{pl,z,Rd}}} \leq 1.0 \tag{2}$$

where:
V_{Ed} – shear force
$V_{\mathrm{pl,Rd}}$ – shear force resistance
The bending capacity check is done according to section 6.2.9:

$$\frac{\mathrm{M_{Ed,y}}}{\mathrm{M_{pl,y,Rd}}} + \frac{\mathrm{M_{Ed,z}}}{\mathrm{M_{pl,z,Rd}}} \leq 1.0 \tag{3}$$

where:
$\mathrm{M_{Ed}}$ – bending moment
$\mathrm{M}_{pl,\mathrm{Rd}}$ – bending moment resistance
In the case that cross-sectional utilization for shearing is greater than 0.50, it is necessary to consider its interaction with the bending for capacity check (section 6.2.8).

3.1.2. BEARING CAPACITY DETERMINATION BY ELASTICITY THEORY

When the theory of elasticity is used, the shear capacity can be checked according to section 6.2.6. and expressions:

$$\tau_{Ed,\mathrm{y}} \leq \frac{f_y/\sqrt{3}}{\gamma_{M0}} \tag{4}$$

$$\tau_{Ed,\mathrm{z}} \leq \frac{f_y/\sqrt{3}}{\gamma_{M0}} \tag{5}$$

where:
τ_{Ed} – shear stress
f_y – yield strength of steel
γ_{M0} – partial safety factor

The bending bearing capacity check, according to the theory of elasticity, is performed per section 6.2.9 and the following expression needs to be satisfied:

$$\sigma_{x,\mathrm{Ed}} \leq \frac{f_y}{\gamma_{M0}} \tag{6}$$

where:
$\sigma_{x,\mathrm{Ed}}$ – normal stress from bending
In the case that shear bearing capacity, calculated by plasticity theory, is greater than 0.50, it is necessary to consider shear and bending interaction in the bearing capacity check per section 6.2.8.

3.2. SERVICEABILITY LIMIT STATE

A serviceability limit state check is necessary to control deflections in the middle of the purlins span. Deflection check, for continuous beam, can be performed by expression:

$$f = \sqrt{\left(\frac{q_{z,k}L^4}{384EI_y}\right)^2 + \left(\frac{q_{y,k}L^4}{384EI_z}\right)^2} \leq f_{limit} \tag{7}$$

where:
$q_{z,k}$ – load in z-axis direction, calculated for characteristic combination
$q_{y,k}$ – load in y-axis direction, calculated for characteristic combination
I_y – moment of inertia about y-axis
I_z – moment of inertia about z-axis
L – purlins span
E – elasticity modulus of steel
I – moment of inertia
f_{limit} – limit deflection
The limit deflection for purlins per SRPS EN 1993-1-1/NA [12] is L/200.

3.3. BEARING CAPACITY IN A FIRE SITUATION

A bearing capacity check in a fire situation is performed according to SRPS EN 1993-1-2 [13]. Expression for critical temperature $\theta_{a,cr}$ evaluation is given in section 4.2.4.:

$$\theta_{a,cr} = 39.19\, ln\left(\frac{1}{0.9674\mu_0^{3.833}} - 1\right) + 482 \tag{8}$$

where:
μ_0 – cross-sectional utilization for characteristic load combination for time t = 0
The cross-sectional utilization is calculated according to expressions provided in section 3.1. with rigorous criteria for cross-sectional classification provided in section 4.2.2.
The temperature of the insulated steel cross section $\Delta\theta_{a,t}$ is calculated according to section 4.2.5.2. and the expression:

$$\Delta\theta_{a,t} = \frac{\lambda_p A_p/V}{d_p c_a \rho_a}\frac{(\theta_{g,t}-\theta_{a,t})}{(1+\phi/3)}\Delta t - (e^{\frac{\phi}{10}} - 1)\Delta\theta_{g,t} \tag{9}$$

$$\phi = \frac{c_p \rho_p}{c_a \rho_a} d_p A_p/V \tag{10}$$

where:
A_p/V – cross-sectional factor
c_a – specific heat of steel
c_p – specific heat of insulating material
d_p – thickness of insulating material
Δt – time interval
$\theta_{g,t}$ – gas temperature
$\Delta\theta_{g,t}$ – increase in gas temperature
λ_p – thermal conductivity of insulating material
ρ_a – density of steel

ρ_p – density of insulating material

Intumescent coating significantly expands in a fire situation and in that way form the insulating layer around the protected element. The size of expansion mostly depends on the applied thickness of the intumescent coating. Modeling of intumescent coating with changing volume is complex and, for that reason, an approach is proposed for using the layer of initial thickness with equivalent thermal characteristics [14, 15, 16]:

$$c_p = 1200\, J/kgK \tag{11}$$

$$\lambda_p = -0.56 \times 10^2 + 11.8 d_p + 1.4 V/A_p \tag{12}$$

$$\rho_p = 200\, kg/m^3 \tag{13}$$

Gas temperature can be evaluated for standard ISO 834 fire per SRPS EN 1991-1-2 [17] and expression:

$$\theta_{g,t} = 20 + 345 \log(8t + 1) \tag{14}$$

where:

t – time

For the bearing capacity to be satisfactory it is necessary to satisfy the following condition:

$$\theta_{a,t} \le \theta_{a,cr} \tag{15}$$

3.4. GEOMETRICAL CONSTRAINS

In order to exclude the cross-sections of class 4, it is necessary to limit the slenderness of cross-sectional parts. This is done following the cross-sectional classifications in fire situation. Constraints for width (b) and height (h) are formulated as a function of sectional thickness (t):

$$\frac{b-4t}{t} \le 38\varepsilon \tag{16}$$

$$\frac{h-4t}{t} \le 38\varepsilon \tag{17}$$

Coefficient ε can be calculated from the yield stress (f_y) according to section 4.2.2. and expression:

$$\varepsilon = 0.85\sqrt{235/f_y} \tag{18}$$

Besides constraints that are introduced for the cross-sectional class, the following constraints that limit the relative size of width and height are adopted:

$$\frac{h}{b} \le 3 \tag{19}$$

4. OBJECTIVE FUNCTION

The objective function compares possible solutions that are calculated in iterations. Based on that comparison it is determined if the solution is optimal.

For the objective function, the price of purlins' one-meter length is adopted. The following prices are used in the calculation:

- steel with a montage: 2.5 $€/kg$
- intumescence paint: 85 $\frac{€}{2.5l}$
- paint application: 2 $€/m^2$

The adopted consumption of intumescence paint is 1.4 l/m^2 for a 1 mm layer.

Based on those prices and consumption, the objective function is specified as:

$$f_{min} = 2.5 V \rho_a + \left(1.4 \frac{85}{2.5} d_p + 2\right) A_p \tag{20}$$

where:

V – purlins volume

A_p – purlins area

5. OPTIMIZATION METHOD

The chosen method for optimization is a generalized reduced gradient which is implemented in Excel [18]. Its predecessor is the method of reduced gradient [19], in which constraints can only be defined in the form of equality. Extension of this method for inequality constraints is achieved through slack variables, similar to the simplex method in linear programming. The algorithm begins with the adoption of the initial solution $\vec{x}^{(0)}$ and the termination parameter $\varepsilon(\rightarrow 0^{+})$ that defines the acceptable error of the result. The next step is to transform all inequality constraints (type g) to equality (type h) with an introduction of slack variables. Values of y_i are calculated for all variables $x_i, i = 1,2,3 \dots N$, and they represent the relative distance of the current solution from the limits in which it can be located:

$$y_i = \frac{min\{x_i - x_i{}^L, x_i{}^U - x_i\}}{x_i{}^U - x_i{}^L} \tag{21}$$

where:
$x_i{}^L$ – lower limit of feasible solutions x_i
$x_i{}^U$ – upper limit of feasible solutions x_i
Evaluation of variables y_i is followed by their sorting in a descending order. Variables x_i are chosen for basic variables if they have a higher y_i value. The basic variable quantity is equal to the number of equality constraints. The rest of x_i variables are non-basic and their values are determined from constraints, i.e., they are equal to the slack variables. The gradients of the objective function are now determined. Following that the reduced gradient of the objective function $\nabla\tilde{f}(\vec{x}^{(t)})$ is evaluated as:

$$\nabla\tilde{f}(\vec{x}^{(t)}) = \nabla\bar{f}(\vec{x}^{(t)}) - \nabla\hat{f}(\vec{x}^{(t)})J^{-1}.C \tag{22}$$

where:
$\nabla\bar{f}(\vec{x}^{(t)})$ – component of objective function gradient that is composed of basic variables
$\nabla\hat{f}(\vec{x}^{(t)})$ – component of objective function gradient that is composed of non-basic variables
J – component of constraints gradient that is composed of basic variables
C – component of constraints gradient that is composed of non-basic variables
It is checked whether the condition for stopping the calculation is fulfilled, i.e., whether the current solution is close enough to the optimal one:

$$\left\|\nabla\tilde{f}(\vec{x}^{(t)})\right\| < \varepsilon \tag{23}$$

If the previous condition is satisfied, the current solution is considered as final. In case the condition is not met, the direction in which the solution is sought in the next iteration is determined. It consists of two components, the first consisting of non-basic variables, and the second of basic ones. The component with non-basic variables $\bar{d}$ can be determined in the following way:

$$\bar{d} = \begin{cases} 0, if\ x_i = x_i{}^L \text{ и } \left(\nabla\tilde{f}\right)_i > 0 \\ 0, if\ x_i = x_i{}^U \text{ и } \left(\nabla\tilde{f}\right)_i < 0 \\ \quad -\left(\nabla\tilde{f}\right)_i, otherwise \end{cases} \tag{24}$$

while we determine the component of basic variables $\hat{d}$ according to the expression:

$$\hat{d} = -J^{-1}C\bar{d} \tag{25}$$

After that, the parameter $\alpha^{(t)}$ is determined, for which the objective function in the form $f(x^t + \alpha^{(t)}d)$ reaches a minimum. This parameter dictates how far one goes in the direction of d in which the solution is sought for the next iteration. The solution for the next iteration is adopted in the form:

$$x^{(t+1)} = x^t + \alpha^{(t)}d \tag{26}$$

The counter indicates that the iteration of the algorithm is increased by one, and the process returns to the beginning:

$$t = t + 1 \tag{26}$$

The method's limitation lies in the fact that the gradient of the function equals zero not only at global minimum, but also at local minimums, making the solution reliant on the initial solution (Figure 2).

To avoid the problem of local minimum, a set of initial solutions is adopted for variable values. The initial solutions are adopted randomly within predefined domains, ensuring the highest degree of exploration of the space of possible solutions and the greatest chance of reaching the global minimum. Depending on the analyzed problem, i.e., the number of local minimum that exist, it is necessary to adopt a different quantity of initial solutions. A larger number of initial solutions significantly extends the calculation time, so it is essential to conduct a sensitivity analysis of the final solution based on the adopted number of initial solutions. This has been done in this study, and it has been concluded that, for the analyzed optimization problem, it can be confidently assumed that reaching the global minimum is achievable with one hundred initial solutions.

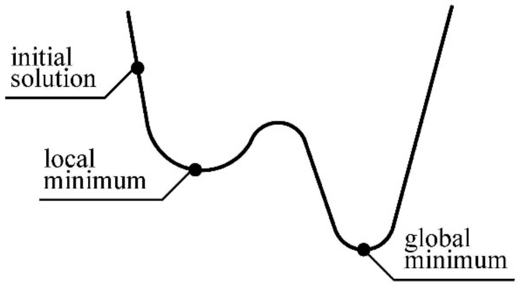

Figure 2. Local minimum problem

6. RESULT COMPARISON

The calculation is carried out for situations without fire and for standard fire durations of 30, 60, 90, and 120 minutes. In the determination of optimal solution, values are varied for: width, height, and thickness of the cross-section, as well as thickness of intumescence paint. The optimization results are shown in Table 1.

Based on the results it can be concluded that for the greater fire duration, a thicker layer of intumescence paint, a thicker cross-section, and a smaller cross-sectional factor are necessary. The thicker cross-section is needed because the thickness limit of intumescence paint, which is cheaper than steel, is achieved and because the thicker cross-section is heating slower. Because of the requirement for a thicker cross-section, its width and height are contracted. In this way, the cross-section has a minimal price and fulfills all constraints for fire situations and permanent and transient situations.

Table 1. Optimization results

variable	t = 0	R30	R60	R90	R120
b [mm]	79.66	79.66	72.55	71.94	57.26
h [mm]	116.24	116.24	118.08	109.99	75.74
t [mm]	3.30	3.30	3.78	5.38	10.66
d_p [mm]	0	0	0.73	1.92	3.00
f_{min} [€/m]	25.29	25.29	29.27	40.22	51.06

7. CONCLUSION

The paper analyses an optimization problem of a purlins cross-section exposed to fire, that is protected with intumescence paint. Constraints that ensure the bearing capacity and serviceability checks are verified in permanent and transient situations, as well as in fire cases are imposed. To formulate the objective function, the price of steel, montage, and intumescence paint are considered. The generalized reduced gradient is adopted for the optimization method. For the effective use of the chosen optimization method, it was necessary to assume a set of initial solutions, which produce different results. The result that corresponds to the minimum value of the objective function is considered as the global minimum.

The presented optimization analysis performed in Excel, in the considered case, enables the determination of a cross-section that fulfills all constrains concerning bearing capacity, serviceability, and geometry and has a minimal cost. Besides that, it provides insight into the behavior of the elements in fire situations, and on a specific example shows the effect of cross-sectional factors on the fire resistance.

Although the paper only analyses an example of a purlin cross-section exposed to fire, the same optimization analysis can successfully solve other complex problems with several constraints. The ongoing study extends the algorithm to the optimization of other structural elements.

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40

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STEPGRAD
СТЕПГРАД

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RESEARCH ON THE LIQUEFACTION POTENTIAL OF THE TERRAIN ALONG THE MONTENEGRIN COAST

Abstract

After the catastrophic 1979 earthquake, a classification according to the degree of damage was carried out on about 40,000 buildings in the area of six municipalities along the coast of Montenegro. The results showed that a significant number of commercial, residential and hotel buildings were destroyed or heavily damaged as a result of liquefaction or ground subsidence of the terrain. The results were systematized in overview maps of liquefaction potential at a scale of 1:5000, which was used as a basis for the adoption of urban plans of coastal municipalities. This paper aims to raise the general level of information among planners and civil engineers about the existence of a high risk of liquefaction in these areas.

Keywords: seismic hazard, deformation, liquefaction, SPT test, urban plans

ИСТРАЖИВАЊЕ ПОТЕНЦИЈАЛА ЛИКВЕФАКЦИЈЕ ТЕРЕНА ДУЖ ЦРНОГОРСКЕ ОБАЛЕ

Сажетак

Након катастрофалног земљотреса 1979 године извршена је класификација према степену оштећења на око 40 000 објеката на подручју шест општина дуж црногорског приморја. Резултати су показали да је значајан број пословних, стамбених и хотелских објеката срушен или тешко оштећен као посљедица ликвефакције или слијегања терена. Резултати су систематизовани у прегледне карте потенцијала ликвефакције у размјери 1:5000 које су коришћене као основ за доношење урбанистичких планова приморских општина. Овај рад има за циљ подизање општег нивоа информисаности међу пројектантима и грађевинским инжењерима о постојању високог ризика од појаве ликвефакције на овим просторима.

Кључне ријечи: Сеизмички хазард, деформације, ликвефакција СПТ-test, урбанистички план

1. INTRODUCTION

As a consequence of geodynamic processes, most of the southern Adriatic has a high degree of seismic hazard. In Montenegro, the seismic hazard is expressed along the coastal belt, where, in addition to the seismic risk, there are also risks of activating large landslides, rock falls, and soil liquefaction during earthquakes. During the 1979 earthquake, in several locations in the Lake Skadar area as well as along the Montenegrin coast, liquefaction phenomena were registered. After this earthquake, a classification according to the degree of damage was carried out on about 40,000 buildings in the area of six municipalities along the coast of Montenegro. Figure 1 shows the markings on the buildings after the classification of the level of damage, the markings were on the buildings that need to be demolished or constructively rehabilitated.

Figure 1. Markings on buildings after the 1979 earthquake classification indicating demolition or constructively rehabilitated

The results indicated that a significant number of commercial residential and hotel buildings that were built according to the principles of earthquake engineering were demolished or heavily damaged as a result of liquefaction or large ground subsidence of the terrain. Locations, where the appearance of liquefaction was documented, were 35 to 70 km from the epicentral area in the settlements, Kumbor, Baošići, Bjela, Tivat, Kotor, Bar, and Ulcinj.

The liquefaction was accompanied by cracks in the ground, from smaller cracks to trenches over one meter wide, vertical subsidence, horizontal movements, sinking parts of the coast, etc. There were numerous occurrences of the eruption of fine-grained sand on the surface, followed by the eruption of water in jets. Large amounts of sand covered the entire surface next to the newly formed trenches and in several cases, the floors of the houses were covered with layers of sand. Such manifestations in the soil and on the surface caused a large settlement and horizontal movement of the foundation, Figure 2.

Figure 2. Subsidence of the terrain under the warehouse in the port of Zelenika, left picture;Heavy damage to Hotel Fjord – Kotor city, right picture

Liquefaction, as one of the most difficult forms of dynamic soil instability, directly threatened the general stability of any object on the surface, causing significant damage. After the 1979 earthquake, it was clear that it was necessary to identify terrain areas with high liquefaction potential. The research was conducted by the Institute for Earthquake Engineering and Engineering Seismology from Skopje and was based on identifying the structure of the terrain, determining their granulometric composition, the degree of their compaction as well as the level of underground water. The results of the research were published in 1981 during the revision of the general urban plans of the municipality along the Montenegrin coast, on liquefaction potential maps, scale R=1:5000.

2. LIQUEFACTION PHENOMENON

In non-coherent soil with a weak possibility of draining underground water, during oscillations caused by the earthquake, the tendency to change the volume cannot be realized, which leads to an increase in pore pressures. An increase in pore pressures leads to a decrease in initial effective stresses in the soil and a weakening of intergranular connections. An increase in pore pressures can be of such a value that it reaches the values of the initial effective stresses in the soil. In such cases, the dynamic shear modulus is close to zero, and the soil loses its shear strength and transforms into a heavy fluid. This condition in the soil is defined as the beginning of liquefaction.

Liquefaction was one of the specific manifestations during a large number of strong earthquakes, however, certain dynamic and geotechnical conditions are required for its occurrence. Liquefaction occurs in earthquakes with a magnitude greater than 5 degrees, also a long duration of the earthquake is required. Also, the soil must be constructed of poorly compacted fine-grained non-coherent materials that have a low filtration coefficient and a high level of groundwater. Liquefaction occurs most often in fine-grained uniform sands.

Determining the liquefaction zone is done by identifying the terrain in which there are geotechnical conditions for the occurrence of liquefaction. Such terrains are marked as areas with a high risk of liquefaction in dynamic conditions, and they can be marked at the stage of creating urban plans, which is of great importance. Buildings can be protected from liquefaction by deep foundations, however, there is a whole series of infrastructural objects that cannot be protected, such as sewage, water supply networks, etc. Figure 3 shows the sewage manhole in the Japanese city of Abiko, which broke out on the surface due to the liquefaction.

Figure 3. Sewage manhole that broke out on the surface due to the liquefaction, Abiko city in Japan

The most effective way to prevent the negative effects of liquefaction is to create a map of the liquefaction potential of the terrain and then limit construction in areas with a high risk of liquefaction in the planning documentation phase. Exactly this approach was applied in Montenegro after the 1979 earthquake when the Institute for Earthquake Engineering and Engineering Seismology from Skopje conducted research that resulted in liquefaction potential maps, scale R=1:5000 for all municipalities of the Montenegrin coast.

3. DETERMINATION OF SOIL LIQUEFACTION POTENTIAL

The first necessary condition for liquefaction is the potential of dynamic oscillation, experience and research results show that liquefaction is caused only by earthquakes of large magnitude. To intensively increase pore pressure, it is necessary to generate oscillations not only of high amplitude but also of long duration. Figure 4 shows the oscillations and the duration of the 2011 earthquake in eastern Japan. For the occurrence of liquefaction, the duration of this earthquake was more than 90 seconds (red zone). Based on the historically recorded earthquakes, we can state that this condition is satisfied in the territory of Montenegro, especially along its coastal belt.

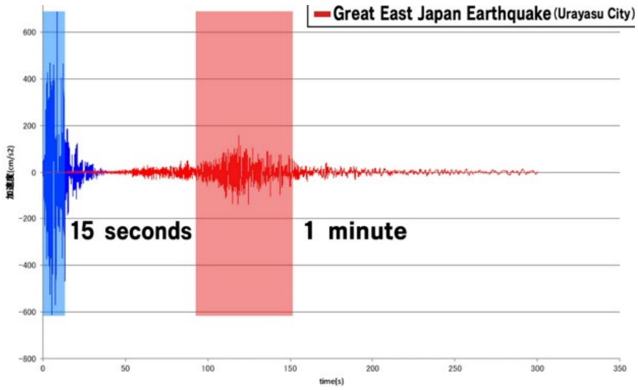

Figure 4. Earthquake duration and oscillations during the 2011 East Japan earthquake (Japan Meteorological Agency)

Another necessary condition is that liquefaction is induced only in certain types of soils with high groundwater levels. A type of soil susceptible to liquefaction is one in which resistance to deformation is mobilized by friction between grains. If other factors such as grain shape, uniformity coefficient, and relative compaction are equal, frictional resistance decreases with decreasing soil grain size. Based on the analysis of the granulometric composition of various alluvial sediments in which liquefaction was registered, Tscuhida proposed granulometric curves that indicate soils subject to liquefaction, Figure 5.

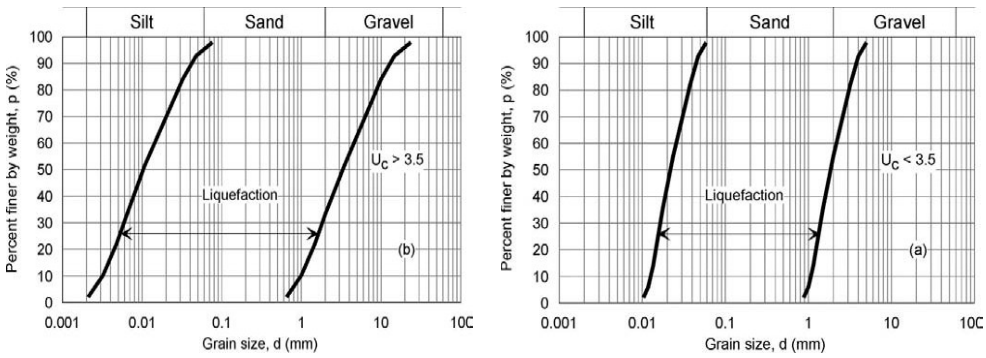

Figure 5. Granulometric curves of materials with high and low uniformity coefficients in which liquefaction was registered, (Tscuchida, 1970)

The area between the two inner curves represents sandy and dusty sands, which have the lowest resistance to liquefaction, also uniformly granulated material is more suitable for liquefaction than well-granulated material. Liquefaction can also occur in soils with a higher content of gravel, or clay fractions, however, these soils mobilize greater shear strength.

If the soil has a favorable granulometric composition, this still does not mean that liquefaction will occur in it, namely, compaction is the basic parameter that determines the risk of liquefaction. Greater compaction will result in less vertical deformation (settlement) under dynamic loading conditions. Liquefaction usually occurs in saturated clean sand and dusty sand when compaction is less than 50%. In compacted sand, dilation can occur during cyclic loading, which generates negative pore pressures and thus increases shear stress resistance.

Soil liquefaction potential is a quantitative expression of the possibility of soil liquefaction. It is defined as the relationship between the dynamic excitations that can be received by a certain geotechnical environment and the dynamic excitations that cause liquefaction in that environment. The safety factor for liquefaction is given by the expression:

$$F_s = \frac{CRR}{CSR} \geq 1.0 \tag{1}$$

where:
Fs-factor of safety for liquefaction;
CRR-coefficient of cyclic loading required to cause liquefaction;
CSR-coefficient of cyclic loading induced by an earthquake.

If the liquefaction resistance is greater than the expected earthquake effect, Fs will be greater than unity, otherwise, liquefaction is expected to occur. The earthquake-induced cyclic loading coefficient (CSR), is usually determined as equivalent of 65% of the maximum cyclic shear stress, by the expression:

$$CSR_{M,\sigma'v} = 0.65\ \frac{\sigma v}{\sigma' v}\frac{amax}{g} rd \tag{2}$$

where:
σv (kPa)-vertical overburden stress,
σ′v (kPa)-effective vertical overburden stress,
a_{max} (m/s^2)-peak ground acceleration,
g (m/s^2)-acceleration due to gravity,
rd-stress reduction factor accounting for the flexibility of the soil profile.

The coefficient of cyclic load required to cause liquefaction (CRR) can be calculated using the cone penetration test (CPT), through the correlation given by Juang et al. (2005), however most often cyclic load required is calculated based on parameters obtained by performing a standard penetration test (SPT), using the corrected blow count value:

$$(N1)\_60 = Cn \cdot Ce \cdot Cr \cdot Cb \cdot Cs \cdot Nspt \tag{3}$$

Cn-overburden correction factor,
Ce-energy correction factor,
Cr-rod length correction factor,
Cb -hole diameter correction factor,
Cs-correction factor for sampling method,
Nspt-measured number of blows in field test.

The correlation for a magnitude 7.5 earthquake to calculating the CRR from the SPT as a function of the percentage of smaller particles in the soil (FC), is given in Figure 6.

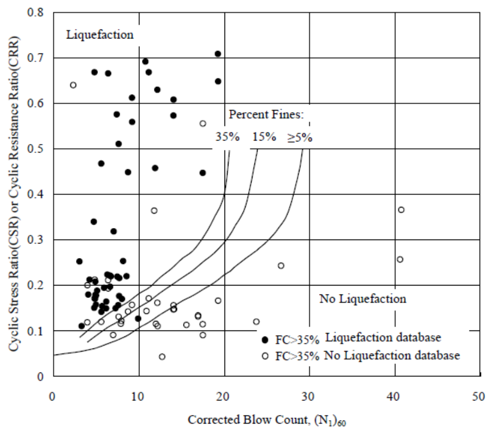

Figure 6. Liquefaction diagram based on standard penetration tests (SPT) for magnitude 7.5 earthquakes (Seed et al. 1985)

4. TERRAIN ZONING BASED ON LIQUEFACTION POTENTIAL

During the creation of liquefaction potential maps after the 1979 earthquake, the focus of analysis was on defining the type of soil, its geological age, granulometric properties, compaction, and underground water level. Based on such an analysis and a global assessment of the liquefaction potential, the area was zoned into four zones with different degrees of liquefaction occurrence.

The main characteristic of the then separated zones with a high liquefaction potential is the presence of surface layers of sand 15-20m deep, which rest on flysch or over layers of silty debris, rarely clay. Granulometric curves from zones with high liquefaction potential are very typical for their occurrence. Standard Penetration Tests (SPT) performed in zones with high liquefaction potential also show that the soil is in a state of compaction very typical for the occurrence of liquefaction. Figure 7 shows the liquefaction potential map of the municipality of Ulcinj, created as part of the revision of the urban plans. We can see that four zones of liquefaction potential have been identified and that large parts of the terrain as marked as high risk zones.

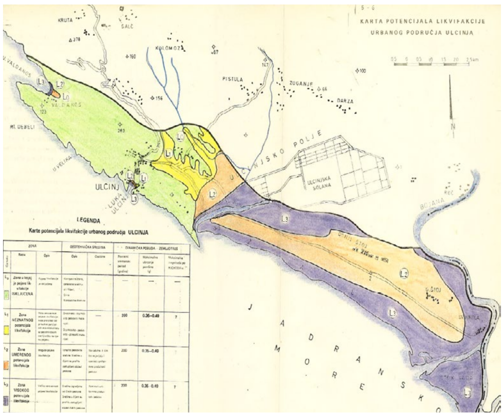

Figure 7. Liquefaction potential map of Ulcinj municipality (Institute of Earthquake Engineering and Engineering Seismology, Skoplje 1981)

The main goal of creating liquefaction potential maps after the 1979 earthquake was to estimate the global probability, however, today's liquefaction potential map uses the liquefaction potential index (LPI) as the main criteria. Liquefaction procedures predict that the soil will liquefy at a specific depth, but they do not predict the liquefaction strength at the ground surface. To fill this gap, Iwasaki et al. (1982) proposed the following assumptions in formulating the liquefaction potential index (LPI) to estimate the potential for liquefaction damage:

- The strength of liquefaction is proportional to the thickness of the liquefied layer,
- The strength of liquefaction is proportional to the proximity of the liquefied layer to the ground surface;
- The strength of liquefaction is related to the factor of safety (FS) against the initiation of liquefaction, but only the soils with FS < 1 contribute to the strength of liquefaction.

Moreover, the effect of liquefaction at depths greater than 20m is assumed to be negligible, since surface effects of liquefaction at such depths have not been reported. Due to all of the above, the criterion of liquefaction based on the LPI index is considered more appropriate, and it is given by the expression:

$$LPI = \int_{0}^{20m} F\,w(z)\,dz \tag{4}$$

w (z) = 10 – 0.5z depth weighting factor,

z (m) depth;

z = 0 weighting factor is 10 and decreased linearly to 0 at z = 20 m.

The variable F is defined as follows: F = 1 – FS, for FS ≤ 1; and F = 0 for FS > 1, Fs-factor of safety for liquefaction.

A liquefaction Potential Index was developed to predict the potential of liquefaction to cause foundation damage at a site, as follows: There is no risk of liquefaction if LPI = 0; risk is low if 0 < LPI ≤ 5; high if 5< LPI ≤ 15; and very high if LPI > 15.

5. CONCLUSION

Liquefaction potential maps created by the Institute for Earthquake Engineering and Engineering Seismology from Skopje were used as a basis for adopting urban planning plans for the coastal municipalities of Montenegro.These maps, created in 1981, recognize the risk of liquefaction in a wider area along the Montenegrin coast.

The liquefaction potential is closely related to the geotechnical properties of the surface layers, which are highly variable from one micro-location to another, so when adopting new urban plans for municipalities along the Montenegrin coast, it would be necessary to conduct research that would more closely define the potential for liquefaction.

Unfortunately, in Montenegro there are no plans to create new liquefaction potential maps of the coastal area, and we can say that even the existing liquefaction potential maps are not used, which certainly significantly increases the risk of a future earthquake.Today, the current criteria for evaluating liquefaction based on the LPI index are significantly different from the criteria that were used 45 years ago when the existing liquefaction potential maps were created for the Montenegrin coastal belt.

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41
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REVIEW OF STRUCTURAL DEVELOPMENT OF DAMS WITH AN EMPHASIS ON THE CONSTRUCTION OF THREE GORGES DAM

Abstract

Dams are hydrotehnic engineering structures that have undergone significant advancement throughout history from an engineering standpoint, and today they represent some of the most complex constructions. Additionally, they play a crucial role in the economic development of many countries. Four basic types of dams have been developed: embankment, gravity, buttress, and arch dams. Each of them poses unique challenges that require significant efforts from engineers, which include the constant development and application of new technologies. One of them is the Three Gorges Dam, which represents the largest gravity dam, as well as the largest hydroelectric complex in the world. The technology of the project is extremely complex, and together with the comprehensive benefits to the community, makes the project more challenging than any other hydro project in the world.

Keywords: embankment dam, gravity dam, buttress dam, arch dam, Three Gorges Dam, hydrotehnic engineering

ПРЕГЛЕД КОНСТРУКТИВНОГ РАЗВОЈА БРАНА СА АКЦЕНТОМ НА ИЗГРАДЊУ БРАНЕ ТРИ КЛАНЦА

Сажетак

Бране су хидротехничке конструкције које су кроз историју доживјеле значајан напредак у инжињерском погледу, и данас представљају једне од најкомплекснијих конструкција. Поред тога, имају кључну улогу у привредном развоју многих земаља. Развијена су четири основна типа брана: насуте, гравитационе, контрафорне и лучне. Иза сваког од њих се крију јединствени проблеми који захтјевају значајна залагања инжењера, који захтјевају стални развој и примјену нових технологија. Пројекат Три Кланца представља највећу гравитациону брану, а уједно и највећи хидроенергетски комплекс на свијету. Технологија пројекта је изузетно сложена, и заједно са свеобухватним користима за заједницу, чини га изазовнијим од било ког другог хидропројекта на свијету.

Кључне ријечи: насуте бране, гравитационе бране, контрафорне бране, лучне бране, брана Три кланца, хидротехничке конструкције

1. INTRODUCTION

1.1. HISTORY

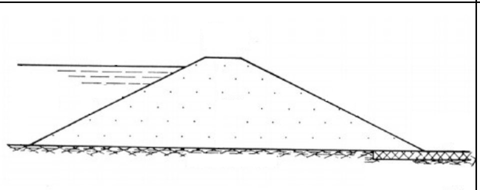
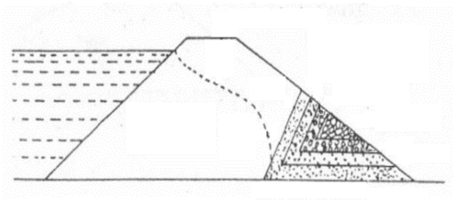
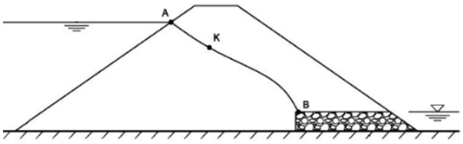
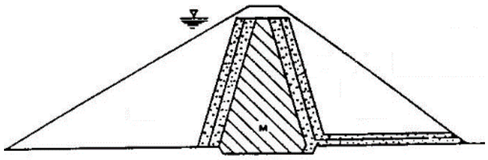
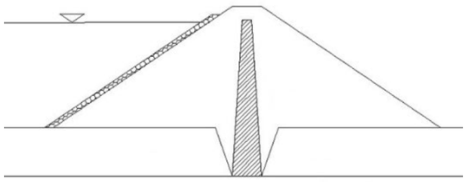
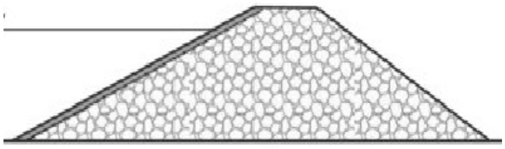
People have been constructing hydotehnic structures since ancient times, such as low earth dams, irrigation canals, spring intakes, etc. Today, remnants of these structures cannot be found as they were constantly exposed to water and atmospheric environment, but it is assumed that they existed.
It is believed that the first hydotehnic structures were irrigation canals, constructed by the Sumerians around 5.000 years BCE. Additionally, in Egypt, unlined irrigation canals have been built around 5.000 BCE. According to Herodotus, the earliest engineering works were associated with the construction of the city of Memphis on the Nile River, where embankments were dug, the old riverbed was drained, and the river channel was diverted between hills. At that time, the Kosheh Dam was built, which was 15 meters high and 450 meters long at its crest, [1].
Today, remnants of the foundation of the Sadd el-Kafara Dam exist in the now-dry Garawi Canal, approximately 32 kilometers south of Cairo. This dam was built around 2.900 BCE. It stood about 11 meters high and had a crest length of around 107 meters. The dam walls were made of hewn stone, and the reservoir capacity was approximately 570.000 cubic meters. During the first flood, the reservoir was too small to accommodate the floodwater, resulting in the flooding of the dam and the collapse of its central part. After that, dams were not built in Egypt for several hundred years.
Throughout the valleys of the Euphrates and Tigris, there existed numerous irrigation canals even before 2.100 BCE. During the construction of canals to divert water from the Tigris, a massive stone embankment dam was built. To divert the nearby tributary of the Tigris, the Atem River, the Atem Dam was constructed, the remnants of which could be seen at the beginning of this century. It was a stone masonry dam, diverting water from the river into two channels. Another significant dam on the Tigris is the Marduk Dam, which was built around 2.000 BCE. It was made of earth materials and had a height of about 12 meters.
In the area of present-day Yemen, around 950 BCE, the Andra, Adshma, and Marib dams were constructed. The largest among them was the Marib Dam, estimated to be 37 meters high and 3.200 meters long. The Andra and Adshma dams were built in canyons and are believed to have been 15 to 20 meters high.
On the island of Ceylon, present-day Sri Lanka, many dams and irrigation systems were built. Remains still exist today near the old capitals. The Kalaba Reservoir, which served for irrigation near the capital Anuradhapura, was an embankment dam with a height of 24 meters and a length of 6.000 meters. In 430 BCE, the Basavakulam Dam was built, followed by the Tisa Dam in 407 BCE, which were lower but longer.
Near the old capital of Petra, now in Jordan, several centuries before BCE, a stone embankment dam was constructed, with a height of 14 meters, as well as the gravity dam of Kurnubu in Israel. These two dams have been preserved to this day, [1].

1.2. TYPES OF DAMS

1.2.1. EMBANKMENT DAMS

The oldest and most widespread type of dams are embankment dams. Since prehistoric times, there has been a need for dam construction due to human dependence on water. Especially in countries such as Egypt, the Middle East, and India, where dry periods occur, dam construction has been essential to preserve seasonal rainfall. In Europe, the construction of these dams began later, after the Industrial Revolution when there was a greater need for water due to urban and industrial development [2]. Embankment dams are constructed by controlled deposition and compaction of locally available materials. These dams resist forces through their own weight, transferring the load to the ground over a much larger surface area compared to concrete dams, thereby reducing stresses in the soil. The main issue with this type of dam is its susceptibility to erosion due to water action. Depending on the material they are constructed from, dams are divided into earth-filled and rock-fill dams. Throughout history, these dams have been extensively built but also frequently collapsed. Possible reasons include dam overtopping, which is accompanied by erosion. Then there's internal erosion, which involves the removal of particles of incoherent material, leading to the formation of a large opening through the foundation of the structure. In case of high pore pressure in the embankment or foundation, downstream slope sliding and dam failure occur. On the other hand, an additional advantage of these dams is much lower costs of constructing compared to the costs of constructing concrete dams, [3]. Some types of embankment dams are shown in Table 1.

Table 1. Types of embankment dams, [4], [5], [6], [7], [8], [9].

Homogeneous type of earthen dam	Modified homogeneous type of earthen dam with a filter and a downstream leg made of selected stone
	
A modified homogeneous type of earthen dam with a drainage carpet under one downstream part of the dam	Zoned type of earthen dam
	
Diaphragm earthen dam type	A rock dam
	

An example of an embankment dam is the Vlasina Dam, which is 34 meters high, has a volume of 365.000 cubic meters, and its reservoir has a volume of 165.000.000 cubic meters. This dam is used for hydroelectric power generation and irrigation [1].
The Nurak Dam, located on the Vakhsh River in Tajikistan, Fig. 1, has a unique construction because its core is built with concrete, and then the dam is embanked with compacted earth. The Nurak Dam is 304 meters high and has a length of 700 meters, [3].

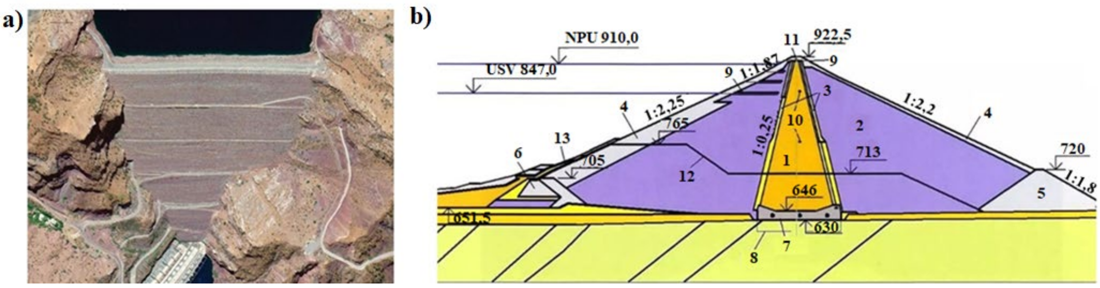


Figure 1. a) The Nurek Dam, [10]; b) The cross-section of the Nurek Dam: 1 – sandy loam core; 2 – shells of coarse; 3 – filters (d=0-5 mm and d=0-50 mm); 4 – oversize rockfill surcharge stones on upstream slope (20-40 m thickness), downstream slope (5-10 m thickness) and downstream cofferdam; 5 – downstream cofferdam of oversize rockfill; 6 – upstream cofferdam; 7 – concrete block; 8 – consolidation grout and grout curtain; 9 – anti-seismic belts; 10 – control gallery 2x2 m; 11 – control gallery 4x4 m on dam crest; 12 – contour of first-stage dam construction; 13 – temporary clay blanket of first-stage dam construction, [11].

1.2.2. BUTTRESS DAMS

We distinguish dams with buttresses, which have either an upstream massive head or a flat upstream slab. There is significant freedom in shaping these dams during the design process [2]. Buttress dams resist sliding and overturning by their own weight as well as the vertical components of hydrostatic force, i.e., the weight of water above the sloping upstream face, Fig. 2. Unlike massive gravity dams, buttress dams only have buttresses-wall supports on the downstream side and reinforced concrete slabs on the upstream face. Sometimes even the buttresses can be hollow, making this dam concept lightweight. In these dams, the structure can be founded on the dam's foundations, reducing the load-bearing area, but increasing the stresses in the foundation joint. Although less concrete is required for buttress dams compared to gravity dams, the construction costs are higher due to the need for more complex formwork, resulting in increased expenses and requiring a more skilled workforce. There are multiple-arch dams where instead of reinforced concrete slabs between the buttresses, arches are installed. This solution significantly reduces the amount of reinforcement required but increases the complexity of construction. Massive buttress dams, whose upstream face is formed by thickening the buttresses themselves, are devoid of tensile stresses, so the heads are made of unreinforced concrete, but this increases the weight of the dam. The weight can be reduced by hollowing out the buttresses, further complicating the concrete pouring work, [3].

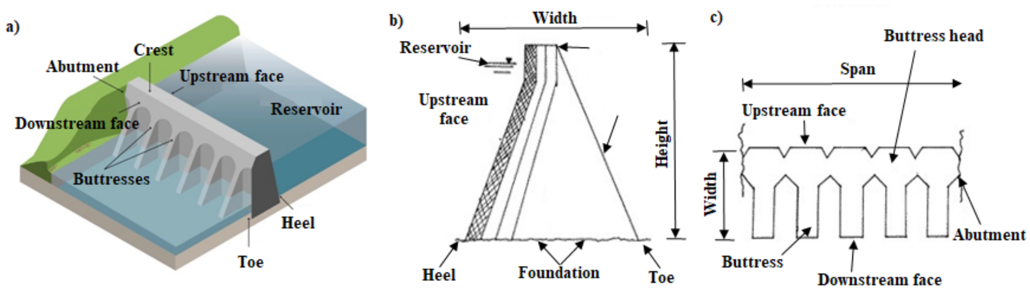


Figure 2. a) Buttress dam, [12]; b) Cross-section, [13]; c) Top view, [13].

An example of a buttress dam is the Bajina Bašta Dam, Fig. 3, which was built in 1996. It has a height of 90 meters and a crest length of 461 meters. The reservoir volume, used for hydroelectric power generation, is 340.000.000 cubic meters [1].

Figure 3. a) The Bajina Basta Dam, [14]; b) Construction of the Bajina Basta Dam, [15]; c) Cross-section of the Bajina Basta Dam, [16].

1.2.3. ARCH DAMS

Arch dams represent structures defined by their arch-shaped or curved form, with the load primarily transmitted to the abutments. The safety and stability of the structure depend on the physical-mechanical characteristics of the material from which the considered structure is built and the bearing capacity of the foundation soil in general, which involves the foundation bond and abutments of the arch dam. Arch dams represent a more economical construction method, being 40 to 60% more cost-effective than gravity dams, but they require better foundation conditions and more complex construction technology. Additionally, the design process of arch dams is significantly more demanding. The construction of arch dams necessitates constant and coordinated supervision throughout all construction phases, with particular emphasis on concrete quality, the method of concrete placement in segments, monitoring of the temperature of the poured concrete mass, and continuous observation and measurement of dam structure and abutment displacements.

An arch dam can be represented as a continuous vault (shell-like structure), supported on three sides (early builders considered it 'wedged'). It is a statically multiple-indeterminate structure, which, in order to be more easily analyzed, must be divided into elements of simple shapes [2].
With the increasing demand for electric power, the number of constructed dams is rising, leading to dams being built in increasingly unfavorable terrains, including unfavorable gorges in terms of span, height, and quality of rock mass. At the Gordon Arch Dam in Australia, Fig. 4, an elliptical shape was adopted as more suitable for transferring forces from the dam to the abutments.

a) b)

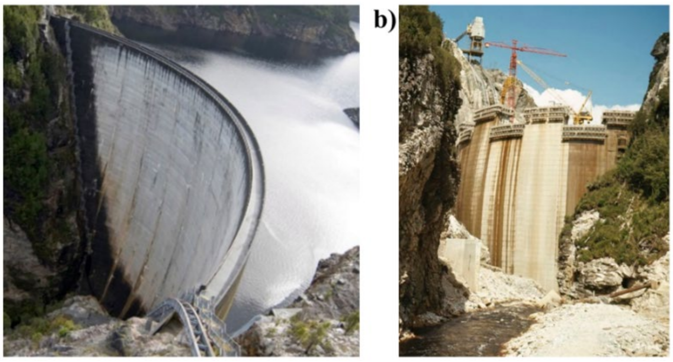


Figure 4. a) The Gordon Dam, [17]; b) Construction of the Gordon Dam, [18].

It should be emphasized that a special group of arch dams consists of arch-gravity dams whose base in the foundations has a ratio of (0.33 - 0.65) H, where H is the height of the dam. Due to the considerable thickness of these dams, the majority of the load is transferred to the valley floor, while a smaller portion of the load is transferred to the abutments. The Jablanica Arch Dam belongs to this type of dam, Fig. 5.

Figure 5. Jablanica Dam, [19].

In the case of reservoirs with large arch dams, the discharge of large volumes of water is carried out via lateral spillways on the crest of the dam or outside the dam body, with a high-velocity flow on the slope and a spillway in the riverbed, as well as through the bottom outlet. This procedure aims to mitigate the impact of the water surge, which is discharged via spillways, on the downstream water level of the hydroelectric power plant or to protect the riverbed from erosion. The geometric design criteria for arch dams are stricter than for other types of dams because the arch action is limited by the L/H ratio, where L is the length at the crest and H is the height of the dam. It was once believed that an arch dam could not be constructed if the L/H ratio exceeded 3.5.
Control galleries and 'passerelles' are used for injecting radial joints. In the case of the annular and longitudinal injection system, where the injection mixture is supplied from the downstream face, 'passerelles' are used, [2].

1.2.4. GRAVITY DAMS

A gravity dam is a solid concrete structure that resists external forces by its own weight, hence it has a large volume and a wide base. They are usually (straight), however, sometimes they can be curved or angled to better adapt to the topography of the terrain. These are the most common types of concrete dams and the simplest to design and construct.

The design of gravity dams involves collecting and considering geological, hydrological, and seismic data, conducting studies on the site and type of dam, and researching the materials and characteristics of the foundation. After conducting these investigations and studies, the design of the dam and its analysis follow. The project ensures the arrangement of project-defined structures, cross-section profiles, as well as the location and details of other features of the dam such as monolithic and structural joints (expansion joints), galleries, chamber gates, channels, and injection and drainage facilities.

Gravity dams consist of spillway and non-spillway sections, Fig. 6, [20]. If the dam is used for electricity generation, part of the non-spillway section of the dam usually serves as an intake section with an embedded pipeline leading to the power plant, [21].

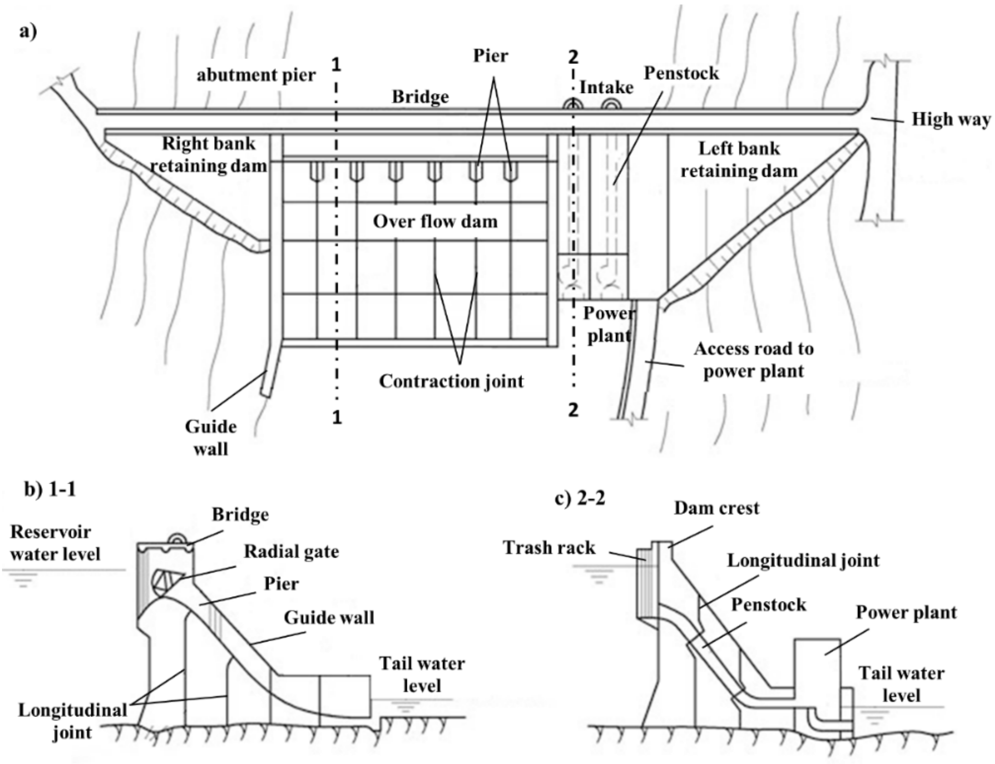


Figure 6. a) Top view of gravity dam; b) Cross section of over flow dam; c) Cross section of power plant.

The non-spillway sections have a uniform downstream slope of about 1 : 0.7-0.8. The upstream side is usually vertical, but sometimes batter slopes are added to increase resistance to sliding or to locate the resultant within the boundary area of the middle third.

Both faces are sometimes provided with a fillet at their intersections with the foundation to reduce stress concentrations. The crest of the dam is typically dimensioned to provide a roadway and should have sufficient strength to withstand ice pressure and the impact of floating objects. In areas of significant seismicity, the mass of the crest should be minimized, and the interruption of the slope at the junction of the crest and downstream slope should be gradual or eliminated.

The spillway section has a rounded crest, and at the lower part, a sharp-profiled weir. The downstream side slope is set to tangent the crest curve and also the curve at the junction with the stilling basin. Piers are installed for intermediate support when a bridge is provided over the spillway and, for controlled crests, also to support gates. Gated outlets, when required to regulate downstream flows for navigation, irrigation, or other purposes, are usually placed in the spillway monoliths.

The powerhouse typically contains trash racks, intake pipes, stop logs, discharge gates, and penstock pipes. When there is sufficient space, the power plant is located immediately downstream of the intake section. For low-head dams, the intake, power plant, and discharge pipes are often one structural element, [21].

Table 2. Top 4 largest gravity dams in the world by capacity, [22], [23], [24], [25], [26].

View of Dams	Description
	Three Gorges Dam Location : Yangtze River, China Height: 181 m Length: 2.335 m Capacity: 22.500 MW The Three Gorges Dam is the largest dam globally, both in terms of height and power generation capacity. It's a colossal structure on the Yangtze River, serving flood control, electricity generation, and navigation.
	Itaipu Dam Location: Paraná River, Brazil/Paraguay Height: 196 m Length: 7.919 m Capacity: 14.000 MW The Itaipu Dam is a binational project between Brazil and Paraguay. It ranks as one of the largest hydroelectric power plants in the world and provides a significant portion of both countries' electricity needs.
	Guri Dam Location: Caroni River, Venezuela Height: 162 m Length: 1.300 m Capacity: 10.235 MW Guri Dam is a crucial component of Venezuela's power generation infrastructure.
	Tucuruí Dam Location: Tocantins River, Brazil Height: 78 m Length: 12.750 m Capacity: 8.370 MW The Tucuruí Dam represents one of the key facilities for electricity production and the development of the state.

The Table 2 shows the four largest gravity dams in the world, with the Three Gorges Dam in first place, described in detail below.

2. THREE GORGES DAM

The Yangtze River is the largest in China and the third largest in the world, with a main stream length of 6300 kilometers. The total volume of water flowing into the sea averages 960 billion cubic meters annually. Its total water potential reaches about 268,000 MW, with usable reserves around 197,000 MW. The Three Gorges of the Yangtze is one of the places holding the largest water reserves in the world.

The Three Gorges Dam is a large-scale hydroelectric project with enormous comprehensive benefits in flood prevention and control, electricity generation, transportation, and water supply.

The dam project is crucial for controlling the Yangtze River. Its main tasks include preventing and mitigating catastrophic floods in the middle and lower reaches of the river, particularly in the Jingjiang section of the main stream, providing electricity to central and eastern China and the eastern province of Sichuan, and improving navigation conditions in the middle reaches of the river.

The dam controls a drainage area of about one million square kilometers, with an average annual flow of 451 billion cubic meters. The dam is a concrete gravity dam, with a crest length of 2335 meters and a maximum height of 175 meters. The main construction volume of the project involved excavating 10.28 million cubic meters of earth and rock, approximately 31.98 million cubic meters of embankment, around 27.94 million cubic meters of concrete, and 460,000 tons of reinforcement. Calculated at the end of May 1993 prices, the total cost was estimated at 50.09 billion yuan ¥.

The first phase, including preparatory work, lasted for 5 years, from 1993 to 1997, representing the formation of the dam. The second phase lasted for 6 years, marked by the operation of the first group of generating units in 2003. The third phase also lasted for 6 years, until 2009, encompassing the start of operation of the left hydroelectric plant and ship lock, as well as the construction of the section of the dam where the right hydroelectric plant will be located. The entire project was completed in 17 years as planned, [27].

2.1. THREE GORGES PROJECT

The Three Gorges Project, in addition to the dam, includes two separate hydroelectric power plants, as well as sections dedicated to water traffic. After extensive research, it was decided that the spillway section would be located in the middle of the riverbed, while the power plants would be situated on the sides. The spillway section is 483 meters wide and has 23 spillway gates at a height of 90 meters and 22 surface temporary outlets. The left hydroelectric plant is 643.7 meters long with 14 generator turbines, while the right one is 584.2 meters long with 12 generators. Additionally, on the Baiyanjian Mountain, located on the right bank, there is an underground power plant with 6 hydro turbines, Fig. 7. The transportation section consists of a ship lock for both directions, designed for ships with a cargo capacity of 10,000 tons, and the crossing takes about 4 hours. For smaller cargo and passenger ships, there is a ship lift, which speeds up transportation, with a maximum carrying capacity of 3000 tons. These facilities overcome the water level difference of 175 meters between the two sides of the dam, [28].

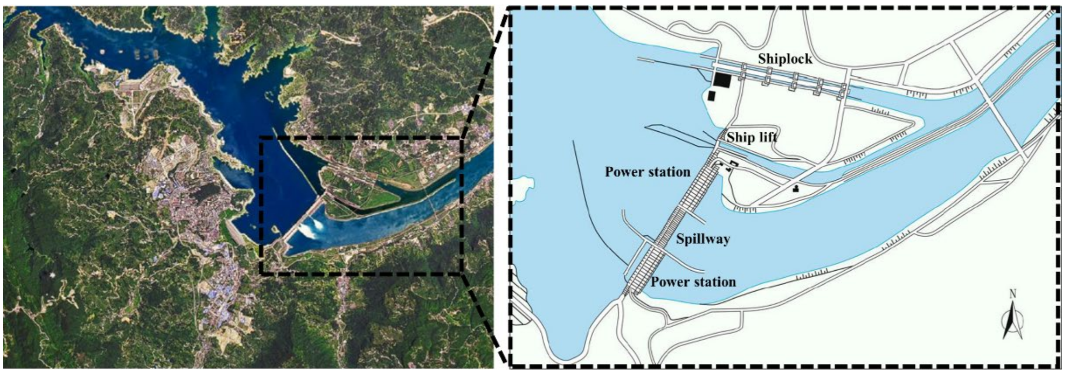


Figure 7. Layout of the Three Gorges Project, [29], [27].

2.1.1. RESETTLEMNT

The Chinese government has made a significant effort in relocating people, and the relocation officially began in 1993, when construction started eight years after pilot projects began in 1985. By the end of 2004, 45 billion yuan had been invested in relocating 980,900 people, accounting for 87% of the total number, including 658,300 people from urban areas and 322,200 from rural areas, with 13 new cities and county seats (fully or partially submerged by the reservoir) rebuilt according to the principle of rehabilitating original standards, size, and functions, significantly improved in terms of land space, transportation, telecommunications, electricity supply, and water supply. A total of 39 million square meters of houses and buildings have been completed, of which 31 million square meters, or 89%, have been rehabilitated. Out of the total number of factories and mines, 1428, or 88%, have been relocated; 1105 kilometers of roads have been constructed, which is 135% of the total planned length; and 2955 kilometers of power lines have been installed, accounting for 90% of the total planned length [27].

2.1.2. CONSTRUCTION

The project officially started in 1993 with the efforts of nearly 20,000 employees from the design, engineering, and supervision sectors.

The river was successfully dammed in November 1997, with the completion of the auxiliary dam before the start of the flood season, which endured tests from eight major flood waves in 1998, ensuring the safety of the construction site. In 1999, the construction of the dam transitioned from the excavation phase to mass concrete pouring, setting a world record for annual concrete pouring with 4.58 million cubic meters, averaging 554,000 cubic meters per month. However, the record was surpassed the following year, with 5.43 million cubic meters of concrete poured, Fig. 8.

In June 2003, the reservoir of the dam reached a height of 135 meters, and in 2004, the dam successfully halted approximately 500 million cubic meters of floodwaters, demonstrating its initial function of flood defense. By November of the same year, the water level of the artificial lake had reached a height of 139 meters, providing initial confirmation of the necessity of constructing such a massive structure. By the end of 2004, the financial resources invested in construction had reached 66.043 billion yuan, with preparatory work and excavation of earth and rock amounting to 139 million cubic meters. Earthen embankments totaling 52 million cubic meters were constructed, and the total amount of concrete installed amounted to 26 million cubic meters. Additionally, it is important to note that machinery and electrical equipment weighing 97,100 tons were installed, and 177,100 tons of steel were used for various steel structures on the project site, [27].

a) b)

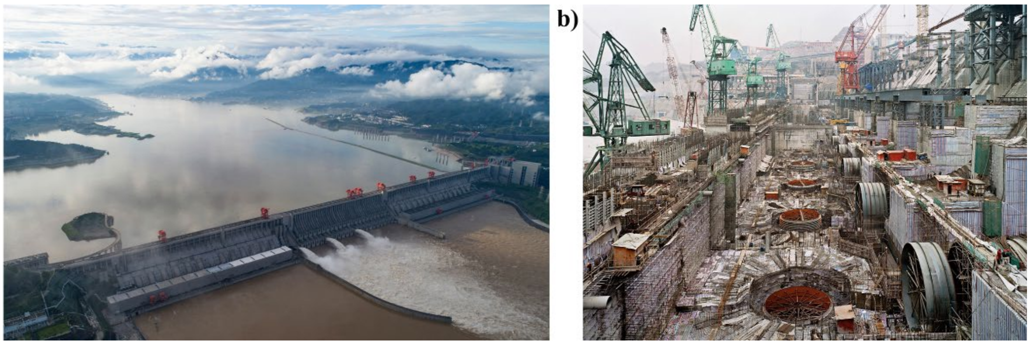


Figure 8. a) Three Gorges Dam, [30]; b) Construction of Three Gorges Dam, [31].

The entire process was accompanied by a rigorous quality control system, from the procurement of raw materials, equipment production, construction, through testing, experiments, and supervision. Regulatory bodies conducted independent oversight alongside a full set of on-site tests. World-renowned foreign companies were invited to provide consulting services and oversee the construction of key parts of the dam and equipment production. To enhance quality control, an expert group for quality inspection was established, composed of numerous academics from the Chinese Academy of Sciences and the Chinese Academy of Engineering, to conduct regular quality inspections and evaluations, [27].

2.1.3. KEY TECHNOLOGY OF THE GRAVITY DAM PROJECT

Due to the large capacity of floodwaters and the large number of discharge units, it is necessary for this part of the dam to be as short as possible. After several years of research, through optimization and adaptation of the shape and structure of the flow path, as well as the arrangement of gates and associated facilities, a successful implementation of staggered triple-layered large discharge openings has been achieved. The length of the leading edge of the flood release section of the dam is determined to be 483 meters, divided into 23 monoliths. One of the 23 foundation outlets, with dimensions of 7m × 9m, is located in the middle of each monolith, and the lower elevation of the inlet is 90 meters above sea level, Fig. 9. One of the 22 upper openings is placed over each transverse joint, with a spillway crest elevation of 158 meters and a width of 8 meters. Immediately below the upper openings and over the transverse joints, 22 lower diversion openings are installed, with dimensions of 6m × 8.5m. The lower elevation of the inlet is 56 meters or 57 meters above sea level, [32].

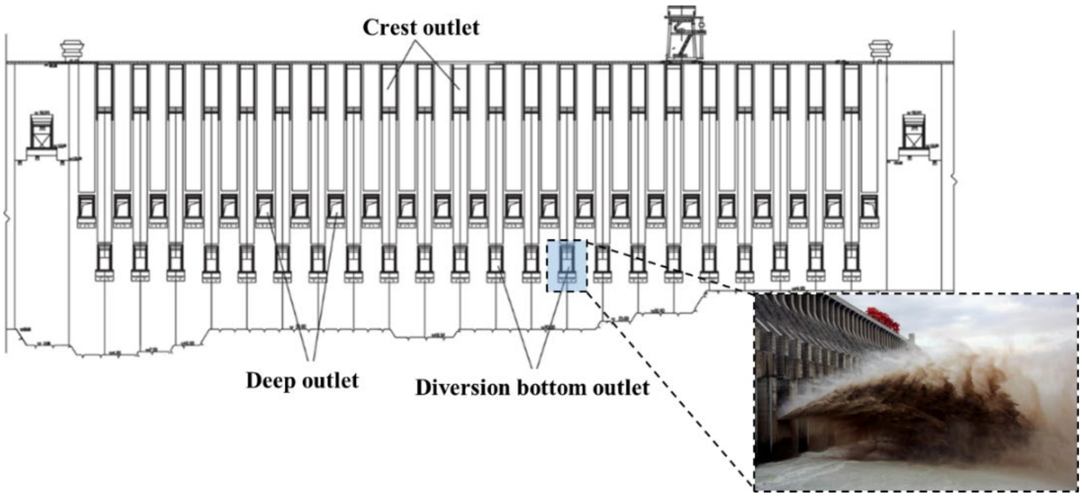


Figure 9. Layout of the three-layer orifices, [32], [33].

This innovative layout not only meets multi-purpose requirements, such as water discharge during energy production, lowering water levels when necessary, sediment release, but also significantly shortens the length of the spillway section of the dam, reduces excavation on both embankments, and saves on engineering investment.

The most important characteristic of the lower diversion outlet is its position at the monolith joints and the significant amount of sediment passing through it, thus sediment abrasion and erosion of the flow surface due to cavitation pose a serious problem. After numerous scientific studies, certain measures have been adopted. Firstly, a long pressure pipe of appropriate size has been adopted to reduce the flow at the outlets. Secondly, a concrete erosion protection slab has been placed over the joint. Finally, a sediment retention groove has been installed at the inlet.

The discharge structures of the Three Gorges Project have the features of large flood discharge, high water head, and huge discharge power. Based on the layout with staggered three-layer large discharge orifices, combined with the actual situation of a downstream energy dissipation zone, ski-jump energy dissipation with a largely differential flip bucket was used for crest outlets and deep outlets. The drop points of the water tongues are staggered in a longitudinal direction, and the scour depth is greatly reduced, [32].

2.1.4. KEY TECHNOLOGY OF THE POWER PLANT PROJECT

One of the key technological challenges of the power plant at the toe of the dam is how to select the type of intake structure to create good water intake conditions and ensure the safety of both the dam and the intake. Considering that the diameter of the intake for the power plant at the toe of the Three Gorges Dam project is large, there are several issues if the pipe is fully embedded within the body of the dam. These include weakening the dam structure, interference during the construction process, and a prolonged construction period. On the other hand, if the entire pipeline is located on the downstream surface of the gravity dam, there are issues with lateral stability, especially seismic stability for the intake with high HD values. Therefore, it is challenging to ensure the safety of the structure. A new type of intake called "shallow-buried reinforced concrete intake with steel lining at the dam crest" (short: shallow-buried pipe at the dam crest) has been proposed. In this intake, a shallow trench is pre-installed on the downstream surface of the gravity dam, with one-third of the pipe diameter buried in the trench. Steel lining and reinforced concrete bear the water load together, as shown in Fig. 10.

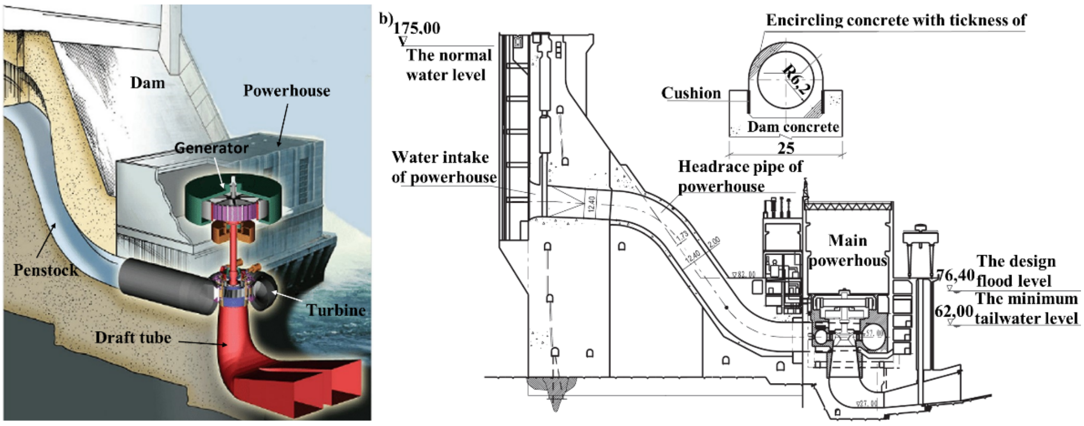


Figure 10. a) Powerhouse, [34] ; b) Schema of preset shallow slot for headrace penstock and reinforced concrete pipe with steel lining, [32].

The left power plant at the dam crest of the Three Gorges Project has been in operation for 14 years, [32]. Surveillance data for the shallow-buried intake from 2008 to 2013 show that the stress laws of the steel lining and reinforcements at the upper, lateral, and lower parts of the intake remain consistent with the design analysis.

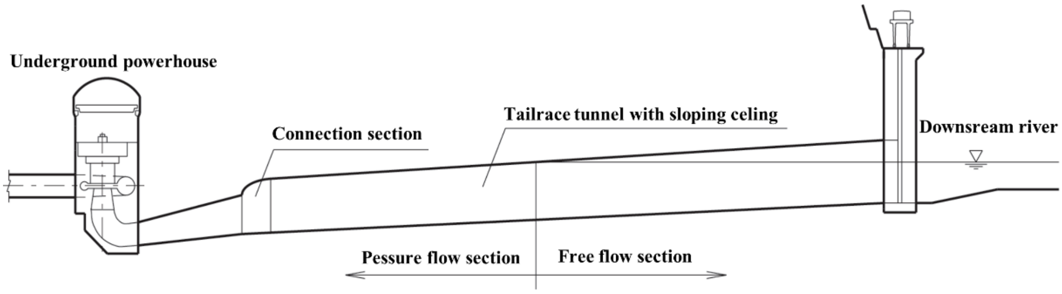


Figure 11. Schema of tailrace tunnel with sloping celing, [32].

The maximum flow of an individual unit of the underground power plant in the Three Gorges project is 991.8 m3/s, with a nominal head of 85 m. According to the traditional design method, a surge chamber of large volume should be installed. However, deep excavation of the chamber would significantly affect the stability of the surrounding rocks. Through deeper investigation of the relationship between the turbine installation elevation, the length of the pressurized drainage channel, and the downstream water level, methods such as theoretical analysis, numerical simulations, and model testing were utilized. This led to the proposal of a new type of drainage tunnel with both a free surface and pressure, termed the "drainage tunnel with an inclined ceiling".

The principle of operation of the new drainage tunnel relies on the relationship between the variation in downstream water level and the length of the pressurized tunnel section, Fig. 11. With the sloped roof, it automatically meets the vacuum degree requirement at the entrance of the drainage tunnel in case of different turbine submersion depths. When the downstream water level is low, the depth of turbine submersion is small. Consequently, the free-flowing section is long while the pressurized section is short. In this scenario, the negative pressure of water impact is minimal during the transit process, and the degree of vacuum at the entrance of the drainage tunnel meets the project standards. As the downstream water level rises, the length of the free-flowing section gradually decreases, while the length of the pressurized section increases. In this situation, the negative pressure increases, but the depth of turbine submersion gradually increases as well. Therefore, the positive and negative aspects neutralize each other to maintain a controlled degree of vacuum at the entrance of the drainage tunnel, satisfying the project standards. This indicates that this tunnel serves as a surge chamber. Considering that the surge chamber becomes unnecessary when using the inclined roof drainage tunnel technology, the layout of the underground caverns can be simplified, and the stability of the surrounding rock can be improved, [32].

2.1.5. SHIP LIFT TECHNOLOGY

The ship lift at the Three Gorges Dam is the world's largest vertical gear-based lift, Fig. 12. It has a lifting height of 113 meters, with usable space dimensions of 120x18x3,5 meters and a moving mass of approximately 15.500 tons. Four sets of rack and pinion climbing drive mechanisms of the Three Gorges ship lift are installed on the ship compartment, and four sets of accident safety mechanisms are arranged adjacent to the drive mechanism. The safety mechanism adopts the long nut column short rotating screw type, and uses the friction self-locking condition of the screw and nut trapezoidal thread to realize the safe locking of the ship's cabin. The ship chamber is the key equipment of the ship lift, and the design of other structures, equipment, and facilities is focused on the ship chamber. The self-supporting ship carrier consists of two main beams, two safety beams, two drive beams, chamber plate structure, and ship carrier head structure, as well as auxiliary structures. Both ends of the safety cross beam and the drive cross beam are suspended on the outer side of the main longitudinal beam to form the side platform structure, [35].

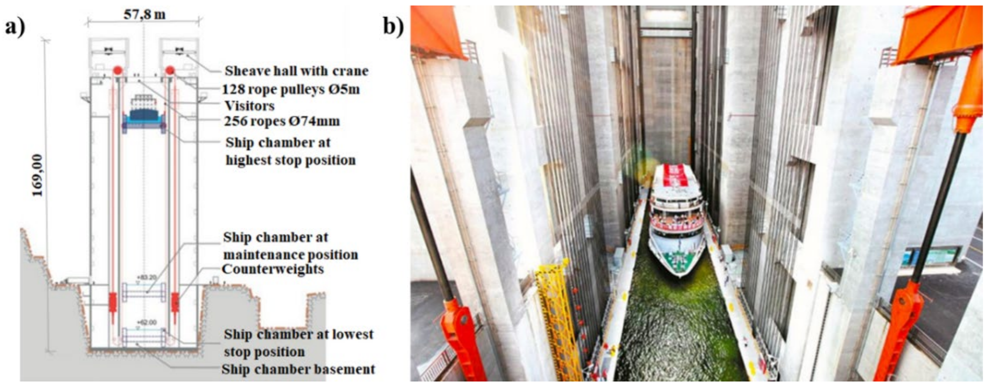


Figure 12. a) Shematic view of ship lift, [36]; b) Process of ship lifting, [37].

The lift utilizes a beam stacking scheme with the same gate slot for gate sealing and straight gate lifting. This scheme offers exceptional advantages in gate sealing reliability, equipment operation safety, as well as accommodating water level variations during navigation. The upper gate of the ship lift has 7 operational overlapping beams and 1 operational straight gate. The auxiliary water retention gate is constructed in the form of the same beam that overlaps with the slots and lifts the straight gate, located upstream of the operational gate. This gate is used for maintenance in case of accidents.

The process of a ship passing through the lift takes approximately 40 to 60 minutes in one direction, and the lift can accommodate only one ship at a time. After detaching from the gate at the upper stream, the ship vertically descends at a speed of 0,2 m/s until it reaches the same level as the other side of the dam. The lift then connects to the gate on the opposite side of the dam, after which the ship exits the lift. This operation is then repeated in the opposite direction, i.e., the second ship is raised to the upper reservoir. For safety reasons, the speed of the ship during entry and exit from the lift must not exceed 1 m/s, [38].

2.1.6. KEY TECHNOLOGY OF FIVE-STEP SHIP LOCK

Medium and large ships, weighing over 3.000 tons, must use the five-step ship lock. With a ship lock, it is possible to enable the passage of ship on both sides of the dam simultaneously, Fig. 13. The southern route is used by vessels from the upper watercourse, while the northern route is used by ships from the lower watercourse. Ships must pass through each of the 5 chambers, one after the other, in order to overcome the difference in water level. The maximum allowable speed of the ship during entry and exit from the ship lock is 1 m/s, while the maximum allowable speed between two consecutive chambers is 0,6 m/s. Compared to the ship lift, the five-step ship lock has a greater capacity, allowing the passage of four ships in each group, but the passage takes at least 2,5 hours, [38].

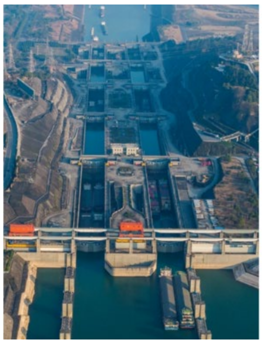
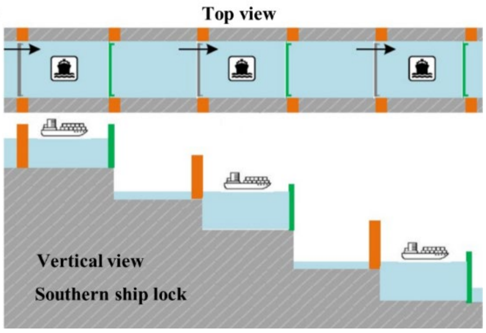
a)  b) 

Figure 13. a) Ship lock, [39]; b) Process of passing through a ship lock, [38].

2.1.7. TECHNOLOGY FOR TRANSFERRING WATER WITH HIGH HYDROSTATIC PRESSURE AND LARGE FLOWRATES.

The dual-line continuous five-step ship lock of the Three Gorges Project represents the largest river lock in the world. The designed water level is 113 meters, with a maximum operating valve height of 45.2 meters. The one-way carrying capacity is designed as 5 x 10^7 tons, and the allowable free space height is 18 meters. The effective dimensions of each chamber are 280 meters x 34 meters x 5 meters (length x width x minimum water depth above the sill), Fig. 13.

The key technology in the hydraulic project deals with ensuring the safety of the canal system and valve gears, as well as the resting state of the chamber during the required water transfer time.

The type of water transmission system adopted in the Three Gorges Dam includes the following: The main water transport gallery is symmetrically arranged on either side of the ship locks. Separate water outlets with four segments and eight branch pipes with constant inertias are installed on the lower plate of the chamber, and water energy dissipation plugs are placed over the water outlets. Excellent dynamic balance characteristics and dual dissipation of water energy (through the cover and water cushion of the locking chamber) ensure stable and rapid water transport in the chamber.

The ship lock is located on the left bank of the dam. The main structure is 1.6 km long and is constructed within the mountain, excavating the rock mass to a maximum depth of 170 m. If a traditional gravity construction were adopted for the ship lock, the amount of excavation and concrete would be enormous, construction would take a long time, and the high slope would be extremely complex. Based on the geological conditions of the lock location, it was proposed that the lock be fully lined. For this type of ship lock, the head of the lock and the side rock chamber are lined with a thin reinforced concrete lining. This lining works together with the rock mass to withstand the loads from the gates with inclined ladders, water pressure, and ships, through specially developed high-strength shear bolts. The ship lock of the Three Gorges Dam, with its double lines and 5 steps, is the world's first fully lined ship lock, [32].

2.1.8. STABILITY OF THE FOUNDATION

The Three Gorges Dam consists of 23 spillway sections, located in the middle of the river channel with a total length of 483 meters, while 26 sections of the dam with powerhouses are located at both ends of the spillway dam, with a total length of 1.228 meters. Along the foundation line, the dam sections are built on different ground levels, low on the river bottom and high on the riverbank. Detailed geological investigations show that although the dam foundation mainly comprises plagioclase granite that is intact, homogeneous, of low permeability and high strength, there also exist weathered zones, faults and joints in the rock mass.

The dam foundation mainly consists of rock blocks, various faults, fractures, joints and so-called ‘rock bridges’ (defined as the intact rock between the ends of sub-parallel fractures). Most of the faults and joints have a steep dip angle, but there are gently downstream-dipping joints that are actually the most important factors influencing the stability of the dam. On the other hand, even in the regions where the gently dipping fractures are most developed, no deterministic and through-going sliding paths in the rock mass exist due to the presence of the rock bridges. Thus, the dam could slide only if some of the rock bridges fail, so as to create at least one throughgoing sliding path, [40].

2.2. BENEFITS

2.2.1. FLOOD CONTROL

The dam is considered an indispensable key project in controlling serious floods in the middle and lower reaches of the Yangtze River because the upper Yangtze generates flood peaks much larger than the capacity of the middle and lower reaches, especially at Jingjiang, where the land outside the embankments is lower than the level of floodwaters. In the event of an extraordinary flood, it would overflow the embankments, directly endangering 15 million people, 1.53 million hectares of arable land, and a number of large and medium-sized cities, enterprises, and vital infrastructure facilities.

That has always been a potential threat to China. With the completion of the project, a large reservoir of 39.3 billion cubic meters has been formed, of which 22.15 billion cubic meters are intended for regulating flood peaks and storing floodwater, raising the flood control capacity of the Jingjiang to the standard of a 100-year flood control, and if combined with other measures, it can prevent the occurrence of devastating floods. Therefore, the construction of the Three Gorges Dam is an important step in ensuring the safety of people and the economic development in the middle and lower reaches of the Yangtze, [27].

2.2.2. ELECTRICITY PRODUCTION

The Three Gorges Dam is an important component of China's energy program and electricity production, as well as one of the important measures in balancing the proportions of energy sources, achieving the transmission of electricity from west to east, and coordinating the arrangement of electricity supply throughout the country. The total installed capacity of the Three Gorges Dam is 18,200 MW, with an annual production of 84.7 TWh. If we add six generating units of the underground power plant and two units for supplying the power plant, the total installed capacity reaches 22,500 MW, which constituted one-tenth of the total national capacity in 1996. With this in mind, the Three Gorges Dam power plant is the leading power plant in China's electrical grid, [27].

2.2.3. NAVIGATION

The Yangtze River is considered the "golden waterway" of China, accounting for about 80% of the country's domestic inland water transport. It has always been a navigational route for Eastern, Central, and Western China. However, the navigational channel, especially the 660 km section from Yichang to Chongqing, passes through steep canyons where the water level can reach up to 120 meters, the currents are fast, and there are many dangerous rocks. The depth and width of the navigation routes are insufficient, leading to high navigation costs. The dam has fundamentally improved navigational conditions by submerging dangerous rocks, increasing the depth of navigation, calming water currents, and expanding the navigable area. This allows 10,000-ton tugboats to travel from Shanghai to Chongqing. The low navigation costs and large transport capacity have far-reaching significance in alleviating pressure on railway transport and speeding up the flow of goods between the east and west, thereby altering industrial arrangements, [27].

2.3. IMPACT ON THE ENVIRONMENT

A large portion of China's electricity is generated by thermal power plants, which burn one of the dirtiest fossil fuels - coal, and the Three Gorges Dam reduces its usage. However, there are significant ecological and geological changes in the Yangtze River basin, both upstream and downstream of the dam itself, [41].

2.3.1. EMISSIONS

The Three Gorges Dam has reduced coal consumption, which was used for electricity generation, by 31 million tons per year. This has avoided the emission of 100 million tons of greenhouse gas emissions, one million tons of dust, one million tons of sulfur dioxide, 370.000 tons of nitric oxide, 10.000 tons of carbon monoxide and a significant amount of mercury. Hydropower saves the energy needed to mine, wash, and transport the coal from northern China. Furthermore, maritime traffic has reduced carbon dioxide emissions by 10 million tons compared to truck usage, while costs have decreased by 25%, [42].

2.3.2. EROSION

Erosion and sedimentation in the area of the dam are directly linked to it. As much as 80% of the land area around the dam experiences erosion, with approximately 40 million tons of sediment deposited in the Yangtze River annually. Due to slower flow above the dam, a significant portion of this sediment is retained there instead of flowing downstream, resulting in a much lower sediment load downstream [42]. Sediments primarily accumulate during the flood season, and the operation of the reservoir at the flood control level, which is 145 meters, is favorable for sediment release. Research indicates that if the dam operates for 100 years at a level of 175 meters, the reservoir will achieve sediment balance between inflow and outflow, [27].

2.3.3. LANDSLIDES

Erosion within the reservoir, caused by rising water levels, has led to frequent landslide occurrences, resulting in disturbances on the surface of the reservoir. Two incidents occurred in May 2009 when between 20.000 and 50.000 cubic meters of material fell into the flooded Wuxia Canyon of the Wu River, [42].

3. CONCLUSION

In this paper, we investigated the emergence of the first hydraulic engineering structures. We acquainted ourselves with the four primary types of dam constructions: embankment, buttress, arch, and gravity dams, which developed in line with the requirements and technological capabilities of their times. We analyzed the fundamental structural characteristics of each type mentioned and observed how each construction is tailored to the specific terrain requirements, prioritizing stability, safety, and cost-effectiveness. Understanding these structural elements provides us with a deeper insight into the complexity of dam engineering design and enhances our understanding of their role in water management and infrastructure development.

The Three Gorges Dam represents an extraordinary engineering marvel, showcasing China's dedication to economic development. One of the most significant benefits of the Three Gorges Dam is its contribution to flood control, thereby protecting millions of people living in downstream regions and helping to reduce economic and social disruptions caused by frequent floods. Dam has also reduced fossil fuel consumption, contributing to a decrease in harmful gas emissions. Additionally, the Three Gorges Dam has improved transportation and trade along the Yangtze River. In addition to its benefits, the dam also leaves a few negative consequences. The formation of the reservoir is closely linked to erosion in the surrounding areas, leading to landslides on its banks and sediment deposition.

During the design and construction of the Three Gorges Dam, a series of challenges were continuously faced. Significant attention was devoted to the floodwater discharge system and energy dissipation during high water levels, the formation of the complex power plant structure, and the establishment of transportation routes. After detailed research, these issues were successfully overcome. A five-step ship lock and a ship lift were adopted for vessel passage over the dam, which currently holds the record as the world's largest.

The successful practice of the Three Gorges Project significantly enhances the utilization of water resources in China. Many innovative technologies developed in this project have been widely applied to future projects worldwide and play a significant role in promoting global water conservation and technological advancement in the hydroelectric industry.

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42
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SAFETY REQUIREMENTS FOR TUNNELS REGARDING THE TRANSPORT OF DANGEROUS GOODS (ADR)

Abstract

EU Tunnel Directive 2004/54/EC aims to ensure a minimum level of safety for users in road tunnels in the Trans-European Road Network. EU member states are required to develop, at national level, their own detailed methodology for tunnel risk assessment. Along with that, ADR as the UN regulation in the field of dangerous good transportation by road, contains provisions concerning restrictions on the passage of vehicles carrying dangerous goods in road tunnels. Tunnel category A-E is assigned to each tunnel on the transport route, which regulate the types of dangerous goods to be allowed to go through the tunnel in order to avoid any hazards with major consequences. In this paper, basic principles of risk assessment and categorization of tunnels in accordance.

Keywords: road tunnels, safety measures, dangerous goods, ADR, tunnel category

БЕЗБЈЕДНОСНИ ЗАХТЈЕВИ ЗА ТУНЕЛЕ У ПОГЛЕДУ ПРЕВОЗА ОПАСНИХ МАТЕРИЈА

Сажетак

Директива ЕУ о тунелима 2004/54/ЕЦ има за циљ да обезбједи минимални ниво безбједности за учеснике у саобраћају у тунелима. Од држава чланица ЕУ се захтијева да развију, на националном нивоу, сопствену детаљну методологију за процјену ризика код тунела. Паралелно с тим, АДР као пропис УН у области друмског транспорта опасних материја садржи одредбе које се односе на ограничења проласка возила која превозе опасан терет у друмским тунелима. За сваки тунел на транспортној траси додијељена је категорија тунела А-Е, која регулише врсте опасних материја које треба да прођу кроз тунел како би се избјегле опасности са већим посљедицама. У овом раду су приказани основни принципи процјене ризика и категоризације тунела у складу са АДР, са посебним освртом на регулативу у нашој земљи.)

Кључне ријечиs: друмски тунели, безбједносне мјере, опасне материје, АДР, категорија тунела.

1. INTRODUCTION

Road traffic, especially heavy goods traffic in tunnels increases during years. While most engineering techniques concerning tunnel construction and safety requirements have been continually improving, the problem of dangerous goods transport through tunnels has not been satisfactorily solved yet. Tunnel risk assessment became mandatory for trans-European tunnels via EU Tunnel Directive 2004/54/EC [1] on minimum safety requirements for tunnels in the Trans-European Road Network (TERN), the length of which exceeds 500 meters. Many European countries adopted the requirement for all their tunnels with the goal to have a comparable and uniform safety standard for all tunnels within the TERN. Since EU does not impose a methodology, member states are required to develop, at national level, their own detailed methodology for their country. Managing the risks involved with transporting dangerous goods through road tunnels and finding solutions to these complex problems required varied scientific experience and strong financial support. For these reasons, the OECD's Road Transport and Intermodal Linkages Research Programme and PIARC's Committee on Road Tunnels launched a joint research project, which resulted in the Report [2,3] covering both regulatory and technical aspects of dangerous goods passage through road tunnels. A quantitative risk assessment (QRA) model has been developed as part of that research, which compares the risks of transporting dangerous goods through a tunnel to using an alternative route. A decision support model (DSM) was also developed as part of the research which allows decision makers to combine the results from the QRA with other relevant data. Authors in [4] presented a three step method to categorize Swedish road tunnels according to the regulation ADR-S 2017. The first is a logical decision model which, when followed should lead to well-founded basis for decisions regarding the appropriate categorization. The second is a simplified risk analysis method that can be used in the risk-based categorization of existing and new tunnels. Finally, expert assessment as a method for risk-based categorization is introduced as a third step. Authors in [5] dealt with tunnel hazards due to fires and explosions from a number of sources including transportation of dangerous goods, traffic accidents, combustion of mechanical or electrical installations, sabotage or terrorism. A quantitative risk analysis regarding hourly traffic volume and percentage of heavy goods vehicles in order to assess their impact on the risk level of a directional road tunnel were analyzed in [6]. This paper proposed risk charts useful for quickly assisting in making decisions on the most appropriate traffic control strategies. In Republic of Srpska, Ministry of Transport and Communications adopted the Rule book on minimum security requirements for tunnels [7] which came in force in 2021. This regulation presents the first step authority of our country has taken in managing the risks and safety requirements for tunnels located on road routes which are part of the Trans-European Road Network, the length of which exceeds 500 meters.

2. DANGEROUS GOODS AND ITS CLASSIFICATION ACCORDING TO THE ADR

Transport of dangerous goods by road is regulated by the UN Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) with its constituent parts, annexes A and B and the act on notification. The aim of this regulation is to permit the free movement of dangerous goods at an acceptable level of safety. ADR is a 1957 UN regulation concerning the international carriage of dangerous goods by road, valid in 54 countries. "ADR" is derived from the French name for the treaty: ***A**ccord relatif au transport international des marchandises **D**angereuses par **R**oute*. Every two years the regulations are updated with the latest version applicable being the ADR 2023.

In ADR, it is stated that, with the exception of certain exceptionally dangerous materials, hazardous materials may in general be transported internationally in wheeled vehicles, provided that two sets of conditions be met:

- Annex A regulates the merchandise involved: a classification system to regroup the large variety of dangerous goods, notably their packaging and labels;
- Annex B regulates the construction, equipment, and use of vehicles for the transport of hazardous materials

Table 1 shows the thirteen different classes and subdivisions of dangerous goods as defined in the ADR [8].

Table 1. Dangerous goods classes according to ADR

Class	Description
1	Explosive substances and articles
2	Gases – Flammable gases – Non-flammable and non-toxic – Toxic
3	Flammable liquids
4.1	Flammable solids, self-reactive substances, polymerizing
4.2	Substances liable to spontaneous combustion
4.3	Substances which, in contact with water, emit flammable
5.1	Oxidizing substances
5.2	Organic peroxides
6.1	Toxic substances
6.2.	Infectious substances
7	Radioactive material
8	Corrosive substances
9	Miscellaneous dangerous substances and article

3. TUNNEL CATEGORIES ACCORDING TO ADR

The categorization of a tunnel is based on the assumption that there are three major hazards that could cause any of the types of harm [8]:

- explosions,
- release of toxic gas or volatile toxic liquid,
- fires.

The main consequences of these hazards and the efficiency of possible mitigating measures, are following [2, 8]:

- “Large explosions”, where two levels could be distinguished: 1) “Very large” explosion is the explosion of a full loading of LPG in bulk heated by a fire (Boiling Liquid Expanding Vapour Explosion – BLEVE – followed by a fireball, referred to as “hot BLEVE”); 2) “Large” explosion is the explosion of a full loading of a non-flammable compressed gas in bulk heated by a fire (BLEVE with no fireball, referred to as “cold BLEVE”). A “very large” explosion (“hot BLEVE” or equivalent) would kill all the people present in the whole tunnel or in an appreciable length of tunnel and cause serious damage to the tunnel equipment and possibly its structure. The consequences of a “large” explosion (“cold BLEVE” or equivalent) would be more limited, especially regarding damage to the tunnel structure.
- “Large toxic gas releases” can be caused by leakage from a tank containing a toxic gas (compressed, liquefied, dissolved) or a volatile toxic liquid. It would kill all the people near the release zone and in the area where the ventilation (natural or mechanical) would push the gas. A part of the tunnel may be protected but it is not possible to protect the whole tunnel, especially in the first minutes after the accident.
- “Large fires” could have more or less important consequences (a certain number of victims and limited to serious damage to the tunnel) depending on the tunnel geometry, traffic and equipment.

The order of these hazards: explosion / toxic release / fire, corresponds to the decreasing consequences of an accident and the increasing effectiveness of the possible mitigating measures. From the above assumptions, a system with five groupings is derived, ranked A to E *in order of increasing restrictions* concerning goods permitted in tunnels:

- **Tunnel category A**: All dangerous goods loadings which authorized on open roads (that means there are no restrictions for the transport of dangerous goods). No road sign or additional panel is necessary.
- **Tunnel category B**: All loadings in grouping A except those which may lead to a very large

explosion - "hot BLEVE" or equivalent (that means there are restriction for dangerous goods which may lead to a very large explosion).

- **Tunnel category C**: All loadings in grouping B except those which may lead to a large explosion - "cold BLEVE" or equivalent or a large toxic release (that means there are restriction for the carriage of those dangerous goods which may lead to either a very large explosion, a large explosion, or a large toxic release).
- **Tunnel category D**: All loadings in grouping C except those which may lead to a large fire (that means there are restrictions for the carriage of those dangerous goods which may lead to either a very large explosion, a large explosion, a large toxic release, or a large fire.

Tunnel category E: No dangerous goods are permitted, except those which require no special marking on the vehicle (that means there are restrictions for all dangerous goods other than UN numbers 2919 (nonfissile radioactive material), 3291 (clinical waste), 3331 (fissile radioactive material), 3359 (fumigated cargo transport unit) and 3373 (biological substances)).

Grouping A is the largest category. It contains all loadings which are authorized for road transport, including the most dangerous ones. Grouping E is the most restrictive one, containing only those loadings which do not require a special marking on the vehicle, i.e. the least dangerous ones. All loadings in Grouping E are included in Grouping D, all loadings in Grouping D are in Grouping C, and so on.

It is the responsibility of each national authority to categorize its tunnels accordingly and properly label it. Figure 1 shows one example of the tunnel category label.

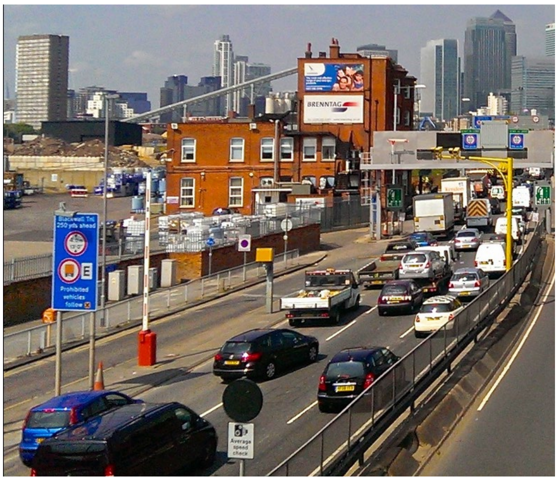

Figure 1. The sign "Class E", the Blackwall Tunnel approach road, East London [https://en.wikipedia.org/wiki/ADR_(treaty)#/media/File:Towards_Blackwall_Tunnel_(14075187245).jpg]

European countries have different strategies regarding the acceptability of the dangerous goods transport through tunnels on their trunk road networks. For example, France is quite restrictive, while on the other hands, Austria's tunnels have high safety standards. In Spain, there is a designated subset of the road network for the transport of dangerous goods. Sweden also has designated primary and secondary dangerous goods routes [9].

4. A RISK ASSESMENT

The seriousness of damage that can occur during the transportation of dangerous goods through the tunnel can be expressed by the loss of human life, environmental pollution, tunnel damage and interruption of transportation. The types of harm are the same for vehicles transporting dangerous goods as for other vehicles, the difference is only expressed in the potential level of damage. Types of damage which can be analyzed are following [9]:

- Harm to people: People injuries or fatalities are the most important hazard type relating to the assessment of the transport of dangerous goods through tunnels. Statistical fatalities is the most commonly used indicator for the quantitative assessment. Affected people could be: the tunnel users (primary), people situated next to the tunnel, and people (possibly) situated downwind.

- Economic losses: There are the direct capital losses due to the damage caused by the event, and indirect economic losses due to the tunnel closure.
- Impact on the environment: In the case of an accident in the tunnel, even though release of hazardous material is limited to a narrow area in the tunnel, however, the consequences can also occur in the open (pollution of soil, groundwater, habitat destruction, etc).

To managing the risks involved with transporting dangerous goods through road tunnels, it is necessary to perform a risk assessment. The risk assessment is a tool to identify the hazards and analyze the probability and magnitude of damage in order to obtain a quantifiable risk indicator.

Figure 2 illustrates the typical procedure for a risk assessment [9, 10]. The risk assessment procedure includes the stages of risk analysis, risk evaluation and risk reduction. The first step of the risk analysis stage is the description of the tunnel itself (the geometrical and the traffic characteristics along with the operating procedures and the emergency planning are described). Next is the hazard identification step, where all potential hazards that may result in particular risks are identified and categorized. For each potential risk, a frequency and consequence analysis is performed resulting in risk estimation. Following the risk estimation step, a risk evaluation is performed by comparing the risk estimation with the risk criteria. In case the risk criteria are satisfied, the risk level is acceptable. On the other hand, where the risk is above the acceptable level, additional measures are proposed and the procedure of risk assessment is being performed again until the risk falls in levels where acceptable criteria are met [10].

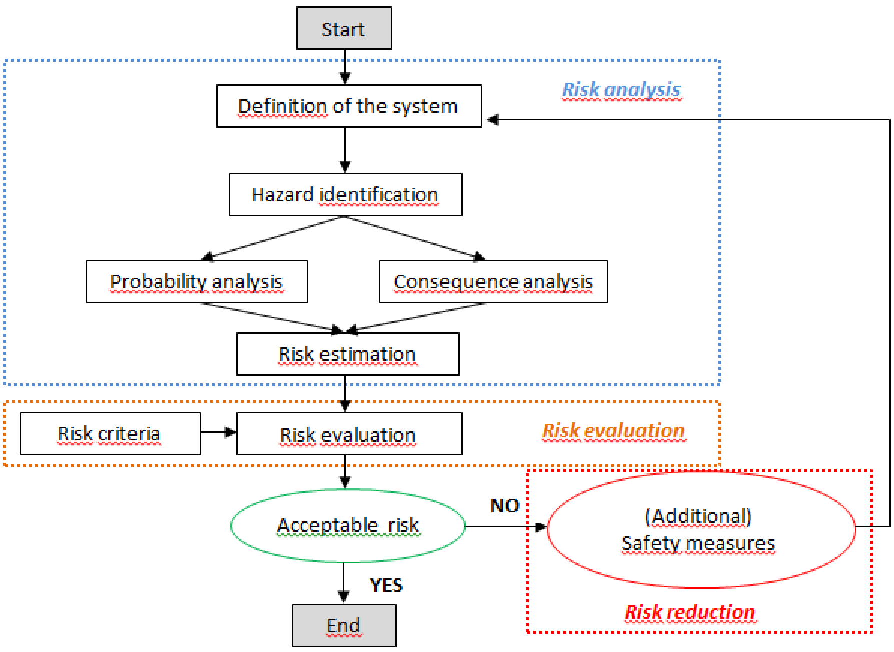

Figure 2. Risk assessment flowchart [9, 10]

There are two approaches to analyze a risks regarding dangerous goods in a tunnel: quantitative or qualitative, or combined it. Qualitative methods are paying particular attention to the interaction and the interdependence of events. On the other hand, quantitative methods are based on the calculation of characteristic risk values. However, due to the lack of sufficient data for complete quantitative analysis, it is applicable to combine qualitative and quantitative components.

4.2. THE QUANTITATIVE RISK ASSESSMENT MODEL (QRAM)

As the numerous factors and variables influence probabilities and consequences of accidents involving dangerous goods, it is very demanding to quantify a risk, both into and outside tunnels. A comprehensive model, named quantitative risk assessment model (QRAM) [2], was developed through international co-operation and can be used in all countries. The QRAM aims to quantify the risks regarding transport of dangerous goods on given routes of the road system, as well as to compare one route including a tunnel with an alternative route in the open area. Components relevant for the developing of the QRA model are as follows:

- Indicators
- Accident scenarios
- Evaluation of accident probability
- Determination of physical consequences, structural and environmental damage
- Evaluation of consequences on humans (open and tunnel sections)
- Uncertainty/sensitivity analysis
- Validation

A complete assessment of the risks regarding transport of dangerous goods could require the consideration of many variables: variety of dangerous materials, variety of meteorological conditions, variety of type of accidents, sizes of breaches, vehicles fully or partially loaded, etc. It is almost impossible to consider all of it, so some simplifications need to be made. The model is based on consideration of 13 accident scenarios, presented in Table 2, which are representative of the groupings described in the proposed regulations. The use of QRAM software for conducting tunnel categorization according to ADR agreement as proposed by the developers of the QRAM software can be made by assigning the proper scenarios to each tunnel category.

Table 2. Scenarios representative of each grouping in the QRA model [2]

Grouping	Scenario No.	Description
E	1	Heavy Goods Vehicle fire with no dangerous goods (20 MW)
	2	Heavy Goods Vehicle fire with no dangerous goods (100 MW)
D		*In addition to scenarios for Grouping E*:
	3	BLEVE of Liquid Petroleum Gas (LPG) in cylinders
	4	Release of acrolein in cylinders
C		*In addition to scenarios for Grouping D*:
	5	Pool fire of motor spirit in bulk
	6	Vapour Cloud Explosion (VCE) of motor spirit in bulk
B		*In addition to scenarios for Grouping C*:
	7	Release of ammonia in bulk
	8	Release of chlorine* in bulk
	9	Release of acrolein in bulk
	10	BLEVE of carbon dioxide in bulk (not including toxic effects)
A		*In addition to scenarios for Grouping B*:
	11	BLEVE of Liquid Petroleum Gas (LPG) in bulk
	12	Vapour Cloud Explosion (VCE) of LPG in bulk
	13	Torch fire of LPG in bulk

BLEVE: Boiling Liquid Expanding Vapour Explosion, LPG: Liquefied Petroleum Gas
*Chlorine is considered in countries where its transport is allowed in appreciable quantities on roads

4.3. THE DECISION SUPPORT MODEL (DSM)

In decision making process about which groupings are to be permitted in tunnels, it must be taken in consideration that the goods not allowed in the tunnel should be transported on some alternative route. One of the primary aims for the decision on which grouping to permit in a tunnel is to minimize the risk to human life, but there are other factors that need to be taken into account. The features that are evaluated and weighted by a decision support model (DSM) are following [2]:

- Injury and fatality risks to road users and the local population using the indicators from the QRAM.
- Material damage due to possible accidents on tunnel or alternative route.
- Environmental impact due to an accident on tunnel or alternative route.
- Direct expenses (investment and operational cost of tunnel risk reduction measures as well as possible additional costs in the transport of dangerous goods).
- Inconvenience to road users due to a possible accident (time lost during repair works after an incident in the tunnel).
- Annoyance to local population (environmental impact of dangerous goods traffic, with the exclusion of possible accident consequences, but possibly including psychological impact).

In decision making process, the decision maker must determine which features are relevant and how these should be weighted against each other. A computerized tool has been developed, making it possible to take account of the mentioned features in a rational manner.

4.4. RISK REDUCTION MEASURES

In order to reduce either the probability or the consequences of an accident in a tunnel, there are several measures that could be implemented in tunnels. A number of these measures are included in the QRAM. Using qualitative and quantitative methods for the analysis of the effects of risk reduction measures, it is possible to assess the effects of these measures for a given tunnel. For each tunnel, the results of measures and related costs are specific, depending on the traffic characteristics and local circumstances. Also, costs can differ notably if the measures are implemented during the initial design and building stage compared to the cost of retrofitted measures. Risk reduction measures classified according to their main purpose are listed in Table 3.

Table 3. Risk reduction measures classified according to their main purpose [2]

MEASURES TO REDUCE THE PROBABILITY OF AN ACCIDENT		
Related to tunnel design and maintenance		
Tunnel cross section and visual design	Alignment Lighting (normal)	Maintenance Road surface (friction)
Related to traffic and vehicles		
Speed limit Prohibition to overtake	Escort Distance between vehicles	Vehicle checks
MEASURES TO REDUCE THE CONSEQUENCES OF AN ACCIDENT		
Alarm, information, communication of operator and rescue services		
Close-circuit television Automatic incident detection	Automatic fire detection Radio communication (services)	Automatic vehicle identification Emergency telephone
Communication with users		
Emergency telephones Radio communication (users)	Alarm signs/signals	Loudspeakers
Evacuation or protection of users		
Emergency exits Smoke control	Lighting (emergency) Fire-resistant equipment	Failure management
	Reduction of accident importance	
Fire-fighting equipment Rescue teams	Drainage Road surface (non-porous)	Emergency action plan Escort
Reduction of the consequences on the tunnel		
Fire-resistant structure	Explosion-resistant structure	

5. TRANSPORTATION OF DANGEROUS GOODS THROUGH TUNNELS IN THE REPUBLIC OF SRPSKA

In our country, Republic of Srpska, Ministry of Transport and Communications declared the Rule book on minimum security requirements for tunnels [7] which entered into force in 2021. In order to provide traffic in the tunnel to be safe, it is necessary to undertake infrastructural safety measures and measures related to the use of the tunnel. The Rulebook prescribes that safety measures are based on the following basic parameters: 1) the length of the tunnel, 2) number of tunnel pipes, 3) number of traffic lanes, 4) cross-sectional geometry, 5) harmonization of vertical and horizontal road elements and road facilities with tunnel elements, 6) type of construction (tunnel and roadway) and surface characteristics of the roadway structure, 7) one-way or two-way traffic, 8) traffic load per tunnel tube (including time distribution), 9) risk of traffic congestion (daily or seasonal), 10) response time of emergency services, 11) percentage of heavy goods vehicles in the total traffic in the tunnel (expressed as a percentage), 12) percentage share of vehicles that transport dangerous goods substance and type of hazardous substance, 13) construction and traffic characteristics of access roads, 14) traffic lane width, 15) vehicle speed, 16) geographical environment and meteorological conditions.

A risk analysis is a detailed risk assessment for a specific tunnel, taking into account all project factors and traffic conditions that affect safety, especially the characteristics and type of traffic, the length and geometry of the tunnel, as well as the predicted number of heavy goods vehicles per day. By risk analysis, additional safety measures are determined in order to increase safety, that is, reducing the risk in a given tunnel (reducing the evacuation route, reducing the distance of cross roads by emergency services, increasing the fire resistance of building structures and equipment, positioning of the fire station services with the definition of special equipment, additional traffic signaling, integral management of safety systems in accidents and the like). Risk analysis is a mandatory part of the documentation in the procedures for obtaining construction and use permits for tunnel.

When it comes about transporting the dangerous goods through the tunnel, this Rule book prescribes the regulation governing the transportation of dangerous goods (ADR) should be applied. Also, following measures should be taken:

- to perform a risk analysis before defining conditions and ways of transporting dangerous goods through tunnels,
- placement of appropriate traffic signs on entrances to the tunnel, i.e. before the tunnel at a sufficient distance, to enable drivers to choose alternative routes direction,
- to determin a special operational measures whose purpose is to reduce risks during the transportation of dangerous goods through the tunnel.

6. CONCLUDING REMARKS

Safety measures to be applied in road tunnels are based on a systematic consideration of all aspects including: tunnel infrastructure, works in tunnels, users and vehicles. If there are additional characteristics which must be taken in account, such as the transport of dangerous goods through tunnel, a detailed risk analysis must be carried out to determine if there is a need for additional safety measures and/or additional equipment to ensure a high level of tunnel safety. Risk analysis is applied both in the design of new tunnels and for existing ones. The risk analysis must take into account possible accidents, which clearly affect the safety of road users in tunnels, and which could happen during tunnel operation, and the nature and magnitude of their possible consequences. On the basis of the risk analysis for the transport of dangerous goods through tunnels, the categorization of tunnel is done (A - E), regulating the types of dangerous goods to be allowed to go through the tunnel, in order to avoid any hazards with major consequences. Categorization is a complex process where it is necessary to address the risks in the tunnel, the risks along the alternative route for loadings restricted for passing the tunnel and what risk reducing measures that are practically applicable. The decision making regarding categorization of tunnels can be structured using quantitative and qualitative approaches, known as the quantitative risk assessment model (QRAM) and the decision support model (DSM), or combining these two.

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43
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THE ROLE OF RESERVOIRS IN MITIGATING THE CONSEQUENCES OF CLIMATE CHANGE: CASE STUDY OF THE VRBAS RIVER BASIN

Abstract

The consequences of climate change are becoming increasingly evident in all aspects of human activity, particularly in the field of water, affecting the availability and accessibility of water resources, and intensifying extreme phenomena such as droughts and floods. These impacts, in combination with existing vulnerabilities, can have significant consequences for society as a whole. Consequences of climate change in the Vrbas River basin, with a special focus on flood protection, particularly in the city of Banja Luka, and the provision of water for irrigation in the downstream part of the basin, were analyzed in the article. It analyzes the role of existing and planned reservoirs in mitigating adverse events, emphasizing the importance of integrated water resources management.

Keywords: climate change, water storage reservoir, flood waves, irrigation, reliability

УЛОГА АКУМУЛАЦИЈА У УБЛАЖАВАЊУ ПОСЉЕДИЦА КЛИМАТСКИХ ПРОМЈЕНА: ПРИМЕР СЛИВА РИЈЕКЕ ВРБАС

Сажетак

Посљедице климатских промјена све су очигледније у свим аспектима људског дјеловања, а посебно су изражене у области вода, утичући на доступност и расположивост водног ресурса, посебно интензивирајући екстремне феномене као што су суше и поплаве. Ови утицаји, заједно са постојећим рањивостима, могу имати изражене посљедице на друштво у целини. У чланку су анализиране посљедице климатских промјена на сливу ријеке Врбас, са посебним освртом на заштиту од поплава, посебно града Бања Луке, и обезбијеђеност испоруке воде за наводњавање површина у најнизводнијем дијелу слива. Анализира се улога постојећих и планираних акумулација на ублажавање неповољних догађаја, наглашавајући значај интегралног управљања водним ресурсима.

Кључне ријечи: климатске промјене, акумулације, поплавни таласи, наводњавање, обезбијеђеност

1. INTRODUCTION

Adverse impacts of climate change, irrespective of greenhouse gas (GHG) emission scenarios, are expected to have profound effects on water systems and the entire water sector, thereby impacting society as a whole. This is primarily due to the fact that problems in the water sector, arising from water scarcity and inadequate reliability of water management systems, are transmitted to all other social, economic, urban, and other systems. There are numerous examples from the past [1, 2] that have shown that a disruption in the normal functioning of water management systems quickly led to the destruction of the social, economic, and other stability of the entire community. On the other hand, there are examples showing that the development of water management systems has been the strongest driver of the entire society, and through intensifying the development of water management systems, countries have created conditions for overcoming economic and social crises.

The consequences of climate changes are well documented by different authors [3], and the most important ones affecting the water sector are:

- Increased temperatures - the last decade, 2011-2020, has been the warmest on record. Each successive decade since the 1980s has been warmer than the previous one, with nearly all land areas experiencing more hot days and heat waves.
- More severe storms - destructive storms have become more intense and more frequent in many regions.
- Increased drought - climate change is changing water availability, making it scarcer in numerous regions. Global warming exacerbates water scarcity in already water-stressed regions, increasing the risk of agricultural droughts that impact crops, and ecological droughts that increase the vulnerability of ecosystems.

The consequences of climate change in the Vrbas River basin will be analyzed in the article and the role of existing and planned reservoirs in mitigating adverse events will be examined. The primary focus will be on flood protection and on increasing the reliability of water supply for irrigation purposes.

2. DESCRIPTION OF THE ANALYZED AREA

The Vrbas River is a right tributary of the Sava River and is the largest river in the western part of the Republika Srpska (Bosnia and Herzegovina). Total area of the Vrbas basin is about 6273 km^2, of which 63.5% belongs to the Republika Srpska, and 36.5% is in the Federation of B&H (Figure 1) [4]. Vrbas springs below the mountain Vranica at about 1715 m above sea level and flows into the Sava near Srbac at an altitude of 90 m above sea level. The total length of the watercourse is 248 km (of which 131 km flows through the territory of Republika Srpska). The Vrbas basin is a typical example of a mountain landscape that occupies 90% of the area and is mainly located in the upper and middle part. The remaining 10% is the lower river plain, primarily located in Lijevče Polje and the Skopaljska valley. The Vrbas drains important karst areas (especially the Pliva and Crna Rijeka river basins), so the exact boundaries of the sub-basins are difficult to determine, because the boundaries of the orographic and hydrographic basins often do not coincide.

In the downstream part of the basin, the river flows through Banja Luka, the capital of Republika Srpska with approximately 180,000 inhabitants. The Vrbanja River, a torrential tributary, flows into the Vrbas within the urban area. Banja Luka is protected from the flooding by passive protection measures - embankments along those two rivers. However, due to increasingly unfavorable flood events (such as the flood in 2014), which are a consequence of climate changes as well as changes in the watershed, additional protection measures are necessary in order to adequately protect the city.

Average annual temperatures range from 8.6°C in the southern part of the basin to 11.3°C in the northern part (Banja Luka meteorological station) [4]. The analysis of average annual temperatures for period 1961-2019, shows an increasing trend of around 0.5°C for each subsequent decade. The intra-annual temperature distribution is similar for the entire basin, with the lowest temperatures in the December-January-February season gradually increasing until the warmest months of June-July-August.

The average annual precipitation in the basin (period 1961-2019) is about 1000 mm and ranges from about 800 mm per year in the south, to about 1,500 mm per year in the northern part of the basin [4]. The average potential evaporation is 700-750 mm. In the summer months, evaporation exceeds the precipitation. Maximum precipitation occurs mainly in late spring and early summer (May and June), while minimum precipitation occurs in January and February.

The hydrographic network of the Vrbas river basin is relatively good developed. Figure 1 shows a simplified hydrographic map of the basin. Vrbas has 36 direct tributaries longer than 10 kilometers, of which 11 have catchment areas greater than 100 km^2. The most important tributaries are Pliva with Janja, Ugar, Crna Rijeka and Vrbanja. The months with maximum flows are March, April and May, and the minimum flows occur in August and September. Intra-annual flow irregularities are pronounced, with maximal average monthly values over 3 times higher than the minimal values.

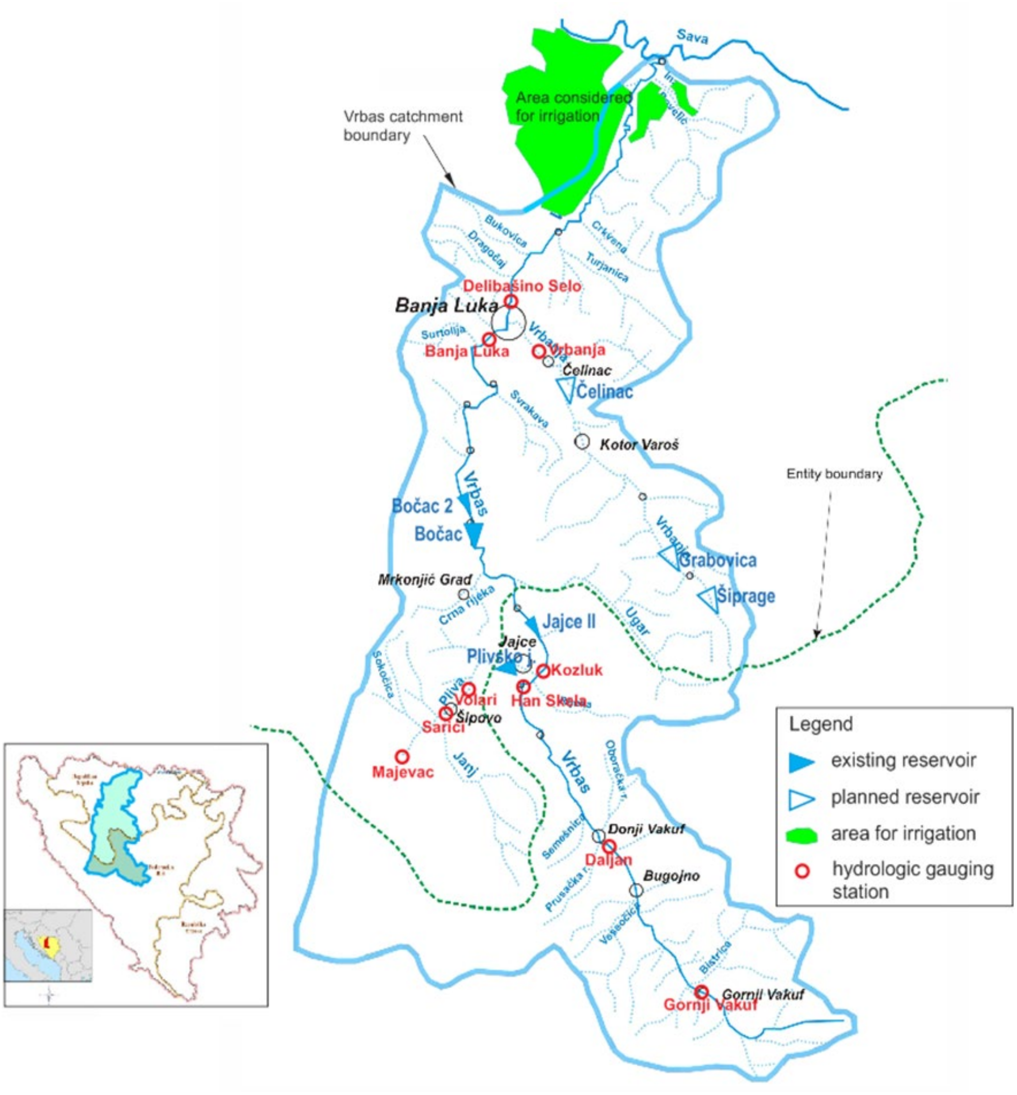

Figure 1. Hydrographic map of the Vrbas River basin (modified [4])

There are four reservoirs and hydroelectric power plants in the Vrbas river basin: Plivsko jezero with HPP Jajce I, Jajce II and Bočac with HPPs of the same name and Bočac 2 with the SHPP of the same name. The most significant reservoir is Bočac, with an active volume of 42.9 × 10^6 m^3, which can regulate the flow on a weekly level. Other reservoirs are with small active volumes enough just for daily flow regulation.

It is possible to irrigate about 36,000 ha in the area of the Vrbas river basin (the area that belongs to the Republika Srpska), but the most significant areas are located in the downstream part of the Vrbas River (Figure 1) – Lijevče polje, between Vrbas and Sava rivers. Net area for irrigation is about 20,000 ha. Based on the developed designs water abstraction for irrigation is planned: from the Vrbas River, from Vrbas - Osorna - Borna channel, by discharge of water from the water storage reservoirs, or, in limited quantities, from underground, because groundwater is reserved for water supply of Laktaši and Gradiška settlements.

3. CONSEQUENCES OF CLIMATE CHANGE IN THE VRBAS RIVER BASIN

Observations of climate parameters on the territory of Bosnia and Herzegovina, primarily precipitation and temperature, indicate the following important facts: there is an increase in temperature in all parts of the country, the average annual precipitation has not significantly changed, but the number of days with precipitation has decreased, and the number of days with intense precipitation has increased. These observed changes also lead to alterations in water regimes, which further affect ecological, economic, social, and other aspects. To timely mitigate the consequences of climate change, it is necessary to assess the magnitude of expected changes and their consequences in future time periods. The analysis of the consequences of climate change in the Vrbas River Basin has been considered in several studies, among which the most significant are: 'Study of the Economic Impact of Climate Change on the Energy and Agricultural Sectors of the Vrbas River' [4], and the Flood Risk Management Plan for the Vrbas River Basin of Republika Srpska.

The consequences of climate change on water regimes in the Vrbas River Basin have been studied for three common climate change scenarios (depending on the predicted concentration of CO_2 at the end of the century): A1B, A2, and RCP8.5. For more detailed analyses, scenario A2 was used, which is the middle of the three considered scenarios, assuming a CO_2 concentration of around 850 ppm at the end of the century [5]. Projections of changes were made for three 30-year intervals: 2011-2040 (near future), 2041-2070 (middle of the century), 2071-2100 (end of the century), with the base period being 1971-2000. The analysis included mean annual temperatures, intra-annual distribution of temperatures, mean seasonal temperature values, annual sum of precipitation, intra-annual distribution of monthly precipitation sums, and seasonal sums of precipitation. Based on data on precipitation and temperatures, as well as analyses of potential evapotranspiration (PET), the hydrological model MIKE NAM was used to determine daily flow rates at the locations of the gauging stations, enabling the analysis of flow rate changes in the considered time intervals until the end of the 21st century. Some indicators of climate, meteorological, and hydrological changes according to scenario A2 in the Vrbas River Basin are summarized.

- The change in average annual temperatures at all considered weather stations (Banja Luka, Bugojno, Jajce) ranges from 0.7 to 0.9°C in the near future, from 2.1-2.4°C in the middle of the century (distant future), to 4.4-4.7°C by the end of the century.
- The change in average monthly temperatures ranges from 0.1 to 1.8°C in the near future, 1.4-2.9°C in the distant future, and 3.6-5.8°C in the far future. Larger increases in monthly temperatures are expected in winter and summer months, while in spring and autumn, these changes are somewhat smaller.
- The change in the annual sum of precipitation ranges from 1.3-3.7% in the near future, -0.7-2.1% in the middle of the century, and -9.5-13% by the end of the century. Note: towards the end of the century, the decrease in annual precipitation is greater.
- Changes in monthly precipitation amounts range from -20 to 21% in the near future, -31 to 26% in the distant future, and -46 to 43% in the far future. It is very concerning that the largest reductions in monthly precipitation are expected in the summer months (June, July, and August), precisely during the growing season when precipitation is most needed. The reduction in summer precipitation in the near future is around 10%, around 20% in the middle of the century, and over 40% by the end of the century.
- The average annual flows at all 10 considered gauging stations: Delibašino Selo, Banja Luka, Kozluk, Han Skela, Daljan, Gornji Vakuf, Vrbanja, Volari, Sarići, Majevac (Figure 1), show similar trends. According to the A2 scenario considered, there could be some increases in mean annual water volumes by 2-8%, while a decrease in flows of up to 7% and 20-45% is expected by the middle and end of the century, respectively. Thus, a significant decrease in mean annual flows in the Vrbas River Basin can be expected towards the end of the century.
- The change in average monthly flows varies widely from -30 to 57% for all months in the near future, -41 to 33% in the distant future, and -58 to 36% in the far future. The greatest reduction in average monthly flow is in August, while the greatest increase in flow is possible in December.
- According to indicators of high-flows, extreme flows with a duration curve of Q1% (duration of 4 days) could increase by an average of about 13% (between -3 and 32% depending on the station) in the near future compared to the reference period. A similar

situation can be expected in the middle of the century, while by the end of the century, a very slight average increase in the flow of duration 1% is expected, with large differences between basins of -33 to 25%.

- All characteristic indicators of low-flows are changing unfavorably: low-flows are becoming less frequent and with longer durations. In the near future, this decrease is not significant, while their decrease in the middle and end of the century is significant. The flows of duration 80% (292 days) on average decrease by about 30% by the middle of the century, and by 61% by the end of the century. The largest decrease in low-flows is in the lower course of the Vrbas River basin, including the Vrbanja River, precisely in areas where the most valuable soil resources are located.
- The values of quantiles of high-flows are increasing on average, with this increase being particularly pronounced in the lower course of the Vrbas River with similar values for the entire period considered. Quantiles of low-flows are significantly decreasing at all stations, with the decrease increasing towards the end of the century. This decrease in the Banja Luka area, for a return period of 100 years, ranges from 40% in the near future to 75% by the end of the century. For the Delibašino selo station, the situation is somewhat more unfavorable, and for the Vrbanja River, these values range from -124% to -100% for the same return period.

The concise conclusion is that, as a result of climate change in the Vrbas River basin, a significant increase in temperatures is expected throughout the year, along with a decrease in total precipitation. However, there will also be an increase in the frequency and intensity of extreme precipitation events, accompanied by extreme flows. More frequent large flood waves with higher peaks than those observed during the last century can be expected, making flood protection conditions much more complex. It will be necessary to use reservoir management based on simulation and optimization models as a measure of active flood defense [6]. On the other hand, the most adverse consequence of climate change is the decrease in both precipitation and flows during the vegetative part of the year, leading to more frequent and longer-lasting droughts. As a result of climate change, the slope of the curve of flow duration becomes steeper in the future, implying that there will be increases in the flows of large, short-duration floods, up to 4 days, but decreases in flows of longer durations, especially those of long duration in the zone of small flows on the flow duration curve. The water sector is facing an increasingly challenging reality: extreme destructive flood waves may occur during the same year, followed almost immediately by a long dry, low-flow period. The downstream area of the Vrbas River basin, where the most valuable soil resources are located, is particularly endangered. The conditions for protecting these areas from floods will become more difficult. At the same time, agricultural production on these soils of the highest quality classes will become increasingly complicated over time and almost impossible without irrigation.

4. FLOOD WAVES AND THEIR MITIGATION

Detailed analyses of the impact of climate change on flood events indicate complex conditions which will require combined mitigation measures, including hydrological simulations and optimization models for reservoir management. The results of the management model for Bočac reservoir, that provides optimal management of the releasing facilities on the dam (gates on spillways, valves on bottom outlets, operation of turbines in hydropower plant) in the case of flood event, according to the criterion of minimizing flow in the downstream urban area [6] are presented. In addition to the flood wave in the main course of the Vrbas River, that can be mitigated by the Bočac reservoir, there is also a flood wave from Vrbanja River. It comes from the part of the catchment between the reservoir and the urban area (Banja Luka town), with no facilities to mitigate the flood wave (uncontrolled part of the catchment).

Analyzes were performed for flood waves of different return periods: 20, 50 and 100 years (FW20, FW50 and FW100), which were determined by applying a hydrological model based on the simulation of rain episodes [5]. The rain duration in the upstream part of the catchment was 12 hours, with total precipitation from 87 mm to 103 mm (for the 100 years return period). In the downstream part of the catchment (Banja Luka region), the rain duration was 24 hours, with total precipitation of 169 mm. All current rules for managing the release structures (gates, hydropower plant, outlets etc.) were incorporated in the model. The analyses were performed under the assumption that the initial water level in the reservoir was at 281 m a.s.l (working level), the maximum water level was 282 m a.s.l., and the minimum level was 271 m a.s.l. (during the intensive emptying of the reservoir).

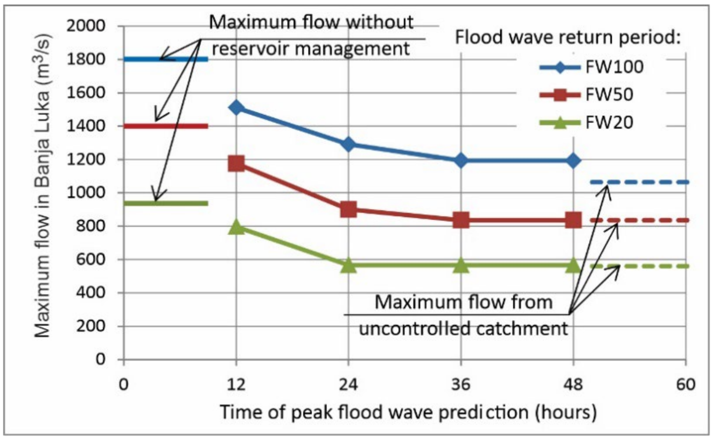

Figure 2. Maximum flows in Banja Luka for different flood waves return period and different times of peak flood wave prediction

The results of performed analyses show that despite the relatively small reservoir volume it is possible to significantly reduce the maximum flows in the city of Banja Luka (Figure 2). By effectively managing the reservoir, it is possible to delay the peak of the flood wave from the Vrbas River, avoiding its coincidence with the wave from the Vrbanja River. This is particularly important for mitigating floods in Banja Luka due to the rapid occurrence and high peak flows of the Vrbanja flood waves. When the optimal reservoir management strategy begins 36 hours before the peak flow, the maximum flows through Banja Luka do not exceed the maximum flows from the uncontrolled part of the catchment (Vrbanja River flood wave), for flood waves FW20 and FW50. Water is mostly discharged through the HPP Bočac. Gated spillways are open only a few hours (5 h for FW20 and 16 h for FW50). For FW100 maximum flow is higher than the maximum flow from uncontrolled catchment (by 130 m^3/s), and about 600 m^3/s lower than the flow that would occur without the Bočac Reservoir. Even if the optimal reservoir management begins one day before the peak flow, significant mitigation of flood wave is possible. Maximum flow through Banja Luka in that case is slightly above maximum flow from the uncontrolled catchment for FW50, and flood wave FW100 can be significantly mitigated, with maximum flows 230 m^3/s higher than the maximum flows coming from the Vrbanja River.

Planned reservoir Čelinac could further reduce the flood waves through the city of Banja Luka. The reservoir is planned in the downstream part of the Vrbanja river at site that controls an area of 607 km^2, with an average discharge of 13.2 m^3/s. The planned volume of the reservoir is 56×10^6 m^3, and the active volume is 43×10^6 m^3. An analysis of the effects of the reservoir on mitigation of flood waves was conducted using an approximate method, because all necessary data for detailed analysis were not available. The spillways are equipped with gates, allowing flexible flow management. The dam also has a bottom outlet and a hydroelectric power plant, with an installed flow rate of 30 m^3/s. The possible mitigation of the flood wave peak was carried out based on the balance equations of water inflow and outflow from the reservoir. Two calculation variants were performed: 1. with a constant maximum value of the outflow wave flow rate, and 2. with a gradual increase in the outflow flow rate. The first variant provides smaller maximal flood rates of the outflow wave and represents the upper limit of possible wave mitigation. According to the second variant, smaller reductions in the peak of the wave are obtained, but these values more closely correspond to realistic reservoir management. The analysis was performed for several initial water level values in the reservoir (PNV), or for several levels of pre-flooding: PNW = KNU = 233 m a.s.l., PNV(0.8 × Vk) = 230.45 m a.s.l., PNV(0.6 × Vk) = 227.6 m a.s.l. The calculation results for variant 1 show that it is possible to reduce the maximum flow rate of a 100-year return period wave by between 25% (without pre-flooding of the reservoir) and 63% if the water level is lowered to 227.6 m a.s.l. According to variant 2, for the same wave, reductions are slightly smaller, ranging from 3% (without pre-flooding) to 44% for pre-flooding up to 227.6 m a.s.l. Waves of smaller return periods can be significantly mitigated (Figure 3). From the results presented, it is clear that the Čelinac reservoir would significantly impact the mitigation of flood waves in the city of Banja Luka.

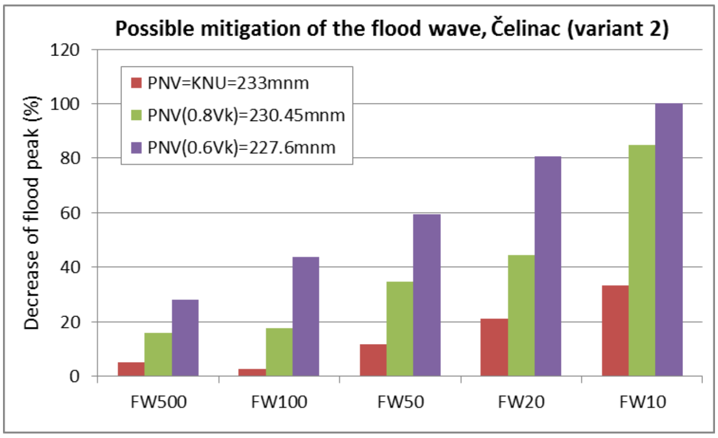

Figure 3. Reduction of the maximal flow of the Vrbanja River downstream of the Čelinac reservoir, for different water levels in the reservoir at the time of flood wave arrival (various pre-release volumes)

5. ISSUES IN THE LOW-FLOW PERIOD

Another equally important issue is the management of reservoirs during low-flow periods. This problem is significant because the lower part of the Vrbas basin contains high-quality soil resources that need irrigation. Therefore, it is necessary to consider the possibilities of irrigation under existing system conditions (primarily the effects of the existing Bočac reservoir), as well as measures that should be taken to enable reliable irrigation [7]. To meet this goal, the effects of reservoirs on the Vrbanja River (planned within the strategic documentation), were considered.

5.1. IRRIGATION WATER DEMAND

The required amount of water for irrigation is determined on the basis of climate parameters - calculating potential evapotranspiration and effective precipitation. The values are determined for the reference period, as well as for future periods taking into account climate changes.

Potential evapotranspiration was determined as a product of the reference evapotranspiration (calculated according to the Penman-Monteith method, which is recommended by FAO) and the crop coefficient, under irrigation conditions [4]. For areas that would be irrigated, a projection of sowing structures has been defined, based on previous production, as well as based on expected changes towards intensifying livestock feed production. Sowing is predicted on at least 15% of the area, and sowing structure related to on-demand irrigation systems has been adopted, considering that the majority of arable land is in private ownership and that it generally consists of small parcels. Effective precipitation was determined using the USDA, SCS method. Since effective precipitation in irrigation is defined as the portion of total precipitation that the plant can utilize, it was calculated only for months of the growing season and for precipitation greater than 2 mm.

Previous analyses were finalized by determining the water requirements (PV) [8]. The total water requirement in an average year is 209 mm, while in the hypothetical dry year, it is 332 mm, which is about 60% higher. This methodological approach yields the insight that water requirements in agricultural areas should be viewed as a dynamic category, especially considering unfavorable climate changes.

Having in mind previously described increase in air temperature and decrease in precipitation in the future, it is clear that an increase in water demands for irrigation can be expected. Especially unfavorable is the fact that the described changes will be most pronounced in the summer months, when the needs for irrigation water supply are the highest. The structure of agricultural production was adopted on the basis of previous production, as well as on the basis of the expected change in the direction of intensifying the production of animal feed. A sowing structure related to on-demand irrigation systems has been adopted. Changes in water requirements were analyzed in detail for scenario A2. The cumulative annual value of PV for an average year in the period 2011-2100 is 269 mm, which is about 40% higher compared to the reference period 1971-2000 (191 mm). This indicates an obvious increasing trend due to climate change. According to scenario A2, the change in water requirements in the period 2011-2100 after the reference period (1971-2000) shows an increase at a rate of 1.6 mm/year.

5.2. RELIABILITY OF WATER SUPPLY FOR IRRIGATION UNDER EXISTING SYSTEM INFRASTRUCTURE

The analysis of possible water supply for the irrigation system was performed for the reference period (1971-2000) and for three future periods according to scenario A2. The calculation was performed with unregulated values of average monthly flows (at site Laktaši), for several reasons:

- Upstream from the considered site there are three dams and HPPs: Jajce I, Jajce II and Bočac and one barrier with gates in the profile of SHPP Bočac 2. Of all the listed facilities only the Bočac reservoir has significant useful volume (42.9×10^6 m^3), while other HPPs work as run of river HPPs, so they do not affect the change of water balance.
- The operational volume of the Bočac reservoir can perform weekly water balance, so there will be no significant balance changes in the flow on a monthly level.
- The main purpose of the Bočac reservoir is hydropower production, so it cannot be required to discharge water for the irrigation of areas located more than 60 km downstream.
- It is necessary to maintain the ecological flow (EF) in the watercourse downstream from the water intake for irrigation. A constant flow of 25% of average annual flow is required: $Q_{EF} = 0.25 \times Q_{av}$, where Q_{av} is the average annual flow determined for the reference period 1971-2000. The priority in meeting the needs is the ecosystem, i.e. the release of environmental flow. The irrigation system captures water only in cases when the flows in the Vrbas River are higher than QEF. The amount of taken water depends on the remaining available water quantities (Qriver - QEF) and it can vary between 0 and the required quantities. Balance analyses were performed under the assumption that water is taken from the river constantly, i.e. the system works 24 h/day.

For each analyzed year, the reliability of water supply (PV) was determined on the basis of the total annual amount of water that could not be delivered to the irrigation system - water deficits (V_{def}) and the total annual water needs (V_{total}): $P_V=(1-V_{def}/V_{total})\cdot 100$ (%)

In Figure 4 the percentage of water deficit in each year (the relation of water deficit to the total required amount of water for irrigation) is presented. It is obvious that water deficit increases towards the end of the century. In the near future, a significant deficit occurs in about 12 years, in the distant future (2041-2070) in 22 years, while at the end of the century a larger or smaller deficit occurs in almost every year. The volume of missing water also increases. A deficit of more than 50% of the required quantities occurs in 10 years in the distant future, and in 23 years at the end of the century.

Based on the performed analyses, the average ten-year values of reliability and changes (decrease) of these values in relation to the reference period were determined (Figure 5). The trend of decreasing is obvious, and it is especially pronounced in the second half of the century. It is the consequence of a decrease in available water quantities and increased flow variability due to which low-water periods are longer, and increase in water requirements for irrigation as a consequence of increased air temperature and reduced precipitation.

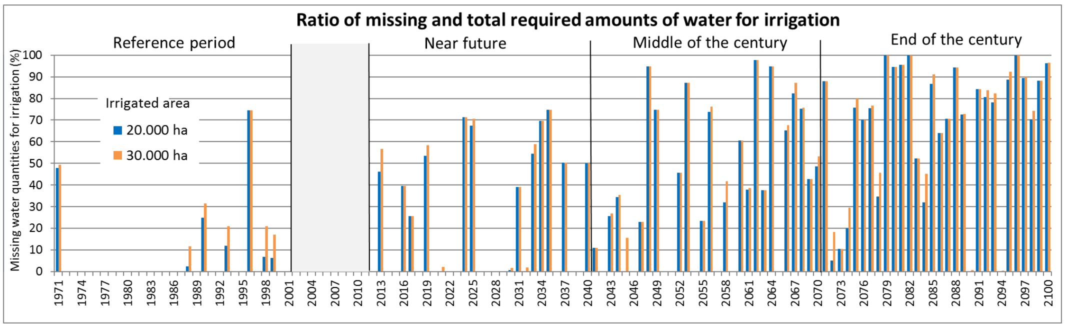

Figure 4. The ratio of missing and total required amounts of water for irrigation

The analysis of water supply reliability was performed for several different values of the irrigated area. Given that these are relative (percentage) values, reliability changes are similar for all analyzed areas, and average values in the analyzed time periods decrease from about 17% in the near future, to over 35% in the distant future, to 63-67% at the end of the century.

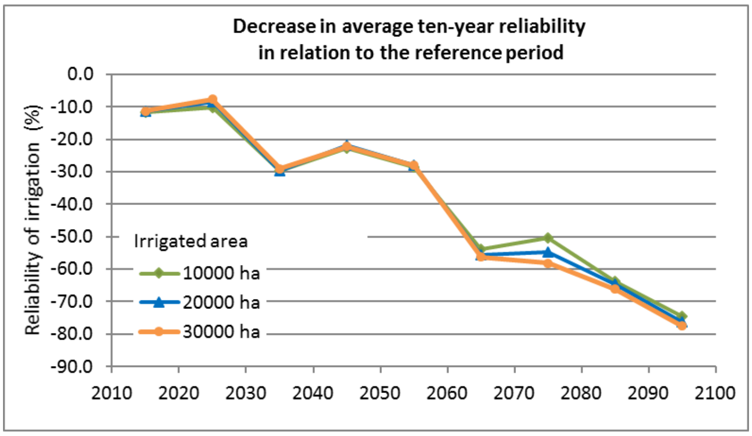

Figure 5. Decrease in average ten-year reliability in relation to the reference period (1971-2000)

Of particular concern is the increasing number of months during which it is not possible to deliver any amount of water for irrigation, as the flows in the river are lower than the environmental flow ($Q_{river} < Q_{EF}$). At the end of the century (2071-2100), there will be years in which water delivery will not be possible during the entire irrigation period.

Described analyses were performed with average monthly flow values. The situation would be even more unfavorable if the analyses were performed with daily flow values. Such analyses were not performed for the entire considered period, but the calculation was performed for several years from each of the three considered periods and the results show that water supply reliability is lower (0 - 20%) in relation to the values obtained with average monthly values. The decrease in reliability increases towards the end of the century.

5.3. RELIABILITY OF WATER SUPPLY FOR IRRIGATION WITH PLANNED MULTIPURPOSE WATER STORAGE RESERVOIRS ON THE VRBANJA RIVER

As shown in the previous section, the reliability of water supply for irrigation will be significantly reduced in future periods, and this reduction will be particularly pronounced in the second half of the century. Reliable irrigation, in such conditions, can be achieved only if there are reservoirs, which can be used to redistribute water over time. Considering the location of irrigated areas, the impact of reservoir Čelinac (with active volume of 43×10^6 m^3) will be analyzed.

Figure 6 show the water deficit in each year in relation to the total required amount of water for irrigation. There is a significant reduction in the amount of deficit water for irrigation compared to the situation without reservoirs. The existence of only this one reservoir (planned are two more reservoirs in the upstream part of Vrbanja river), enables very reliable irrigation of the planned areas at the Lijevče polje site. It is possible to irrigate a net area of about 20,000 ha, which means that water deficits in the near and distant future would occur very rarely, and the missing quantities would be relatively small (mostly up to 10% of the required quantities). Deficits greater than 20% would occur only at the end of the century (1971-2000) in just 6 years. Irrigation of larger areas would affect the more frequent occurrence of deficits. Unlike the situation without reservoirs, in this case deficits higher than 50% would occur relatively rarely (only in 7 years) at the end of the century.

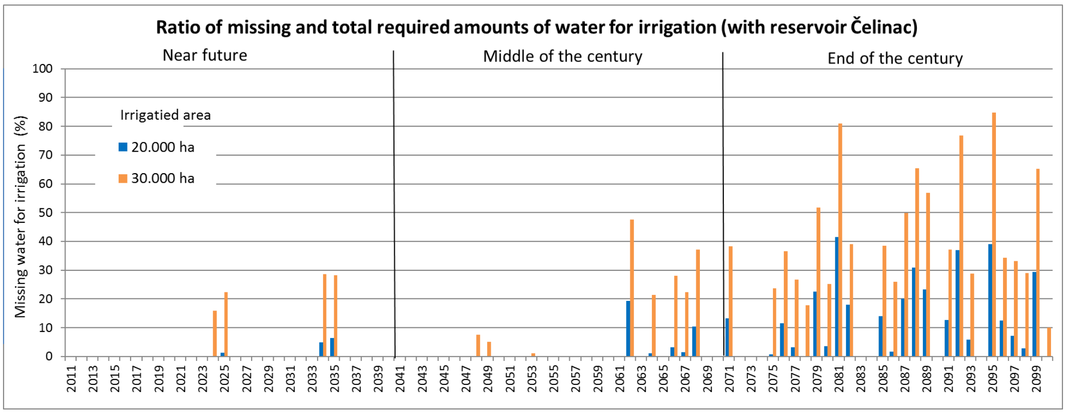

Figure 6. The ratio of missing and total required quantities of water for irrigation in conditions with the reservoir Čelinac

With the inclusion of the Grabovica reservoir, irrigation of an area of about 20,000 ha would be practically without water deficits, except in a few driest years at the end of the century. Irrigation of larger areas (up to 30,000 ha) would be almost without a deficit in the near and distant future, while deficits would occur only at the end of the century, but it would not exceed 50% of the required amount of water.

Figure 7 presents the security of water supply in cases when there are no reservoirs (dashed lines), and with Čelinac reservoir. It can be seen that reliability of providing water for irrigation is considerably increased if Čelinac reservoir is in use. The reliability of water delivery for 20,000 ha would amount to over 80%, which is a satisfactory value for that user (irrigation). The same area could be irrigated completely reliably in the case of the Čelinac and Grabovica reservoirs.

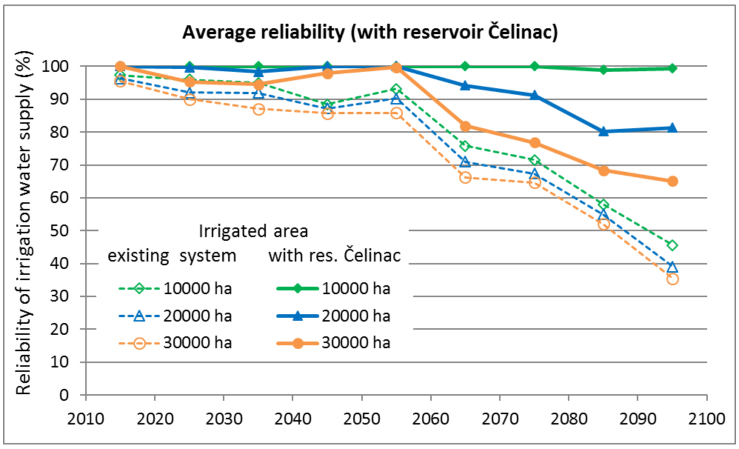

Figure 7. Average ten-year reliability of irrigation water supply

In the case of construction of all three reservoirs Čelinac, Grabovica and Šiprage, the required amount of water for irrigation would be fully provided, even for the largest irrigation area of 30,000 ha.

It should be noted that the analyzes were performed under the assumption of irrigation as a priority user in relation to energy. The performed analyzes do not consider other roles of the planned multipurpose reservoirs at Vrbanja River, such as the reduction of flood waves in the downstream area, especially in the city of Banja Luka. Hydrological analyzes have shown that in the future, in the conditions of climate change, an increase in high water flows can be expected (for return period of 100 years, scenario A2, average increase is about 15% in the near and distant future, and up to 35 % at the end of the century). Considering that river Vrbanja has the characteristics of a torrent flow, with a very short time of flood waves concentration and large flows (peaks), transformation of flood waves in the reservoirs would significantly reduce the risk of floods in the downstream area. Performed analyzes gives only approximate values of the impact of reservoirs on increasing the security of water supply for irrigation purposes. More accurate values could be obtained by more detailed analysis of the needs of all users, with the optimization of the operation of reservoirs.

6. CONCLUSION

In the context of climate change and the increasing variability of water regimes, the significance of reservoirs is heightened. They play a crucial role in providing required water quantities by balancing water throughout the year and actively mitigating flood waves. To optimize the use of the reservoirs' active volume, improved reservoir management is necessary.

A reservoir management model, aiming to minimize flow in downstream urban areas, was applied to the Bočac reservoir. The potential for mitigating flood wave were analyzed for different initial water levels in the reservoir (representing preemptive reservoir volume). The results indicate that these models can be effectively utilized, especially when coupled with hydrologic models that simulate flood event hydrograph, enabling preempting of the reservoir. In the case study, predicting the flood wave two days in advance and implementing optimal management measures significantly delayed and reduced the flood peak in Banja Luka.

The planned Čelinac reservoir in the downstream part of the Vrbanja River would further reduce flooding in Banja Luka. This reservoir would retain a portion of the highly unfavorable Vrbanja River flood wave, characterized by steep flow increases and high peaks. Additionally, the multi-purpose nature of this reservoir would provide necessary water quantities for irrigation.

One area under consideration for agricultural expansion and irrigation system construction in Republika Srpska is located in the Vrbas River basin, particularly in its downstream region. As a result of climate change the demand for irrigation water increases in time. The analysis indicates a significant reduction in the reliability of irrigation water supply, which will worsen by the end of the century. Therefore, the construction of reservoirs on Vrbanja River, especially the Čelinac reservoir, would increase the irrigation water supply reliability.

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44

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STEPGRAD
СТЕПГРАД

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VIRTUAL PROTOTYPING (VP) IN THE ARCHITECTURAL, ENGINEERING AND CONSTRUCTION INDUSTRY (AECI)

Abstract

Information Technologies are lieders in the fast industrial development. Virtual Prototyping, as relatively young technology, is combination of Virtual Reality and computer technologies with digital prototypes as result. It represents original's true copy in the real world, providing more efficient models' testing, prior construction. With it's implementation in the Construction Industry all the work becomes cheaper, faster, safer, environmentaly friendly and more efficient in comparison to the traditional ones. The paper's primary purpose is brief introduction to modern technologies towards which the future construction industry strives. Description of the basic terms is being followed by the explanation of main characteristics and need for the Virtual Prototyping implementation in the Architectural, Engineering & Construction Industry. Virtual Prototyping tools and real-life applications have been stated as well. At the end, limitations and possible problems are mentioned. Therefore, link between Virtual Prototyping and Architectural, Engineering & Construction Industry is created.

Keywords: Virtual Prototyping, Virtual Reality, Computer Technologies

КРЕИРАЊЕ ВИРТУЕЛНИХ ПРОТОТИПА У АРХИТЕКТОНСКОЈ, ИНЖЕЊЕРСКОЈ И ГРАЂЕВИНСКОЈ ИНДУСТРИЈИ

Сажетак

Информационе технологије су лидери у убрзаном индустријском развоју. Виртуелни прототипи, као релативно млада технологија, представљају комбинацију виртуелне стварности и компјутерских технологија. Представљају копију оригинала пружајући ефикасније тестирање модела. Њиховом имплементацијом у грађевинарству сви послови постају јефтинији, бржи, сигурнији, еколошки прихватљивији и ефикаснији у односу на традиционалне. Сврха овог рада је кратак увод у савремене технологије којима тежи грађевинска индустрија. Након описа основних појмова слиједи објашњење карактеристика и потреба за имплементацијом виртуелног прототипа. Наведени су и алати за виртуелне прототипе и апликације из реалног свијета. На крају су наведена ограничења и могући проблеми. На тај начин створена је веза између виртуелне израде прототипа и архитектонске, инжењерске и грађевинске индустрије.

Кључне ријечи: виртуелни прототипи, виртуелна стварност, компјутерске технологије.

1. INTRODUCTION

Humanity lives in the time when technology is evolving so fast, that people just are not able to keep up with the speed of this development. Today it is common buying a new mobile phone, or even a car, but tomorrow it's becoming unfashionable because on the market is appeared more advanced model of the newer generation. Computers are literally from hour to hour significantly inferior compared to the new ones that are showing up. The rapid technological development has a crucial role in providing a much more comfortable life for all humanity. The technologies that lead to fast development of industry are Information Technologies (IT). It can be said that all other technologies depend on their development.

The construction industry is lagging most other fields in taking advantage of new technologies (Arditiet al. 1997) [2]. Unlike other industries, the implementation of modern technology is going much slower in the Architectural, Engineering & Construction Industry (AECI). Research and development accounts for an embarrassing 0.4% of the annual construction output in the United States (Nicolas & Lemer 1992) [20]. Improving the quality of work and therefore the quality of the final product is highly dependent on availability of possessing resources when performing work. In this study will be pointed attention to the importance of the implementation of computer-advanced technologies in AECI. The focus is, in this case, on Virtual Prototyping (VP). The VP can be a powerful tool for testing and evaluating new products and ideas, decreasing the time to market and reducing product cost (Mujber et al. 2004) [19].

The VP is a relatively new technology, which involves the use of Virtual Reality (VR) and other computer technologies to create digital prototypes (Wang 2002) [31]. Designing different products by using advanced computer software (such is CAD - computer-aided design or CAE - computer-aided engineering) provides designer (for example engineer) possibility to test his model in the virtual world before it goes to production and start usage in the real one, is called VP. The user is making a computer-generated model, in the other words “a digital prototype”, which is in most cases 4D (3D+time), and simulating its behavior in the real world. Observation of its behavior in virtual world can provide designer possibility of improving his idea, redesigning certain characteristics in purpose of bringing it on a higher level of functionality, removing defects, etc. The advantage of VP is that it is giving an opportunity to be tested in much simpler, more efficient and cheaper way, than it would be in the real world.

The other important characteristic is that virtual prototype has to be a true copy of its original in the real world. It also must be more accessible for manipulation and testing than its physical representative. Different challenges project's executors face starting from designs' analyze to the final construction processes, which are easy passed over using Artificial Intelligence (AI) tools. (Elsayed, S., & Radwan, A. 2019) [6] Errors that occur during the testing of the prototype in the physical world as well as the errors that occur during its designing can be quite expensive and complicating for repairing. The main strength of VP is that in much easier, and much more cost-effective way it provides a prototype development while the creator is "playing" with it in the virtual world.

Through several points of this study will be presented main characteristics of VP and illustrated importance for implementing it in AECI, as well as in other industries. Main advantages and disadvantages will be presented as well. The study will propose usage of this approach in the future and will provide examples of the successful implementation so far. As very important segment of study, the limitations and opportunities for improvement will be discussed.

2. KEY FEATURES AND NEED FOR VP

Designing process of certain product includes stages of creation of idea, making the model which is going to be exposed under test and after that production. These processes in the traditional approach can be extremely complicated and expensive. At the moment when the idea was born, designer’s job is to transfer it in physical form, visible to others. This process can certainly be done by making a sketch on paper which is the traditional way, or using various computer software which provides a much simpler approach.

According to (Wang 2002) [31], characteristics of a virtual prototype are:

- A model of a structure or apparatus (or a product);
- Used for testing and evaluate form, design fit, performance, and manufacturability;
- Used for study and training.

Based on Wang's definition, it can be concluded that first required thing is a computer simulation. Most appropriate model presentation is 3D simulation. On a second place is human-product interaction. Characteristics of a model should be effectively viewed, listened, smelled, and touched by a user. All parts of model should be able to tested and evaluated. One of the features of the VP is to enable the transmission of these ideas into materially world in a much simpler and more efficient way for both - the designer and the other. Computer software provides a clearer picture of what the creator intended. Another feature is that the sketch can easily be modified and improved; experiments with design are easy to control. In addition, among the ideas that already exist, VP provides also support from its database by providing additional ideas, giving suggestions etc. Traditional approaches, such is use of sketches on paper, are not able to provide these possibilities. Experimenting with the model using the VP is much simpler and cheaper than experimenting with the ones in real world. Making a "living" model can be a very expensive and time consuming. In addition to debugging and design improvement is much more complicated with the material model to those in the virtual world. The entire process from design to start of production can be repeated many times in purpose of training model in a simple and economical way. Also the presentation of the project interested much more efficient than the traditional method which significantly improves communication.

VP in the AECI provides effective creation, analyze as well as optimization of working schedules. Analysis of constructability is much precise than in traditional way of approach. Considering a large number of parties involved in project, risks curve exponentially grow up. (Bilal, M., & Rahman, I. 2018) [5] Risks during the construction process can be eliminated or put to the minimum. All involved (subcontractors, contractors, investitures) in project can understand much better the scope of it and communicate between each other very precisely. The changes in any stage of project are planned in advance and easier feasible.

A group of researchers from The Hong Kong Polytechnic University and Queensland University of Technology from Australia conduct a survey which clearly shows how implementation of VP in construction industry can significantly improve results in any stage of project development and construction. A Construction VP (CVP) was used in couple of projects in Hong Kong. In research "Construction virtual prototyping: a survey of use; T. Huang, H. Li, H. Guo, N. Chan, S. Kong and G. Chan, M. Skitmore". This questioner survey has been done in 2007 with 28 participants. Their projects used CVP. From 28 participants, a positive response was received from all of them with an accent on visualization and communication. Results showed high potential of VP: Visualization – important for communication and collaboration between all involved in project. CAD 4D reduces 50% of time for explaining designers and 80% of time describing construction operations. Comparing to traditional tools, 4D also provides a more intuitive comprehension of the construction. Testing and verification of functions and performance – integration of geometrical and non-geometrical data, 3D models can carry out extensive and specialized tests and analysis. Collision detection – Software publishers like Autodesk, Bentley Systems, Graphisoft, Vector Works, and Gehry Technologies have this capability. Evaluation of manufacturing and assembly operation – 4D planning allows the analysis of construction schedules prior to the construction phase with advanced tools which support cost management, quantity survey and site layout. Resource modeling and simulation –integration of VP with virtual VR enables user interactions with more realistic 3D models.

Implementing the AI in the AECI offers numerous benefits, including improved project planning and scheduling through predictive analytics, enhanced safety through real-time monitoring and detection of hazards, and increased efficiency in resource allocation and cost management through automated workflows and data-driven decision-making. Additionally, AI-powered systems can optimize construction processes by analyzing vast amounts of data to identify patterns, optimize supply chain management, and enhance collaboration among project stakeholders. (Singh, V., & Loke, S. W, 2020) [25]

According to (Huang et al.) [10] CVP system, which was developed is called DELMIA. It is one of the most powerful VP applications produced by Dassault Systems. The core of DELMIA is a PPRs model that links up with various kind applications – 3D model design, process planning, resources planning, event simulation, 3D visualization, layout planning and VR. The strongest weapon of this approach is visualization and communication. The collaboration efficiency between contractor and sub-contractors is improved around 30% and 30-50% reduction of meeting time. It also provides significantly shorter planning time. In construction implement stage fieldwork is instructed and rework is reduced. CVP approach decreases the workload of project planners. Other important benefit of using this approach in construction industry is much reduced effort in preparing construction documents, as well as close coordination of design and construction work to bring meaningful reductions in the number of personnel and materials.

The result of this study clearly shows through numerical data that implementation of Artificial Intelligence (AI) such is VP is very important for the further advancement of AECI. Any stage of project and construction was very improved using VP as one of main tools to accomplish the work. The AI is becoming inevitable tool in the AECI, revolutionizing the way VP is conducted. AI-powered algorithms offer unfathomable opportunities to rise collaboration among architects, engineers, and construction engineers through the prototyping processes.(Gheisari, M., & Nejat, A 2018), [7] Using the AI, teams can streamline communication, enhance data analysis, and optimize decision-making. The AI techniques can analyze great amounts of complex design data in order to identify potential conflicts or different obstacles, enabling teams to address issues as soon as possible during the prototyping stage. In addition, AI's virtual assistants can facilitate real-time collaboration by providing quick feedbacks, propose design modifications, and facilitating communication among all the parties incorporated in the project's realization. As AI continues to evolve, its integration into VP processes promises to provide higher levels of efficiency, innovations, and collaboration within the AECI. (Shahandashti, S. et al. 2022; Xiao et al. 2018) [27, 30]

3. TYPES OF VP TOOLS IN THE AECI

3.1. BUILDING INFORMATION MODEL (BIM)

BIM is computer-technology, which in digital form presents physical and functional characteristics of building. This concept exists since 1970s. It helps with the decision-making processes during the whole time of designing and building. Also, provides possibility to observe buildings behavior in the future through virtual world and simulations. Recent years, as semantic information modeling, presents one of the most advanced technologies used for improvement of the AECI.

Building Information Modeling (BIM) revolutionizes the construction industry by enabling virtual prototyping, allowing stakeholders to visualize and simulate the entire building lifecycle before construction begins. Through BIM, architects, engineers, and contractors can collaborate more effectively, streamline workflows, reduce errors, and optimize building performance, leading to cost savings and improved project outcomes.(Gu H. et al. 2021) [8]

BIM is usually being combined with the Industry Foundation Classes (IFC). Using BIM designer is able to create a 3D model of building which presents all characteristics of it such are building design, material information, planning details, economics factors, etc. IFC serializes this information and provides communication with other applications related to this. BIM is described as an IT tool, product or process that minimizes waste associated with inefficient information exchange and dramatically improves the construction process.

BIM facilitates the creation of detailed digital representations of buildings, integrating information about design, construction, and operation phases. This enables stakeholders to identify clashes, analyze performance, and make informed decisions early in the project lifecycle, ultimately enhancing efficiency, sustainability, and overall project success. (Hamledari, H., & Eastman, C. M. [9]

However, the lack of agreement between stakeholders pertaining to BIM’s f unction and business value has stifled its implementation (Isikadg et al. 2007) [11] and has confused matters regarding BIM’s impact on construction success measures (Zuppa et al. 2009) [35] are stating three different definitions of BIM. First views BIM as an open standards based information repository for a facilities’ lifecycles. Second one represents BIM as a tool for visualizing and coordinating AECI work and avoiding errors and omissions. The definition explains BIM as a combination of the two and possibility including other factors (Issa & Suermann 2009) [12]. But, there are some other approaches to define BIM such are 3D modeling, interoperability, semantics, clash detection and process integration. Generally BIM remains a complicated to define (Aranda-Mena et al. 2009) [1], which inhibits the collaborative process between stakeholders and makes the measurement of its effectiveness difficult.

BIM is helpful in time and cost estimations, which aid in schedule management for reduced threats of budget and time overruns. The pre-execution visualization feature of BIM enables the construction practitioners in clash detection leading to reduced errors, omissions, and reworks. In addition, visualization in multiple dimensions aids in quality and safety man-agreement with checks on progress of projects.(Raza,M.S. et al. 2023) [24]

BIM can have different applications in AECI such are: visualization 3D, fabrication drawings, code reviews, forensic analysis, facilities management, cost estimating, construction sequencing, conflict, interference and collision detection, etc. Benefits from BIM are: faster and more effective processes, better design, controlled whole-life costs and environmental data, better production quality, automated assembly, better customer service, lifecycle data, etc. Stanford University Center for Integrated Facilities Engineering (CIFE) figures based on 32 major projects using BIM indicates benefits such as (CIFE, 2007): up to 40% elimination of unbudgeted change, cost estimation accuracy within 3%, up to 80% reduction in time taken to generate a cost estimate, a savings of up to 10% of the contract value through clash detections, up to 7% reduction in project time.

One risk related to using BIM is ownership of the BIM data and protection of it through laws. Other is connected to the right to control data entry into the model and responsibility for inaccuracies in it.

As Figure 1 describes, BIM is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space. As a term, BIM has grown tremendously over the years and is now the 'current expression of digital innovation' across the construction industry. It is an intelligent 3D model-based process that usually requires a BIM execution plan for owners, architects, engineers, and contractors or construction professionals to more efficiently plan, design, construct, and manage buildings and infrastructure. [36]

Figure 1. *BIM's purpose [36]*

3.2. COMPUTER AIDED DESIGN (CAD)

Feature-based CAD systems have demonstrated clear potential for creating attractive design environments and facilitating geometric reasoning related to design function, performance evaluation, manufacturing process planning, NC programming and other engineering tasks (Iyer et al. 2006) [13]. CAD is computer software for creation, modification, analysis and optimization of a design. This software simulates behavior of construction and provides clear visualization of structure. It increases productivity, improves quality of product and communications among the members of team by providing a better documentation database.

3D CAD: Three-dimensional drawings of objects who are giving a sense of space are much efficient than 2D drawings because user can have more clear picture of the building for example, as well as feeling and understanding of design and structure.

4D CAD: (Zang et al. 2008) [34] is providing a good example of using 4D in AECI. In his paper "A Framework for Implementing Virtual Prototyping in Construction", he is demonstrating advantage of using VP, as well as difficulties, throe example of residential building in Hong Kong. The main characteristics of using 4D (3D + time) CAD is visual showing of construction site in different stages of building process with possibility of simulating real construction process. Helped with this powerful tool, supervisor can identify errors in process sequence and spatial arrangement. VP integrates 3D CAD, simulation engine, analysis tools and knowledgebase to streamline the whole product design and production process.

Presentation of building components in 3D and construction operations in virtual environment is necessary because it provides possibility that ideas of planners can be captured, communicated and reused. Traditional drawings in 2D are not functional enough. Implementation of VP in AECI is very helpful because constructability data can be evaluated and captured. Engineers can check design efficiency and provide feedback to the designers, using collected data. It allows the discovery of problems in construction early in the designing process which minimizing cost of change. During the construction stage, constructability data can influent on production of a detailed process plan and generation of 3D construction operation instructions for workers. This data can also be used for future 3D maintenance and repairs instruction.

5D CAD: This software is combination of 3D CAD applications with integrated data for schedules (time) and costs (resources) and represents BIM process. Big advantages over simple other programs make 5D CAD the future of the construction industry. It is combining 1D program data, 2D design, 3D building model with an integrated database of information about the building (BIM - Virtual Building), 4D time scheduling (sequencing of construction), and the 5D cost and resources for complete construction. Output from this process can be used after construction for the facility management. This means using the information over the entire life cycle of a building.

3.3. GAMING ENGINES (GE)

Virtual walkthroughs can allow participants to perform design/construction review tasks collaboratively, while locally present, or remotely connected. Collaboration among participants from the initial design stage is important because critical decisions can be made as many and as early as possible to lessen disputes, delays, cost overrun etc.at later stages (Shiratuddin & Thabet 2002) [26]. GE is a system used for designing video games. The characteristic functions are a rendering engine for 2D and 3D graphic models, a physics engine, sound creation engine, scripting and animation, artificial intelligence, networking, memory management, threading, localization support, and a scene graph. GE have possibility to present a realistic virtual environment in real-time. Related to the AECI usage of GE can generate real-time applications in VR that can represent architectural walk- tours, 4D planning and pre-construction planning parts etc. 3D GE is low-cost VR solution with built-in opportunities such are multi-participant capabilities, detection of collision, higher frame rates etc. [29]

GE are providing one very important option more - a better interaction between user and virtual environments. VR is more focused on a graphical section – creating more attractive environment, but whoever works in AECI behind strong graphical part need to have quality efficient control and interaction with the object or its parts that is being designed. GE are providing user possibility to lead avatar throe virtual life/environment. Creating such a feeling of spatial presence can support many geographic application scenarios, such as urban planning or studies on spatial perception, because the experience created by the virtual environment is more similar to the experience created by a real environment. However, the level of immersion of a VR-capable application does not only depend on general VR characteristics, such as a stereoscopic perspective and the tracking on real-world movements. (Keil et al. 2021) [14]

Visualization based on a game engine is more advanced than one on the VR engine base because of several reasons: lower cost, provides more overwhelming results in areas of 3D graphic design and interactivity, needed minimal performance for software and hardware and easy and fast development of functional virtual worlds. Figure 2 is example of successful GE usage in the AECI.

Figure 2. GE sample in the Construction Industry ussage [39]

Some of these engines such are Second Life (Warburton 2009) [32] or Sketch Worlds focus more on fast geometric modeling 3D environment and less on the information modeling. The limitation in these environments is leak of functionality to applications related to AECI. In Sketch Worlds exists possibility to import Orge meshes, which can be used as exportation from AEC applications. However, this is not original information exchange like in AECI.

At the Penn State, a group of engineers is using Immersive Construction (ICon) Lab to experiment with VP (*http://www.joelsolkoff.com/immersive-construction-lab-at-penn-state/sonali-kumar-virtual-reality-modeler-and-designer/*). Sonali Kumar, a graduate research assistant, and John Messner, associate professor of architectural engineering are designing specialized buildings by using a 3D game engine. They managed to develop a life size interactive virtual prototype which is much more economic than physical modeling. Its name is Experience-Based VP Simulator (EBVPS) and functions like a multiplayer video game. A lot of studies have been done where they developed 3D building model and displayed it in the lab. It is similar to 3D movie. Observer has immersion that he is in the space and.

As these researches states, first step is designing a 3D model in Autodesk Revit. After that, they transferred created model to visualization software Autodesk 3DS Max, in which realistic textures were added to the model, and after that to the Unity Game Engine to incorporate interactivity. One of goals is to create a database of standard components that can be used again in some other project.

This team developed a 3D walk through a model of the new Penn State Hershey Children's Hospital. It can help hospital staff as well as patients or visitors to navigate through the building. The idea was to have a decision-making tool for design review, which helps users as well as project team. Design team can communicate more effectively with stakeholders and gather valuable.

3.4. RAPID PROTOTYPING (RP)

Rapid prototyping (RP) is a term, which embraces a range of new technologies for producing accurate parts directly from CAD models in a few hours, with little need for human intervention. This means that designers have the freedom to produce physical models of their drawings more frequently, allowing them to check the assembly and function of the design as well as discussing downstream manufacturing issues with an easy-to-interpret, unambiguous prototype. (Pham et al. 1998) [22] This is technique whose first usage showed up on the market at early '80's for production of different models and prototypes by scaling models of physical parts or installation. During the time that usage becomes much more vide with CAD as a main tool. The purpose is production of prototypes for a short time. These prototypes are being used for further visual analysis and evaluation as well as tools for production. There are various RP systems today on the market.

RP in AECI involves quickly creating scaled models or mock-ups of structures to test design concepts and identify potential issues before full-scale construction begins By rapidly iterating through prototypes, construction teams can refine designs, improve efficiency, and reduce project timelines. (Liu, H.et al 2023; Sun, C. et al. 2022). [16, 28]

In his book, (Noorani 2006) [21] "Rapid prototyping", author states that depending on the materials, this process can be powder based (Selective Laser Sintering - SLS and 3D Printing - 3DP), resin based (Stereo-Lithography Apparatus) or laminated sheet based (Laminated Object Manufacturing - LOM). This technology, however, has some issues related to precision and prototypes quality. Multiple parameters making hard to choose a right combination, in purpose to create an efficient prototype. Integration of this technology with virtual reality creates system, as is VP.

Architects can use this technology for developing models for structure design, which will be useful also for their colleges from construction departments to see more clearly whole project as well as certain parts of it.

3.5. VIRTUAL REALITY (VR) AND MIXED REALITY (MR)

VR is the use of computer graphics systems in combination with various displays and inter face devices to provide the effect of immersion in the interactive 3D computer-generated environment (Pan et al. 2006) [23]. In AECI graphics and information are very important, so practice combination of these two has curtailed significance. VR is computer-simulated environment, which can imitate and simulate physical presence in the real world likewise in imaginary one. It is a computer – generated simulation of the real world, which provides an illusion of participation in a synthetic environment and not a pure observation of the same. This environment is 3D and user is able to look and manipulate with the contest of it. Also, it can be said that VR integrates user with the information.

There are two categories of VR: Desktop (uses PC monitor as an extract-information tool) and Immersive (instead of monitor uses head mounted display unit) VR. Applications of VR in the AECI are in:

- Design: space modeling, interior, lighting, designing of heating ventilation and air conditioning systems, ergonomics and functional requirements, space selling, fire risk assessment, landscaping, etc.
- Construction: site layout and planning, planning and monitoring construction processes, evaluation of construction scenarios, etc.

All data from CAD can be transformed into VR and the process (Whyte et al.) [33]. This is important because users age getting from a 2D architectural drawings 3D models which can be manipulated and simulated like in a real world. The other important characteristic of VR is library-based approach. The database offers different models already designed and especially when it comes to frequently usage of standard parts. Figure 3 demonstrates example of VR projection.

Figure 3. Virtual Reality war simulation (Pan et al. 2006) [23]

(Pan et al.) [23] states, MR in the AECI is used in the later stages of the design process, like are stages in which part of the site is already under construction process. Also, these applications include construction site inspection. Behind that, one more application is project management, specifically for construction progress monitoring. MR visualization can prove a good tool in facility management, building maintenance and renovation and building damage evaluation after disasters.

At Penn State University at the Applied Research Laboratory exists an immersive projection display (four back-projection display screens, stereoscopic and synchronized rendering images, stereo audio and magnetically tracked 3D input devices for creation of VR) system which generates 360 degree, 10'x10'x9' immersive environment. Users can interact with environment and simulate in real-time (Figure 4).

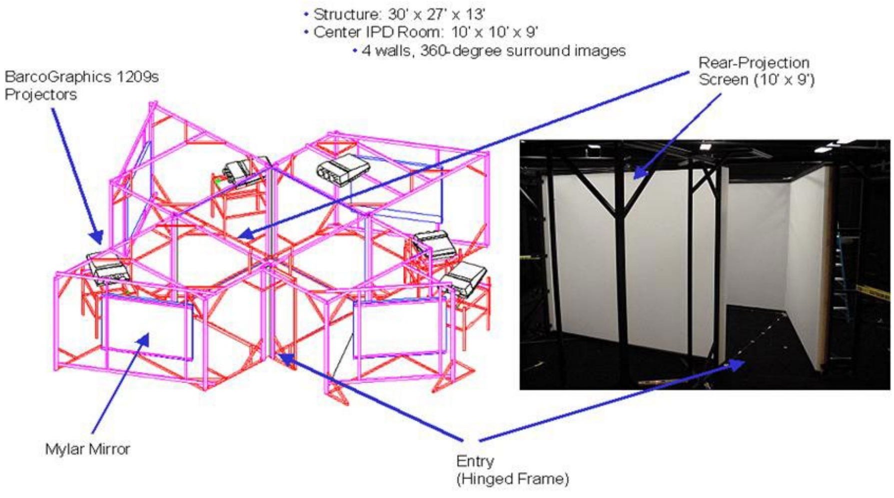

Figure 4. SEAI Projection Display at Penn State Applied Research Lab (Messner et al. 2003) [18]

While there are many benefits from implementing VR into AECI, also some issues can occur as well. One of them is a high price. Using this technology is very expensive because VR facilities are large and provides high-resolution images with also high quality visualization and magnetic tracking features. These display systems can cost over one million U.S. dollars. Other issue is that these facilities have a small footprint. It means that only four to five people can operate. Third problem with using VR is too complicated process of learning how to use it. VR software can be difficult for master the use.

3.6. AUGMENTED REALITY (AR)

AR represents direct or indirect view of real world, whose details are augmented by computer – generated sound, video, graphics or GPS data. The main difference between VR and AR is that the VR presents “copy” of the real world in its virtual representation (simulates it), while AR presents it in a teal-time in a semantic context with environmental elements. AR gives direct interaction between user and world around him and he can manipulate digitally with segments of it. Using AR user can, for example, add virtual objects to the real world elements and create own picture of the real world on the screen.

AR is revolutionizing construction engineering by overlaying digital information onto physical construction sites, enhancing project visualization and coordination. With the AR in construction engineering, stakeholders can experience BIM data in real-time, facilitating better decision-making and collaboration. AR applications in construction engineering allow on-site workers to view 3D models of buildings, infrastructure, and utilities directly within their physical environment, aiding in accurate construction placement and alignment. By integrating BIM models with AR technology, construction teams can identify clashes, verify installations, and troubleshoot issues before they arise, leading to more efficient project delivery. It enhances safety in construction engineering by providing real-time hazard alerts, equipment instructions, and site navigation, minimizing risks and improving worker productivity. Utilizing AR in construction engineering enables remote stakeholders to virtually inspect construction progress, conduct virtual walkthroughs, and provide timely feedback, facilitating smoother project management and communication. The integration of BIM and AR streamlines the construction process, reducing errors, optimizing resource utilization, and ultimately delivering projects on time and within budget. AR applications in construction engineering empower architects, engineers, and contractors to visualize and interact with complex designs, fostering innovation and creativity in project development. AR-enhanced training programs in construction engineering allow workers to simulate construction tasks, practice assembly procedures, and receive real-time feedback, improving skills acquisition and job performance. The marriage of augmented reality and BIM technology holds immense potential to transform the construction industry, driving efficiency, sustainability, and excellence in project execution.(Raza, M. et al. 2023) [24]

As (Azuma 1997) [3] states, three main characteristics of AR are: combination of real and virtual world, interaction in real – time and registration in 3D. The potential of AR is improving architectural construction, inspection, and renovation. AR systems can enable workers on construction site to avoid hidden features (for example electrical wiring). This makes maintenance and renovation operations faster and more efficient, and also reduces the amount of accidental damages. Future versions of AR can guide construction workers through the assembly of actual buildings and improve their work quality. Inspection with AR interfaces may be similarly guided. Work without conventional printed drawings makes job much easier and ensuring that every item is inspected. Example is of the AR potential has been presented at the Figure 5.

Figure 5. Example of AR – a virtual lamp on a real desk [3]

4. APPLICATION OF VP

4.1. OTHER INDUSTRIES

Due to the opportunities provided by VP is widely used in various industries. The significance of this technique is growing rapidly during the time and it can be concluded according to many case studies results that in the near future will be impossible to organize the production of any product without using tools provided by VP software. Design testing in the virtual world prior to its production, as noted above, is much more efficient and cheaper than the traditional method. Aero industry is using this approach for a while. Making real models of tested – subjects in this industry is very expensive. Even a VR technology whose prices a high is worth to use comparing to the models of aircrafts. Also, mimic of some of the conditions in which aircraft will be exposed in a real life, is almost impossible in the real world, so that the simulation in virtual one place almost exactly as in the real and give the necessary results to improve products. For example, aircraft is completely exanimated and tested before it goes to manufacturing. Similar thing is in auto industry.

Virtual prototyping has significance especially in production of expensive products whose testing with real models requires high economical resources. VP has also found its application in the medicine. Future doctors can be trained on virtual models of people or animals that simulate the response of organisms in the same way as in real life.

4.2. IN THE AECI

- Building design and construction: One of the most important industries who provoked development of VP and VR is actually Architectural. Visualization and possibility to immerse them in appropriate design it is gained much clearer understanding of quantitate and qualitative nature of designing space. With VR and VP technologies architects can evaluate proportion and scale using interactive models as well as to simulate different kind of effects. For example, simulation of functionality of fire escapes routes, or anti-fire systems. The other good characteristic and possibility is improved and efficient communication between designers and clients, between ideas and possibilities or opportunities to materialize them.
- Progress monitoring: Visualization and VR technologies can be used for modeling the construction sequence in order to simulate and monitor site progress. This can be successfully accomplished by using a pre-prepared library of building components, which contains 3D graphical images.
- Their related activities are also included and generation of models representing views of the construction sequence in a real time. Control of project progress in a real-time is on a highest level of importance. VP provides to engineers throe visualization efficient supervising of any stage of project with the clear picture of the situation. According to this engineers can remove mistakes, fix errors, planning stages etc. in more accurate and faster way.

- Visual simulation of equipment: As (Li et al. 2012) [15] states, construction equipment is one of the very important factors for successful construction progress. Example can be seen at the Figure 6. Testing of construction machines in virtual world can prevent mistakes like wrong chosen operating machine. Also construction progress supervisors can get familiar with behavior of unknown equipment. This approach can also help with positioning of large and fixed machinery on construction site like cranes or concrete factories etc. Some companies like Leica Geosystems using laser scanners are completing data from real machines, transferring it into a VR world where is possible to manipulate and test certain machine for future usage and manufacturing as well.

Figure 6. Construction machines in virtual world (Lii et al. 2012) [15]

- Facility management: This is area divided into couple of activities such are coordination of space, infrastructure, people and organization. In FM VP can have also crucial role because all these activities can be tested and organize first in virtual and after that in real world. VP enables architects and engineers to simulate and analyze sustainable design features digitally, allowing for the optimization of energy efficiency, material usage, and overall environmental impact before physical construction begins.(Tettey, W. J et al. 2021) [29]
- Demolition and uninstallation of facilities: Demolition and uninstallation buildings can be very dangerous and expensive job (Messner et al. 2012) [17] Facilities can be destroyed first in virtual world where can be recorded exact behavior of different parts of it, so when the real explosion comes almost noting unpredicted can happened. When it’s about uninstallation of a, for example, metal structures planning in virtual world can be done and tested the whole process, so everything can be finished in a most economical and safest way.

5. LIMITATIONS AND PROBLEMS' SOLUTIONS

Although VP brings almost unbelievable advantages, it has some limitations. The development and application of VP in the AECI can be complicated because each construction project is unique in term of their conditions, requirements and constraints unlike manufacturing industry where production line is almost constant. One more barrier for implementation of this technology is also that the companies don’t want to engage it until they are sure of benefits from that business move. VP technology has lack of a seamless method for data exchange between various tools. The main problem regarding this approach to construction progress is that, even certain amount of time has passed, the cost and highly trained stuff leveling has not moved with significant steps forward.(Bademosi,F.M.& Raja RA.I. 2022) [4]

But, the biggest limitation for fast implementation is economic factor. VP technology is very expensive because of need for sophisticated and advanced software which requires high-prices hardware. For effective usage of VP applications stays its high demand on computing power. The challenge and opportunity to solve this problem is developing business processes and accessible and affordable implementation tools, which includes web-based systems. This will make the power of VR affordable to wide specter of projecting teams and companies.

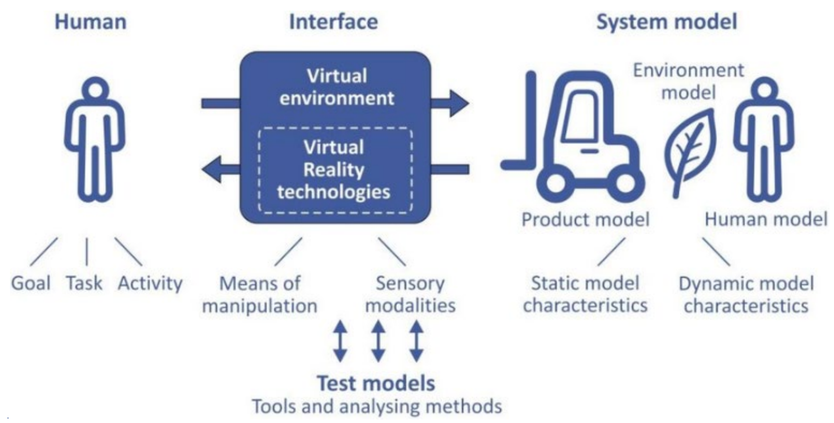

Figure 7. The framework for virtual prototyping in human-machine interaction is a combination of human, interface and system model elements. [37]

Breaking down the models into smaller components and using more advanced modeling techniques can solve the VP models' complexity and large-scale systems. Multiple disciplines integration, which is considering strong collaboration among architects, engineers, contractors, and other parties, is one way ticket to the integration challenges and problems. This might be possible to solve by implementing BIM tools that allow real-time collaboration and seamless integration of different disciplines' models. The VP technologies' cost which requires significant investment in hardware, software, and training is possible to solve "step by step" introducing it to the users, starting with pilot projects and investing in training programs to up skill employees. Regular backups and data auditing can manage managing large amounts of VP data and safe files' storing. Also, providing comprehensive training programs to encourage user adoption will help accelerating future VP implementation in the AECI.

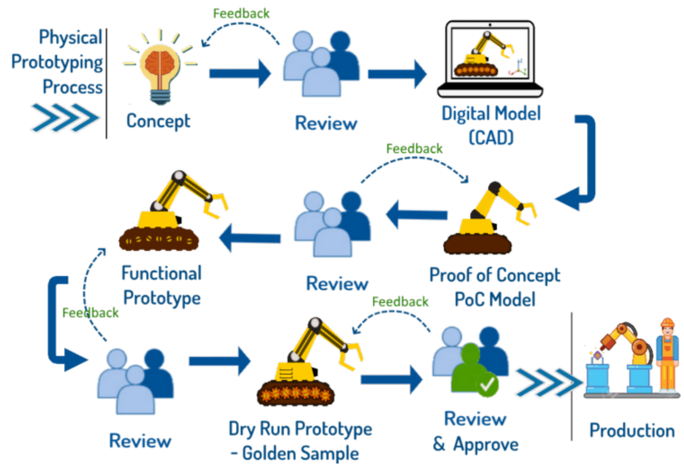

Figure 8. Virtual Prototyping stages. [38]

6. DISCUSSION

The aim of this research is to introduce the reader to the axis of the VP and all the benefits it provides. It is explained through several examples how individual software and techniques function, as well as the specific benefits they provide. Key features and application of Virtual prototyping are stated as well. Also, along with limitations was provided recommendation for solution of problems. However, this is huge area and in one paper could be presented only introduction details.

7. CONCLUSION

VP is providing very powerful tools for improving any stage of design and construction any kind of facilities. Unfortunately, this technique still didn't take part in AECI as it deserves. Problem has economical nature, but in close future should be solved because economical factor is one of the most important on which this technique actually have an influence. Testing models and simulating its behavior in virtual world is much cheaper than in real one and VP is providing exactly that. Also, testing facilities in virtual world prior to the real one has advantages like improving design and functionality, security, etc. Powerful software like VP takes bigger role in other industries than in AEC, and it should be deeper implemented in closest future.

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45
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IMPROVING THE NETWORK OF SECONDARY ROADS IN URBAN SETTLEMENTS: CASE STUDY ISTOČNO NOVO SARAJEVO

Abstract

The spatial development of the city and urban residential areas is inextricably linked with the spatial planning of transport networks. The concentration of population and residential facilities in a small area certainly creates traffic problems and affects the quality of life of individuals and the sustainability of urban settlements. The increase in population standard and the use of individual means of transport creates the need for huge spatial areas for the movement and rest of vehicles. This paper presents one possible way of modifying the planning document (regulatory plan) in the domain of the organization of traffic and free areas with the aim of increasing accessibility to end users, as well as improving the quality of life of individuals.

Keywords: traffic, urban road network, parking, urban planning, regulation plan

УНАПРЕЂЕЊЕ МРЕЖЕ СЕКУНДАРНИХ САОБРАЋАЈНИЦА У ГРАДСКИМ НАСЕЉИМА: СТУДИЈА СЛУЧАЈА ИСТОЧНО НОВО САРАЈЕВО

Сажетак

Просторни развој града и градских стамбених насеља је нераскидиво везан са просторним планирањем саобраћајних мрежа. Концентрација становништва и стамбених садржаја на малом простору свакако ствара саобраћајне проблеме и утиче на квалитет живота појединаца и одрживост градских насеља. Пораст стандарда становништва и коришћење индивидуалних средстава превоза ствара потребу за огромним просторним површинама за кретање и мировање возила. У овом раду је приказан један могући начин модификације планског документа (регулационог плана) у домену организације саобраћајних и слободних површина са циљем повећања приступачности крајњим корисницима, као и унапређења квалитета живота појединаца.

Кључне ријечи: саобраћај, градска путна мрежа, паркирање, урбанистичко планирање, регулациони план

1. INTRODUCTION

Cities experienced an exceptional growth rate at the beginning of this century, and the total world population exceeded 8 billion in 2023. More than 50% of the world's population lives in urban areas, and it is estimated that it will be over 70% by 2050. At the same time, this share in European cities is about 65%, and in the USA about 80% [1]. With a concentration of over 80% of the world's economic activities, cities offer millions of people social mobility and economic prosperity by bringing together creative, innovative, and educated individuals and organizations.

Turbulent past and present, as well as an uncertain future, demographic disturbances, and accelerated urbanization (consequently), move the surrounding settlements and villages closer to the city, while in the meantime they are becoming smaller cities (smaller urban environments) themselves. The big city has almost all the components of the natural environment: air, plants, land, relief, hydrographic network, ground water, bedrock, and climate. However, physical conditions in large cities are worse than those in small ones. As a result, the population of large cities is exposed to extremely large problems, despite the advantages and opportunities brought by urban facilities. Lack of apartments, schools, hospitals, green areas, difficulties in traffic, air and water pollution, high noise levels, chaotic street traffic, cause negative psycho-social consequences for city dwellers, and the traumatic consequences of high population density are increasing.

The successful functioning of today's life and work implies a combination of three elements - human activities, space, and transport. Activities comprise daily or occasional actions that the population performs during the day, i.e. during life. To carry out the activities, a certain space is needed, which will, through its concept, content and appropriate layout enable the most efficient performance. The activity that needs to be performed and the space that is adequate for its performance often have a physical separation that needs to be bridged by transport. This is how we arrive at the third element that enables the connection of people, spatial units, and the environment.

The performance of activities becomes difficult, sometimes even impossible, if good transport connections are not provided. Transport is also distinctive due to the opposite problem - generic connectivity, which is a frequent example in modern cities, where the auto-centric concept of traffic and transport planning and organization dominated through planning documentation (but also physical implementation) for decades. With such a radical adaptation of transport infrastructure to cars, other types of transport became neglected or even rejected as a potential mobility solution in urban areas. The consequences of this are reflected in numerous negative ecological, health and sociological aspects, whereby the negative consequences of industrialization and urbanization, as well as psychophysical stress, take on alarming dimensions in some societies. It must be admitted that traffic is not the only cause of these phenomena, but it is one of the factors that has the power to direct and motivate society to change.

In that key, by overlapping the two functions of transport - physical and social - the meaning of the concept of the territory occupied by this infrastructure is also expanded. Therefore, the areas occupied by transport infrastructure are not only spatial facts, but also cultural, social, economic, and ecological. A wider observation, understanding and interpretation of these spatial elements is possible. With this procedure, sustainable design from "green" units, as the first association, moves towards social improvement in a much broader sense.

In addition to traffic and related infrastructure, modern city construction is characterized by massiveness and industrialization, and therefore designers and urban planners acquire a new role as designers of the living environment, i.e. places for work, housing, rest, and recreation. Often this process is marked (or branded) by the demands of high commercialization and enormous profits. In such conditions, and with the aspiration to reach the concept of sustainable development, the social aspects of city planning and design are gaining more and more importance. There is also more and more talk about sustainable planning and design, i.e. the tendency to harmonize design technology with the economic, environmental, and social functions of urban settlements.

This paper points to one of today's typical approaches to the planning of urban settlements with collective housing, which implies mass construction based on large demands for housing space in larger urban areas without significant analysis of requirements for traffic facilities and areas that improve the standard of living in an urban environment.

2. URBAN ROAD NETWORK

The role of urban traffic is to integrate city amenities, direct and synchronize activities and set the pace of urban life. In addition, urban roads limit the space for the development of physical structures so that traffic is an inevitable factor in the spatial organization of the city. Therefore, the city and its traffic present unique planning and design complex with the same temporal and spatial dimensions [2].

The term “urban road network” represents a network system of structures and facilities that has multiple functions, starting with the movement and rest of vehicles. When using the word “vehicles”, it is understood as all vehicles participating in traffic. The functional classification of the urban road network is reflected in relation to two basic tasks. The first one refers to the connection of certain parts of the city by high-capacity urban arterials - the primary network. The second task is to serve locations and facilities immediately next to the road (i.e. access) - the secondary network. When both tasks are harmonized, a categorization of the urban road network is obtained, as well as the planning and design characteristics of a certain level of road in the urban environment.

Urban roads of higher order (primary) consist of roads intended for circulating traffic on which the basic transport work of all types of motorized surface traffic is carried out. On the other hand, lower-order urban roads (secondary) form a mix of streets and carriageways that serve to access certain destinations. For this level of the network, typical traffic parameters, such as flow and speed, lose their meaning since high vehicle movement speed and strong vehicle flows are, in essence, an unacceptable and unwanted phenomenon. The planning characteristics of the roads within the urban road network can be systematized according to functional classification and basic urban and technical-operational criteria (Table 1). It can be observed that the basic function of the urban road network has a dominant impact - traffic connection or access and servicing of the location and facility. Due to the different nature of tasks and functions, primary and secondary networks have different characteristics and spatial organization.

Table 1. Planning characteristics of urban road network [2, modified]

criteria	primary road network			secondary road networks	
	urban motorway	main urban artery	urban artery	collector street	access street
role in relation to the city	connects distant parts of cities	connects different urban contents	connects residential areas and the city center	serves urban units	serves individual locations
relation to the intercity network	direct connection to long-distance roads	introducing connecting roads in urban areas	introduction of collector roads in urban areas	-	-
relation to urban units	does not pass through urban areas			integral part of the road network of urban areas	
cargo traffic	transit in relation to the city	channeling of destination cargo flows	supply distribution	supply of urban areas	supply of individual locations
urban public transport	fast urban public transport	fast urban public transport	urban public transport	public transport terminals	terminals in the city center

3. URBAN ROAD NETWORK PLANNING

Rational organization of space to achieve its efficient use, as well as directing of construction and arrangement of populated areas, is done by means of spatial and urban planning which reconcile interests of different subjects in a certain area. Two groups of documents i.e. urban planning documentation, can be distinguished in relation to the documents necessary for planning and designing traffic infrastructure in the urban area depending on the size of the territory in question and contents of the plan:

- general urban planning documentation - general purpose plans solving wider problems of socio-economic and spatial development, including the long-term concept of arranging the urban space and transport (regional spatial plan, general urban plan);
- urban planning documentation - special purpose plans solving spatial relationship of the most important linear and network systems as well as regions and specific segments of the

urban area containing both important transport infrastructure (general urban plan, detailed regulation plans, and urban planning design).

When dealing with a specific urban area, regulation plan particularly affects design of transportation facilities as it encompasses all facilities of primary and secondary network, and all main systems of infrastructure defined in the absolute coordinate system, thus becoming a skeleton of space organization and solid numerical basis for further action and developing necessary urban planning and technical documentation.

Processes of spatial planning and designing of transportation facilities are directly interconnected and conditioned. It should be emphasized that great difficulties may arise in the case that the planning process is performed separately from the designing of urban road network. It is of utmost importance to attune contents and period of designing of transportation facilities and planning of space - preliminary design of transportation facilities must represent a base for elaboration of regulation plan. In doing so, one must also consider the leading process depending on the functional level of the section of the urban road network [2]. When considering the primary network, the planning and design of urban road network will, due to the role of this network in the city's transport system, ensure the connection of individual units within the city area. On the other hand, urban planning and design dominates the secondary urban road network when the process is aligned with the requirements of local service of space and activities.

4. MAIN CHARACTERISTICS OF SETTLEMENTS IN THE WESTERN BALKANS

The intense demographic changes that the population of the Western Balkans began to go through in the second half of the 20th century manifested their greatest effect at the end of the last century and the beginning of this century. The process of demographic transition, which the population of the Western Balkans has been undergoing in recent decades, has taken place simultaneously and interacted with the process of urbanization.

Uncontrolled migration has particularly stimulated the intensified demographic and spatial expansion of urban and peri-urban zones (the process of unplanned and unorganized suburbanization) of cities, which has largely caused unplanned and informal construction. Such construction most often took place in an unclear urban matrix with insufficient and/or incomplete capacities of traffic and communal infrastructure, as well as other pronounced conflict phenomena that impede quality living and working conditions of the population.

The process of urbanization of the Western Balkans shows inconsistent characteristics [3]. Focal points of the development are larger urban settlements, dominated by larger centers (national, regional, and sub-regional). They exert influence and transform the environment by the power of their functions, and urbanized and deagrarised zones are created around them. These are peri-urban rings - gravitational regions that form around stronger functional centers. The expansion of urban spatial-functional systems of cities was also followed by a change in the structure of population activity in settlements located not far from urban centers, which eventually merged with them and were subsequently administratively annexed to them. In this way, the urban tissue of all major cities (Banja Luka, Belgrade, Mostar, Niš, Novi Sad, Podgorica, Sarajevo, Skopje, Tetovo, Tirana, Tuzla, Zenica, etc.) was expanded, which by developing industrial zones, locating commercial objects, building residential areas, and increasing the capacity of infrastructure facilities and the supra-structural system were transforming the surrounding rural settlements.

The supply of traffic infrastructure, i.e. the road network in urban areas, is generally inherited and occasionally adapted to the growing demands. Some major links (primary urban roads), usually in large urban settlements have been developed and/or modernized in the last fifty years. The availability and capacity of access streets in the older urban areas remained largely unchanged. New urban settlements built according to the plans are exceptions where the primary traffic infrastructure is planned and designed according to modern principles of adaptation to the size and function of a particular settlement, i.e. urban area, but it often happens that the secondary network (access streets and parking) is missing or remains extremely deficient.

The lack of parking space for individual vehicles in large urban areas is especially visible. As a result, urban roads are often adapted to the increasing demands of stationary traffic by taking away space dedicated for regular traffic flow, even in primary urban roads with mobility function rather than access function. On-street parking is dominant, while organized surface parking lots and multi-story garages (underground or above ground) exist only in urban cores and plan-built parts of larger urban settlements/cities (although not sufficient). Smaller urban settlements, on the other hand, very often do not have any capacity for stationary traffic other than space within private estates, and the vehicles are mostly parked on the part of the carriageway intended for moving vehicles (even on intercity and rural roads passing through those settlements) creating traffic jams and significantly affecting safety.

5. CASE STUDY: ISTOČNO NOVO SARAJEVO

The Block 1 residential complex is located in Istočno Novo Sarajevo and is bounded by Dečanska street and streets 5.1 and 4.1 (names defined in the design documentation of the municipality of Istočno Novo Sarajevo). Dečanska street is a primary urban road whose cross section is composed of two traffic lanes, as well as bicycle and pedestrian paths separated from motorized traffic by a green belt. Streets 4.1 and 5.1 are secondary urban roads with a similar cross section as Dečanska Street, without established bicycle paths, but with a reserved area for them. In Figure 1, it is possible to observe the appearance of the block (red line) before occupation, i.e. the preparation of the planning document and the very beginning of construction through two stages - 2015 and 2019 - with noticeable changes of the surrounding in a relatively short period of time.

(2015)

(2019)

Figure 1. Residential settlement Block 1 in Istočno Novo Sarajevo before planning and construction [Google Earth]

The total area of Block 1 is 34,417 m^2, of which 7,332 m^2 is intended for the construction of buildings up to P+6+Pe. The analysis of the existing regulation plan (Figure 2) revealed certain shortcomings, primarily in terms of traffic connections, both for motorized traffic, and for pedestrian and cyclist traffic. Namely, the residential area is quite closed, with two traffic connections to Street 5.1 that supply eight dead ends within the block with parking lots. All internal roads are 6 m wide, with longitudinal parking, while parking lots with a perpendicular scheme are planned between the residential buildings. In this way, 481 parking spaces are planned on an area of 11,945 m^2 of roads with parking lots. Pedestrian paths, 1.50, 2.00 or 3.00 m wide, occupy 3,347 m^2. The total length of the pedestrian paths is 1,439 m. A block park is not planned, and the green areas are composed in such a way that they only fulfill the form of existence, and not the essence of improving the residential environment. Bicycle traffic is not treated at all inside the block, although it is made possible by the existence of bicycle paths in the peripheral streets.

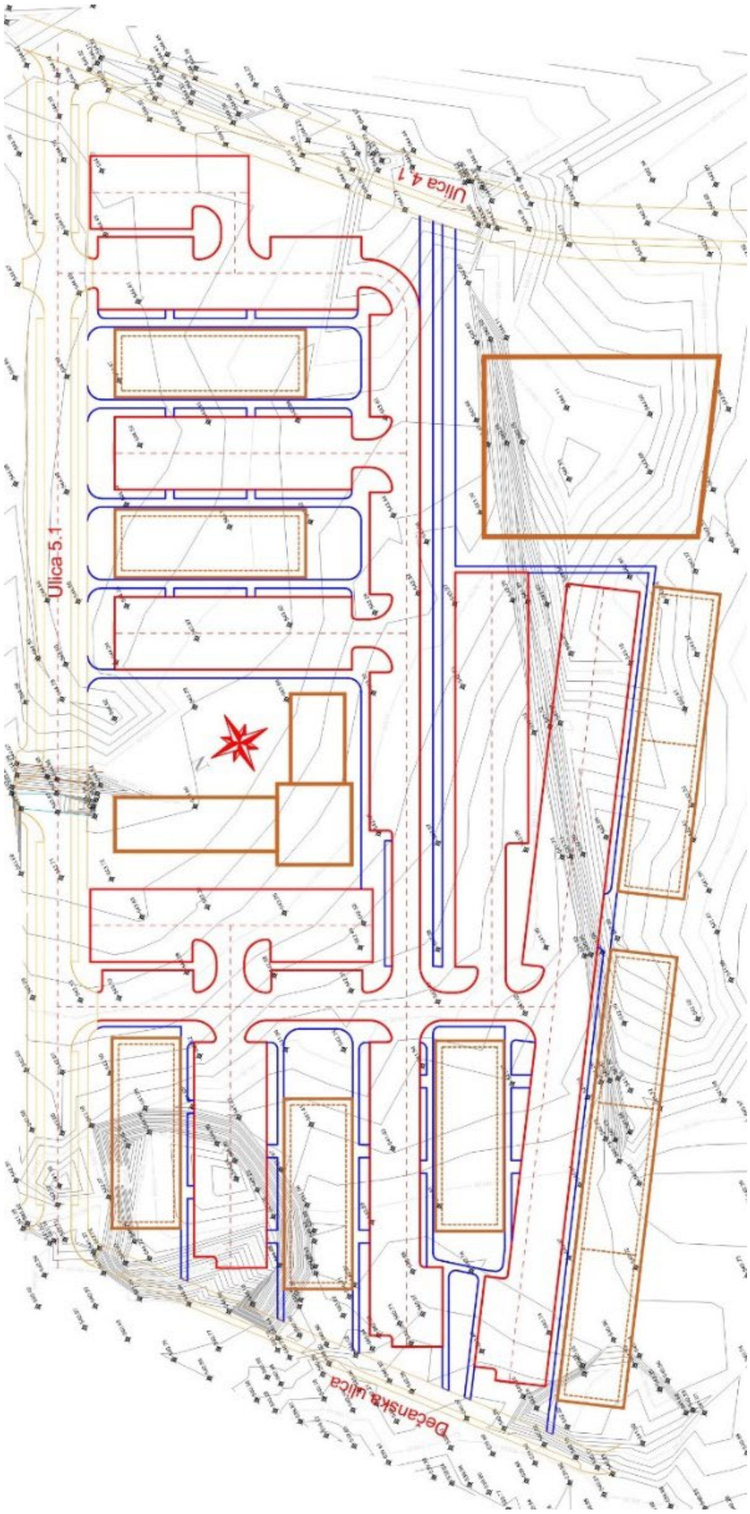

Figure 2. Excerpt from the regulation plan of Block 1 [4]

In the event of possible traffic congestion on Street 5.1, the residential area becomes absolutely non-functional for motor vehicle traffic, thereby jeopardizing the safety and functionality of the space for all users, primarily residents and users of planned business facilities. Additionally, internal congestion will easily transfer to Street 5.1. In relation to the identified shortcomings, and the requirements of regulations, standards for planning and designing stationary traffic, as well as program conditions and spatial possibilities, it was observed that traffic facilities within the residential area must and can be reorganized.

5.2. PROPOSAL OF SOLUTION

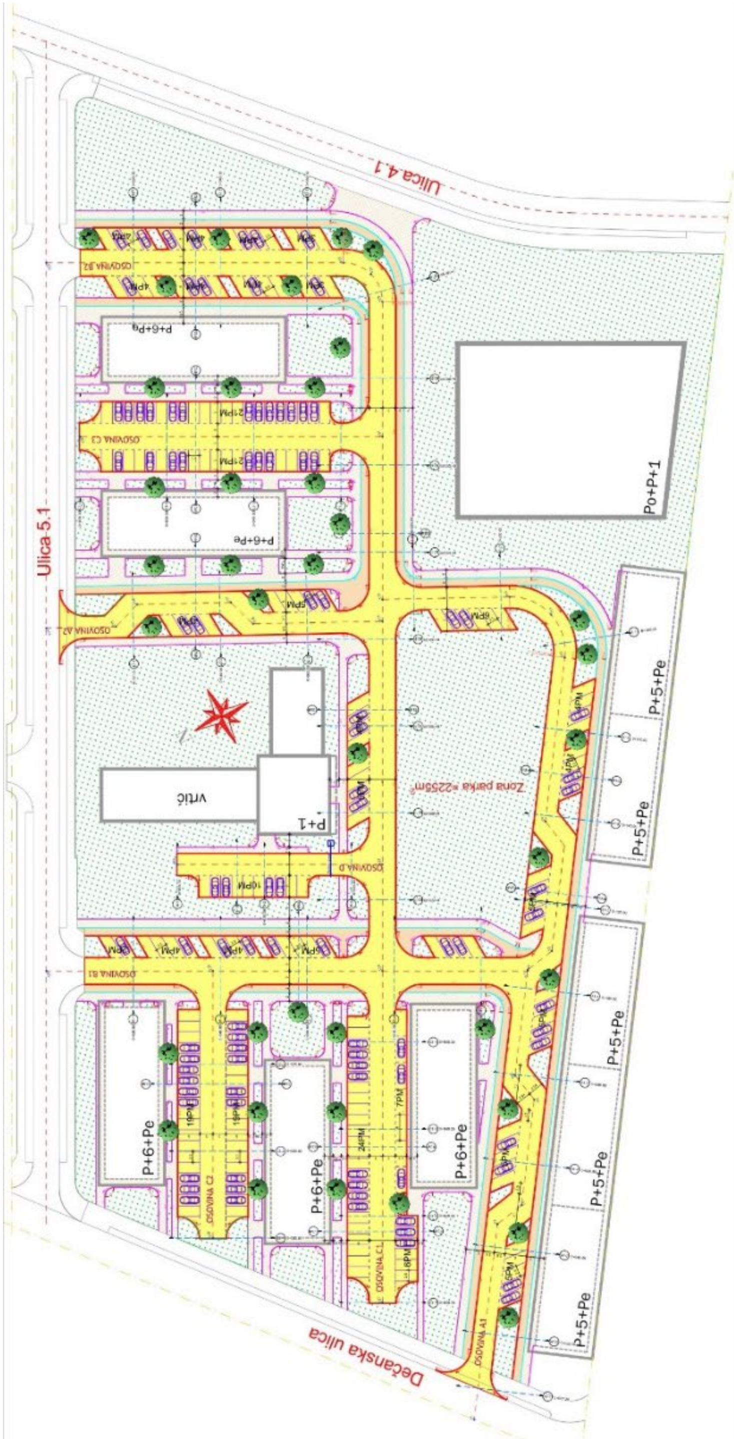

Figure 3. Layout of traffic facilities in Block 1 according to the proposed solution [5]

By creating a solution proposal [5], certain deficiencies identified in the regulation plan (Figure 3) were eliminated. In addition to the two planned access streets for the residential block, two more were designed, opening the block to the west (toward Dečanska Street) and the north (connection to Street 5.1). The connection to Dečanska Street increases the accessibility of the contents inside Block 1 for utility and commercial vehicles, as well as for end users, which reduces the load on the planned streets from the regulation plan. To avoid the use of these streets for through traffic, they are designed in such a way that traffic lanes and parking areas are alternated in the cross section of the streets, which forces motorists to drive more cautiously and calmly. Also, all parking spaces within the streets connected to the peripheral streets are designed at an angle in relation to the axis of the street, which ensures simpler and faster maneuvering when entering and exiting the parking space. Designed streets fit into the leveling of the existing streets and do not require additional work.

Along all the streets that connect to the peripheral streets, 2 m wide bicycle paths have been designed, with a total length of 818 m, which brings this type of movement closer to users, encourages active mobility and creates the potential for reducing air pollution from motor traffic.

In the central zone of the residential area, near the kindergarten, an area of 2,255 m^2 has been reserved for a block park, and white ash trees are planned to be planted along all streets. Thus, the residential area becomes enriched with green areas and rows of trees and completes the pleasant ambience of the residential block.

Table 2 provides an overview of the areas within Block 1 and a comparison with the planned areas from the regulation plan. As can be seen, the areas for the movement of pedestrians and cyclists, as well as the green areas, have been increased at the expense of the reduction of the areas intended for the movement and rest of motor vehicles. The total length of the footpaths has been increased by about 400 m, and conditions have been created for the development of bicycle traffic, unlike the solution adopted through the regulation plan, as already emphasized. By deviating from the regulation plan, the number of parking spaces on the surface parking lots along the streets in the settlement has been reduced (219 spaces). Therefore, it is necessary to carry out a correction of the number of floors in buildings to add basement (and/or ground) floors that would serve as garages for users of residential buildings, whereby such garages would be included in the mandatory equipment of the apartment, and not sold commercially on the market. Adding floors is not the only solution, bearing in mind that some of the lower floors can be converted into garages or, for instance, the purpose of the entire residential building might be changed into a parking garage (an unprofitable solution in the short term from the investor’s point of view, but with a greater potential to create a more humane environment that would be less burdened by motor traffic and population density).

Table 1. Overview of areas within Block 1 [4]

Functional area	Regulation plan		Preliminary design	
	area [m^2]	share [%]	area [m^2]	share [%]
Structures	7,332	24.2	7,332	24.2
Motorized traffic facilities	11,954	39.5	8,230	27.2
Pedestrian paths	3,347	11.1	4,125	13.6
Bicycle paths	0	0	1,483	5
Green areas	7,610	26.2	9,073	30
Total	30,243	100	30,243	100

It is quite clear that with such a proposed solution, the arrangement of the block in relation to the planning document would be abandoned. However, the fact is that the internal arrangement of the block has been improved and the space is closer to the users. Also, as in all cities that put the well-being of the residents first, the movement of motor vehicles along the roads is calmed down, and stationary traffic is removed from the surface. The forgotten practice of equipping residential and commercial buildings with internal parking spaces can be returned to the domain of planning and designing secondary urban roads, without the need to satisfy investors by reducing obligations and endlessly increasing the amount of commercial square footage (regardless of whether it is residential or commercial space). On the contrary, investors must commit themselves to providing useful residential and/or business space and the appropriate amount of parking spaces for users, and not to transfer the entire arrangement practically to the public sector and municipal budgets.

5.3. THE CURRENT ARRANGEMENT

Figure 4 shows the current state of arrangement of Block 1, which largely followed the adopted regulation plan. However, it is also noticeable that there was a deviation from the same since one new building was built in relation to the ones defined in the plan, while the shape of the other one was changed. Since only a small part of the traffic facilities have been built, there is still the possibility of correcting them and adapting them to the proposed solution. This certainly requires a change in the regulation plan, but much more important is the desire and willingness at the competent services. However, it seems that the opportunity to provide parking spaces within the buildings has been lost. As in most cases in the last thirty years, the quick profit of housing investors prevailed.

(August 2022)

Figure 4. Residential settlement Block 1 in East Novi Sarajevo in its current condition [Google Earth]

6. CONCLUSION

Thoughtful use of space and thoughtfulness of transport systems are not only a matter of infrastructure and organization, technique and technology, zones and plots, capacities, and resources. Thoughtfulness rests above all on one important activity - planning. Planning is an activity that equally involves creativity and engineering knowledge. Planning is equally an empirical and research process. Many previous experiences can be incorporated into future quality elements. But that is not enough. Planning requires a systematic approach, collection of numerous data, research work, testing of hypotheses, development of solutions.

Planning and designing the traffic infrastructure in cities is a very complex task that comprises of different levels, starting from the planning considerations of urban development, as a whole, to the separate technical solutions of the individual elements of the traffic structure.

City streets should be shaped in accordance with the cultural environment and the way of life of the specific city. Their design must provide a response to a number of important limiting factors and required services. Streets should be made more efficient not only by means of expansion, but also by positioning of individual elements - maximum utilization to obtain maximum performance during operation.

This paper observes a whole complex within the urban tissue that should provide the highest standards for the development and life of people, as well as for a better business environment. Wide streets with sufficient capacity for pedestrian and bicycle traffic, as well as for parking of vehicles (garage facilities supported by surface parking facilities), are something to strive for in the development of new urban settlements. In addition to fulfilling the requirements of motor traffic, new settlements must also provide conditions for sustainable forms of urban mobility, while taking the uncompromised approach in respect to the unlimited hunger for commercialization and profit.

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46

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REVIEW OF THE DEVELOPMENT OF SUSPENSION BRIDGES AND BRIDGES WITH INCLINED CABLES WITH A FOCUS ON NEW TECHNOLOGIES AND THE OAKLAND BAY AND YAVUZ SULTAN SELIM BRIDGES

Abstract

Bridges are among the oldest structures that humans have built throughout history. Over time, along with technological advancements, various structural systems for bridges have been discovered. This overview paper analyzes suspension bridges and bridges with inclined cables, delving deeper into the issues and construction technology of two specific bridges: the Oakland Bay Bridge in San Francisco and the Sultan Selim I Bridge in Istanbul. The paper showcases innovations adopted from previous experiences that distinguish these structures in their class.

Keywords: suspension bridge, cable-stayed bridge, Oakland Bay Bridge, Yavuz Sultan Selim Bridge

ПРЕГЛЕД РАЗВОЈА ВИСЕЋИХ МОСТОВА И МОСТОВА СА КОСИМ КАБЛОВИМА СА АКЦЕНТОМ НА НОВЕ ТЕХНОЛОГИЈЕ И МОСТОВЕ ОУКЛЕНД БЕЈ И СУЛТАН СЕЛИМ I

Сажетак

Мостови су једни од најстаријих објеката које су људи градили кроз историју. Током времена, заједно са напредовањем технологије, откривени су различити конструктивни системи за мостове. Овај прегледни рад анализира висеће мостове и мостове са косим кабловима, дубље улазећи у проблеме и технологију градње два конкретна моста: Оукленд Беј моста у Сан Франциску и Султан Селим I моста у Истанбулу. Рад представља иновације прихваћене из претходних искустава које ове објекте истичу у својој класи.

Кључне ријечи: висећи мост, мост са косим кабловима, Оукленд Беј мост, Султан Селим I мост

1. INTRODUCTION

The main purpose of a bridge as a structure is to transfer the traffic load over an opening or a discontinuity in the terrain. Different types of bridges are built to withstand the load from pedestrians, motor vehicles, various types of lines, trains or a combination of the above. Bridging is done over highways, rivers, valleys or any other physical obstacle. The need to transfer the load through the specified openings defines the function of the bridge. The design of the bridge structure can only be started after defining the role of the bridge, therefore the bridge construction process is not started by the engineer designing the bridge. It is necessary that the bridge meets the requirements in terms of: safety, functionality, economy and meets all aesthetic requirements. The safety of the bridge is uncompromising, and therefore the bridge should remain safe under all types of loads for which it was designed.

Suspension bridges have a very wide area of use, bridging large spans, and are one of the oldest and most common types of bridges. After the discovery of steel with high mechanical performance, modern suspension bridges began to be developed and built. Two significant forms, load-bearing systems and materials, have made suspension bridges span greater spans than any other type of bridge, including girder, arch and truss bridges.

Also, they can bridge larger spans, while respecting efficiency aspect. Bridge girders of suspension bridges are supported by main cables hanging from pylons, [1].

Cable-stayed bridges belong to the newer types of bridges, and the technology of constructing cable-stayed bridges has become even more important with the increase in the span of the bridges themselves and the complexity of the bridge structures. A cable-stayed bridge consists of three main components, which include pylons, cables and the bridge girder. The constructive system of cable-stayed bridges consists of four components: foundation, pylon, bridge girder and cables. The construction of the foundation can be on piles, crates, caissons, and is similar to other types of bridges [2]. The girder of a cable-stayed bridge is usually a prestressed concrete rigid beam, steel beam, composite beam, or steel truss. Similar to the construction of girder bridges, the bridge girders of the cable-stayed bridge can be made according to the system of in situ formation, pushing, assembly using a crane, etc.

2. TYPES OF BRIDGES

All bridges can be grouped into four basic types: girder bridges, arch bridges, cable-stayed bridges and suspension bridges. There are also specific variations, which will be described in more detail below. Common sense tells us that girder bridges and arch bridges are suitable for short to medium spans, while cable-stayed bridges are suitable for medium to long spans and suspension bridges for very long spans. Based on these assumptions, experience suggests rules to assign each span the appropriate type of bridge. For example, in the 1960s, a reasonable maximum span for a cable-stayed bridge was 450 meters, while for a girder bridge it was approximately 250 meters. These assumptions did not last long, since cable-stayed bridges with spans over 1000 meters were built. When a part of the element does not participate in carrying the load or is not used to the end, more material is needed to carry the same load, therefore the self-load increases, which is a major disadvantage of bridges, especially bridges with large spans [1]. Currently, the world span records for each of these types of bridges are: 330 meters Shibanpo Bridge in China [2], which has the largest girder span; 552 meter Chaotianmen Bridge in China, which has the largest arch span; 1104 meters Vladivostok bridge in Russia, which has the largest span of a cable-stayed bridge; 1991 meter Akashi Kaikyo bridge in Japan, which has the largest suspension span.

3. CABLE-STAYED BRIDGE

The rapid development of cable-stayed bridges begins with the use of high-quality cable steel. The beginnings of modern bridges of this structural system date back to the mid-1960s, and the trend of building these bridges continued and accelerated in the 1960s, 1970s and 1980s, so that today there are bridges under construction with spans of more than 500 meters [4].

The basic structural form of a cable-stayed bridge consists of radially formed cables that form a triangular shape with pylons and stiffening beams, Fig.1. The axial compressive force in the girder and pylons are in balance with the tension forces from the cables. Since the loads transferred are mostly axial forces, and not bending moments, conditions are created for the construction of more effective and economical structures. Cable-stayed bridges are usually self-anchored, which makes them a good solution in locations where the soil quality conditions are not good, as a result of which anchoring in the soil, as is the case with most suspension bridges, would be unjustified - expensive. In a cable-stayed bridge, the axial force in the girder is approximately zero at mid-span and increases to a maximum at the tower [1]. Therefore, if we increase the cross-section of the beam with an increase in axial force, the permissible axial force can be increased, and thus the span of the bridge. In this way, theoretically, the maximum range can be increased to over 10,000 meters. Considering the mutual position of the inclined cables in the longitudinal direction of the bridge, the following characteristic cases are distinguished: Bridges with radial arrangement of cables; Bridges with mutually parallel cables - "harp" layout; Bridges where the cables are connected to the pylon at different levels along the pylon, and the cables are not parallel to each other - "fan" arrangement; "Star" arrangement, where two cables each depart from the pylon at different levels, and intersect at one point on the bridge girder.

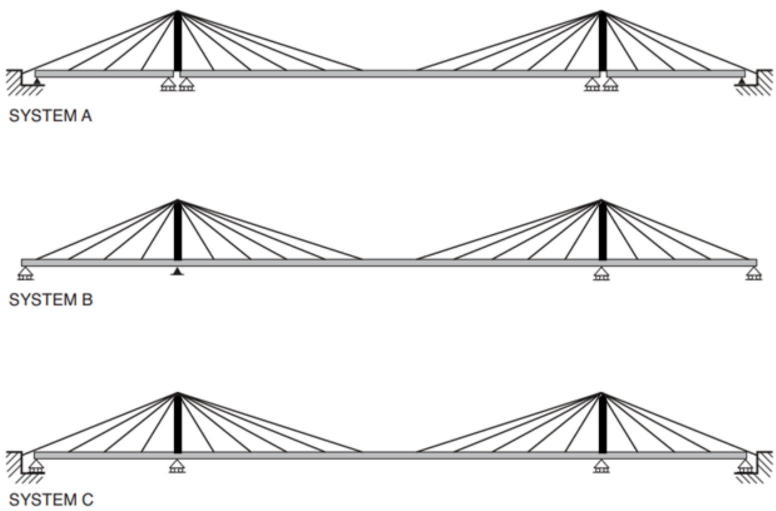

Figure 1. Various support systems for cable-stayed bridges [2].

3.2. MAXIMUM SPANS OF BRIDGES WITH INCLINED CABLES

Cable-stayed bridges became very popular after the construction of the first bridge of this type, Table 1. The Strömsund Bridge in Sweden, was completed in 1955. Due to the versatility of cable-stayed bridges, this type has been adopted for various spans; from pedestrian bridges shorter than 50 meters, up to spans of more than 1000 meters, which carry the traffic load.

Table 1. Table 2 Oldest cable-stayed bridges [3]

No	Bridge	Head engineer/company	Country	Year of completion	Longest span [m]
1.	Strömsund	Demag	Sweden	1955.	182,6
2.	Theodor Heuss	Friedrich Tamms	Germany	1957.	260
3.	Severins	Gerd Lohmer	Germany	1961.	302
4.	Knie	Fritz Leonhardt	Germany	1969.	319
5.	Duisburg-Neuenkamp	Keipke Architekten	Germany	1970.	350
6.	Saint Nazaire	CFEM; SGE	France	1977.	404
7.	Barrios de Luna	Carlos Fernández Casado	Spain	1983.	440
8.	Alex Fraser	Buckland & Taylor; CBA Engineering	Canada	1986.	465
9.	Ikuchi	Honshu Shikoku Bridge Authority	Japan	1991.	490
10.	Skarnsundet	Aker ASA	Norway	1991.	530

The Ada bridge is certainly one of the more famous bridges in our region, Fig. 2. Built with a cable-stayed bridge system, the bridge spans the Sava River and consists of one 207-meter-high pylon and two asymmetric spans. The bridge is 920 meters long, with a main span of 375 meters. The road is 45 meters wide. It’s designers are engineer Viktor Markelj and architect Peter Gabrielcic, while the executing companies were: “Porr Technobau and Umwelt Aktiengesellschaft” (Austria), “SCT” (Slovenia) and “DSD” (Germany).

Figure 2. Ada Bridge, Belgrade [4].

Millau Viaduct is located in France and is the highest viaduct in the world, Fig. 3. It is 2460 meters long, consisting of six spans of 342 meters and two spans of 204 meters [4]. It was built as a cable-stayed bridge. The height of the bridge pylon is 343 meters. It’s designers are engineer Michel Virlogeux and architect Norman Foster, while the executing companies were: “CEVM” (France), “PAECH Construction Enerprise” (Poland), “Dragados” (Spain), “Société di Viaduc de Millau” (France) and “Générale Routiére” (France).

Figure 3. Millau Viaduct [5].

4. SUSPENSION BRIDGES

The beginnings of suspension bridges date back a long time. Primitive suspension bridges or simple bridging elements were the forerunners of today's suspension bridges. These bridges were built with iron chains more than 2000 years ago in China, and similar records exist in India. Iron suspension bridges, which are supposed to have been designed in the Orient, appeared in Europe in the 16th century and were developed in the 18th century. Modern suspension bridges date from the 18th century, and are linked to the development of bridge structures and the realization of maximum production capacities. The Jacob's Creek Bridge was built in the USA in 1801, and had an average span of 21.3 meters [1]. The bridge was special in that a beam was used to strengthen the grid, which gave additional rigidity to the bridge, which enabled the load to be transferred through the cables, thus preventing large deformations. Clifton Bridge, with a middle span of 214 meters, is the oldest suspension bridge for vehicle traffic currently in use, the construction of which began in 1831 and ended in 1864 in the United Kingdom, using iron chains like cables. Suspension bridges can be rationally applied for spans of 250-1500 meters, and there are project solutions for much larger spans, as well as bridges of smaller spans. The main elements of the supporting structure of the suspension bridge are:

- The load-bearing cables, which for modern load-bearing bridges are mainly made of closed spiral ropes.
- Stiffening beam, solid sheer or lattice steel girder of constant height.

The erection procedure of earth anchored suspension bridges can be divided into six stages:

- Stage 1 Construction of the main piers, pylons, and anchor blocks.
- Stage 2 Erection of the main cables.
- Stage 3 Start of erection of the deck from the center of the main span. When the weight of the deck is added stepwise to the main cable, large displacements and changes of curvature occur, and the joints between the segments of the deck are therefore intially left open to avoid excessive bending of the girder sections.
- Stage 4 Erection of the deck in the side spans to reduce the horizontal displacements of the pylon tops.
- Stage 5 Erection of the closing pieces in the deck at the pylons.
- Stage 6 Closing of all deck joints. Actually, the closing of these joints will often start already during stages 4 and 5, as soon as adjoining segments become lined up. Fig. 4. a)

Another erection procedure to be found within suspension bridges exists. The sequence of adding the deck segments is the opposite of that mentioned earlier Fig. 4. b) [2]

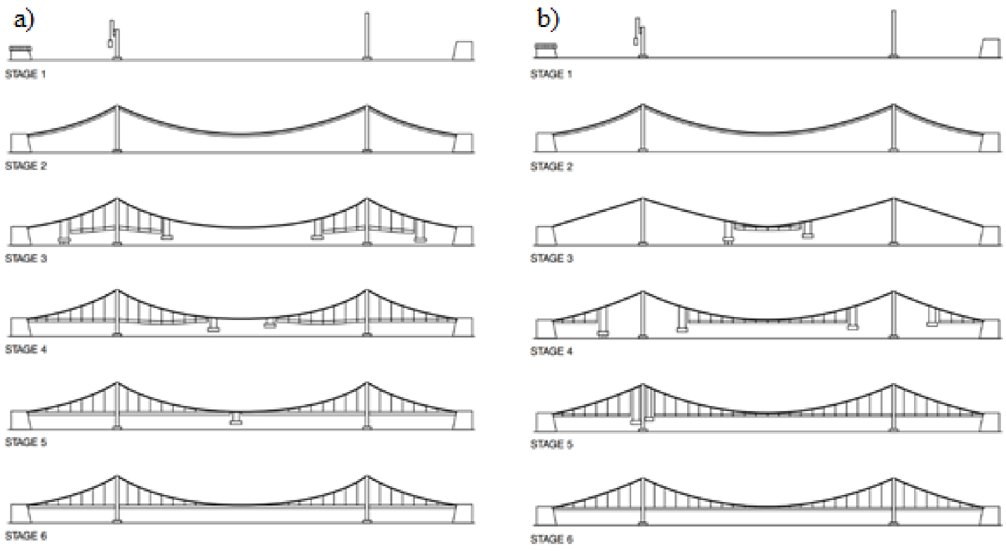

Figure 4. Phases of construction of suspension bridges [2].

The shape of the cross-section primarily depends on: the span, the width of the bridge and the spacing of the hangers. Pylons serve as a support for stiffening beams and supporting cables on the bend - saddle, and can be made of steel or lattice portals made of reinforced concrete. Hangers are made of round steel or steel rope and have a stiffening beam suspended from a supporting cable. Anchor blocks are made of concrete into which the supporting cables are anchored, and they can be located in the ground or in the stiffening beam. Couplings against the wind are omitted in certain cases of beams for stiffening in the horizontal plane.

4.2. MAXIMUM SPANS OF SUSPENSION BRIDGES

Development of modern materials has led to a significant increase in the possible spans of bridges, Table 2, and by the end of the twentieth century, some of the largest spans listed in the table were built.

Table 2. Table 3 Maximum spans of suspension bridges [3]

No	Bridge	Country	Head engineer/company	Year of Completion	Longest Span [m]	Bridge Type
1	Akashi Kaikyo	Japan	Satoshi Kashima	1998.	960+1991+960	3 Spans, 2 Hinges
2	Zhoushan Xihoumen	China	China Communications Construction Company	2008.	578+1650+(485)	Continual
3	Great Belt East	Denmark	COWI; Ramboll; Dissing+Weitling	1998.	535+1624+535	Single Span
4	[1] Runyang Yangtze River	China	Jiangsu Province Communications Planning and Design Institute	2005.	(470)+1490+(470)	3 Spans, 2 Hinges
5	Humber	UK	Freeman, Fox and Partners	1981.	280+1410+530	3 Spans, 2 Hinges
6	Jiangyin Yangtze River	China	Cleveland Bridge and Engineering Co. Ltd.	1999.	(336,5)+1385+(309,4)	Single Span
7	Tsing Ma	China	Mott MacDonald	1997.	355,5+1377+(300)	Continual
8	Verrazano Narrows	USA	Othmar Ammann; Leopold Just	1964.	370,3+1298,5+370,3	3 Spans, 2 Hinges
9	Golden Gate	USA	Joseph B. Strauss	1937.	342,9+1280,2+342,9	3 Spans, 2 Hinges
10	Yangluo Yangtze River	China	China Communications Construction Company	2007.	(250)+1280+(440)	Single Span

4.3. COMBINATION OF SUSPENSION BRIDGES AND CABLE-STAYED BRIDGES

Previous general reflections show that for suspension bridges the maximum span is limited by the permissible tensile stress in the cables, while for cable-stayed bridges the limiting factor is the compressive stress in the beam. It follows that the span can be increased if a combination of these two types of bridges is made. Another way to increase the span of a cable-stayed bridge was found by anchoring some of the cables into the ground.

The purpose of determining the maximum possible range is to ensure that, in a technological sense, the range does not represent a problem in the conceptual solution. The cost of the bridge increases rapidly with the increase of the span of the bridge, and one must be careful when choosing spans that are larger than required. This also suggests that the pursuit of a world span record is not necessarily a wise or practical endeavor. It is actually a waste of money if the spread is unnecessarily higher than required.

4.4. SELF-ANCHORED BRIDGES AND GROUND-ANCHORED BRIDGES

A self-anchored bridge is a bridge that does not need additional horizontal anchorage, as is the case with cable-stayed bridges or girder bridges. The main cables of a suspension bridge must be anchored in some other way at both ends to resist the horizontal forces from the cables. There are two ways to solve the problem of horizontal forces: either cable can be anchored to the ground or the cables can be anchored to the beam at both ends. Another way is to form a self-anchored suspension bridge, Fig. 5.

Since the cables of a self-anchored suspension bridge are anchored into the bridge girder at both ends, and since the force in the cables is transferred to the bridge girder, it must be constructed before the cables are placed, which makes the construction of the bridge difficult. The cables also introduce enormous axial forces into the bridge girder, which, depending on the span, cause the need to strengthen the bridge girder in cross-section, which further increases the cost price. This explains why self-anchored bridges are usually of smaller span.

Figure 5. Types of cable anchoring [2].

The 385-meter span of the San Francisco Oakland Bay Bridge in California, on its eastern span, holds the world record for the largest self-supporting span, which was designed by Donald MacDonald Architects and built by American Bridge Co. and Fluor Enterprises. This span is relatively small compared to the largest span of an anchored bridge in the world – the Akashi Kaikyo Bridge in Japan, Fig. 6, with a span of 1,991 meters. There are situations when self-anchored bridges are the right choice, especially when soil conditions make ground anchoring very difficult.

This is precisely the reason why the Oakland Bay Bridge was built as a self-anchored suspension bridge - although on one side it had a good foundation in the form of solid rock, the other end required a foundation in more than 100 meters of mud, which made ground anchoring practically impossible.

Figure 6. Akashi Kaikyo Bridge [6].

The focus now shifts to two memorable bridges, Oakland Bay Bridge and Yavuz Sultan Selim Bridge. These bridges are chosen on account of the marvelous ingenuity. Oakland Bay Bridge holds the record for the longest self-anchored span. Yavuz Sultan Selim Bridge has a unique mechanism for reduction of the longitudinal displacement of the platform and bending of the pylon under heavy rail traffic, as well as a defense mechanism for seismic activities.

5. SAN FRANCISCO-OAKLAND BAY BRIDGE

The first design for the San Francisco-Oakland Bay Bridge was made in 1914, approximately twenty years before the original bridge was completed. The original construction began in 1933, while the bridge was put into use in 1936.

Bridge designers have known for more than 30 years that a major earthquake on either of the two nearby faults (San Andreas and Hayward) could destroy the bridge's main span, Fig. 7. Little was done to solve this problem until the Loma Prieta earthquake in 1989. The earthquake was of magnitude 6.9 and while the epicenter was far from the bridge, a 15-meter section of the upper bridge structure of the eastern viaduct of the bridge collapsed onto the lower floor, which indirectly resulted in one death at the site of the collapse.

Figure 7. The appearance of the old East Crossing [7].

The design selection process for the new bridge marked a fundamental shift in state and regional decision-making in California on one of the largest and most expensive transportation infrastructure projects in the state. The selection of solutions from the proposed variants began in 1997. However, the state of California halted construction of the $6 billion bridge in 2004 when it faced a $3 billion cost overrun.

Construction of the San Francisco-Oakland Bay Self-Anchored Suspension Span began in 2006, and the bridge officially opened in February 2014. The San Francisco-Oakland Bay Bridge East Span Replacement was a construction project that replaced a seismically failing section of the bridge with a new self-anchored suspension bridge. and viaduct. The viaduct connects the suspension part of the bridge with the Oakland waterfront. Considering that the viaduct crosses the shallower part of the bay, the foundations were made within piles. In the middle of 2009, the final connection of the part of the viaduct with the ground level at the eastern end was completed and the pedestrian path of the completed section was connected. The works were completed 34 hours ahead of schedule, and the bridge was opened to traffic on February 19, 2014.

5.2. GENERAL DESIGN OF THE OLD BRIDGE

The old San Francisco-Oakland Bay Bridge opened to traffic in 1936, it’s designers are Ralph Modjeski and Charles Purcell and it was built by the American Bridge Company. It connects San Francisco and Oakland and is the busiest transportation link in Northern California. The bridge, in fact, is formed of several parts with distinctly different structural systems and solutions, connected together to form a single unit of about 13.7 kilometers across the bay, almost 7.1 kilometers across the water. The complete bridge structure was formed as follows: West Crossing: Nearly 3.1 kilometers from San Francisco to Yerba Buena Island, including a two-pylon suspension bridge with a center span of over 704 meters, A 549-meter segment with a tunnel and a short concrete viaduct, East Crossing: More than 3,400 meters from Jerba Buena Island to Oakland, consisting of several different steel truss systems: four smaller 88-meter spans at Jerba Buena, followed by a 738-meter cantilever structure, and then five truss spans at 155 meters, fourteen spans on the bridge structure of 88 meters each, and the rest on simple steel structures on land.

5.3. SEISMIC IMPACT ON THE BRIDGE STRUCTURE

For the safety assessment event, the bridge was designed with an appropriate return period of 1000 to 2000 years. Movements since the 1980s corresponded to a magnitude 8 event on the San Andreas fault approximately 15 kilometers from the end of the West Pass. Soil properties were based on boreholes and soil testing for each pier location, East Pass geologic information, and previously published data. Appropriate non-linear foundation springs were developed for these soil layers, through which the movement was directed. Later, seismic improvements were made to the western crossing in a five-year project that began in 1999. Improvements included massive rollers placed between the roadway and the bridge girders and 96 new viscous dampers inserted at critical points to allow movement. The bridge's twin spans have been strengthened by adding new steel plates and replacing half a million original rivets with nearly twice as many high-strength bolts.

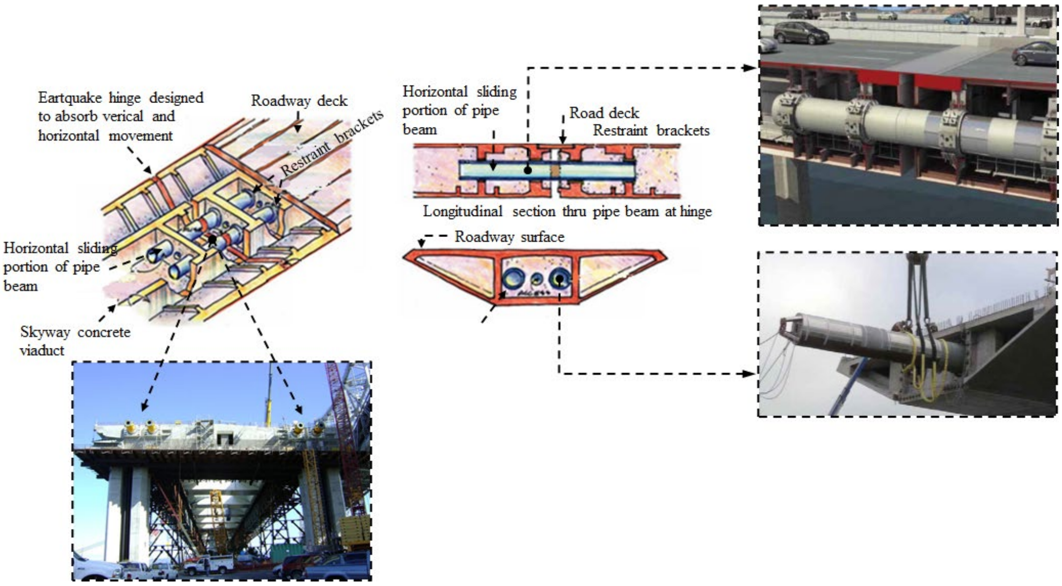

Figure 8. Details of seismic joint of the Oakland Bay Bridge [8] [9].

The design of the new Oakland Bay Bridge prioritized seismic protection to ensure its long-term durability in the face of potential earthquakes [7][8]. The construction of the bridge incorporates numerous seismic isolators and connections with high ductility and ductile joints, allowing the structure to move during seismic events with minimal damage. Fig. 8 illustrates pipe beams connecting different segments of the bridge, capable of accommodating horizontal relative movement between sections. Additionally, in Fig. 9, ductile steel connections within the main bridge are depicted, further enhancing its seismic resilience. These features collectively contribute to the bridge's ability to withstand seismic forces and ensure its longevity [9][10]. The bridge was designed as a limited ductility structure with stable response to ground motions equivalent to the safety evaluation earthquake. The stability of the structure was demonstrated by means of pushover analysis or an equivalent method of structural evaluation [8, 9]. This means:

- The bridge shall have a clearly defined inelastic mechanism for response to lateral loads,
- Inelastic behavior was restricted to piers, tower shear links, and hinge pipe beam fuses,
- The detailing and requirement for full-ductility structures was met.

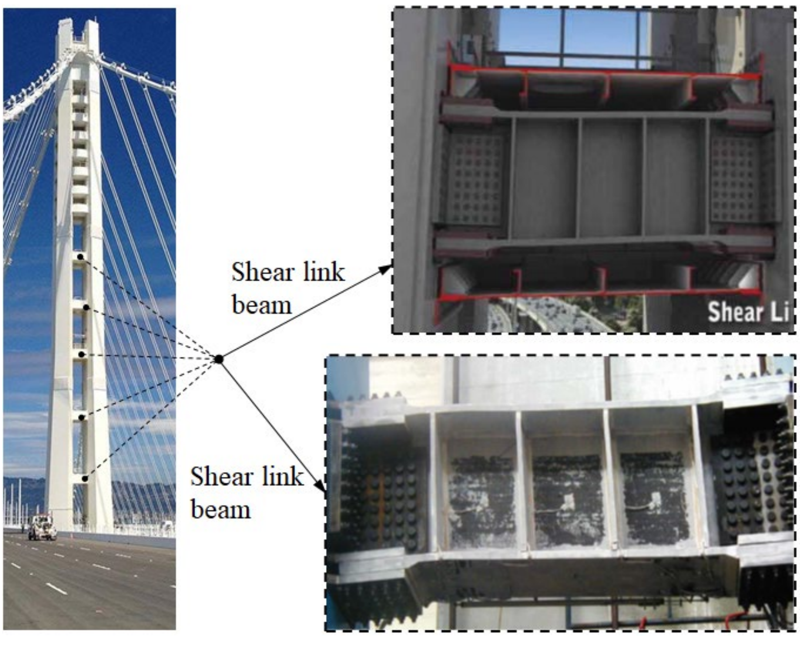

Figure 9. Tower shear link beams of the Oakland Bay Bridge [10] [9].

5.4. PROPOSED BRIDGE LAYOUT VARIANTS

Six variants of the disposition of the bridge are foreseen. Those variants are:

- Reconstruction of the self-anchored suspension bridge,
- Self-anchored bridge with inclined cables and concrete tower,
- Single-pylon, asymmetric bridge with inclined cables,
- Single pylon, symmetrical bridge with inclined cables,
- Two-pylon, symmetrical bridge with inclined cables,
- Viaductal bridge.

VARIANT 1

According to the project, the construction consists of four basic phases, Fig. 10:

- Steel pylon construction,
- Construction of a steel orthotropic bridge structure on temporary pylons,
- Cabling and connecting the bridge structure to the cable using prestressed braces.

Figure 10. 1st proposed variant of the Oakland Bay Bridge [11].

VARIANT 2

The design for variant 2, Fig. 11 is very similar to variant 1, but what differentiates them is that the steel pylons have been replaced by concrete pylons. In order to support the concrete pylon, it is necessary to increase the dimension of the pylon's foundation, thus there are changes in the contract. In addition, the connection of the concrete pylon to the top of the piles, unlike the steel pylon currently in use, is more complex and would require redesign.

Figure 11. 2nd proposed variant of the Oakland Bay Bridge [11].

VARIANT 3

Variant 3 changes the bridge type from a suspension to a cable-stayed bridge with asymmetrical front and rear spans, Fig. 12. This variant provides an appearance similar to that of a suspended one and maintains a span of 385 meters of channel width.

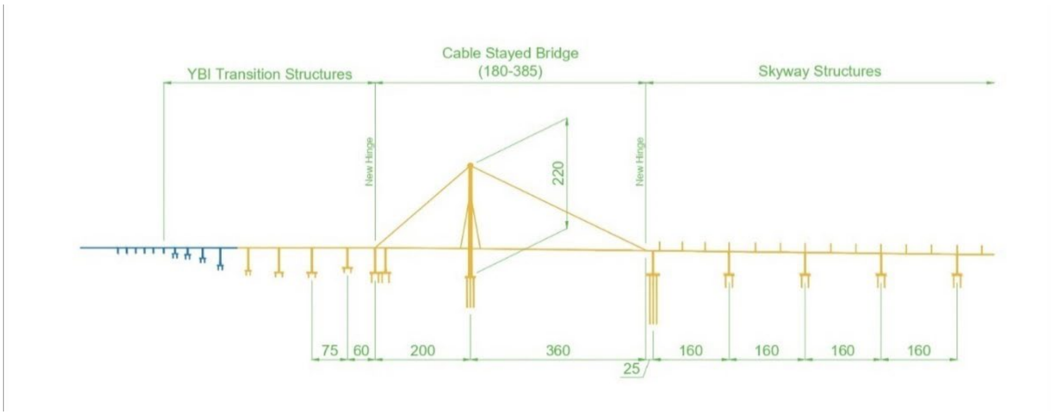

Figure 12. 3rd proposed variant of the Oakland Bay Bridge [11].

VARIANT 4

This variant changes the long-span bridge type from a suspension bridge to a cable-stayed bridge with symmetrical spans, Fig. 13. This approach allows for a suspension bridge-like appearance, but reduces the width of the canal span from 385 meters to 225 meters, in order to create symmetrical spans. The structural difference between the suspension variant and the cable-stayed variant includes the concrete pylon, which is the same height as the suspension bridge.

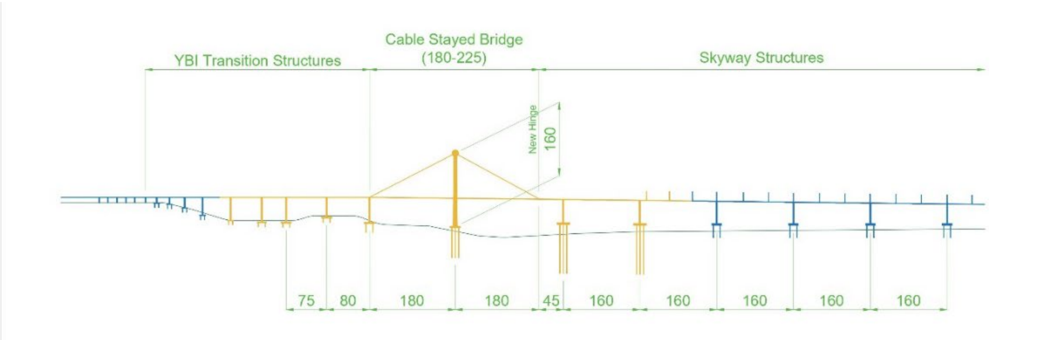

Figure 13. 4th proposed variant of the Oakland Bay Bridge [11].

VARIANT 5

This variant changes part of the bridge type from a single-pylon suspension bridge to a double-pylon bridge with inclined cables and symmetrical spans. This approach to the suspension bridge combines a symmetrical form with a clear channel width of 385 meters, Fig. 14.

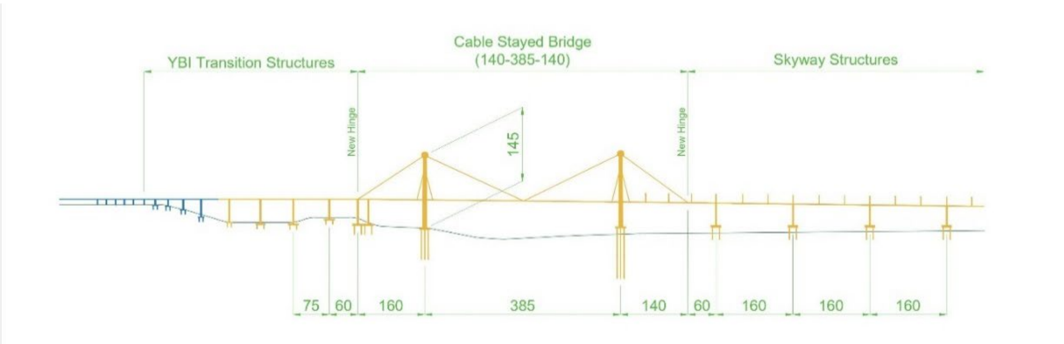

Figure 14. 5th proposed variant of the Oakland Bay Bridge [11].

VARIANT 6

This option would extend the existing road to Yerba Buena Island. This variant is not characterized by a span, but consists of a simple box girder design, which would present fewer challenges in bridge and structural design than other variants, Fig. 15.

Figure 15. 6th proposed variant of the Oakland Bay Bridge [11].

5.5. SELECTION AND DESIGN OF THE SUITABLE VARIANT

The Metropolitan Transportation Commission's proposal aimed to replace the existing two-story configuration with two parallel roads to improve seismic stability, construction efficiency, and aesthetics. It was started with the aim of eliminating the feeling of driving in a cage by placing eastbound passengers in the lower part of the cantilever and lattice structure. The plan called for ten lanes, with five on each side of the bridge, along with a space of 3 meters on each side. Due to the presence of deep silt layers in the eastern part of the bay, the new span had to be raised on shallow piles for 85 percent of its length, Fig. 16.

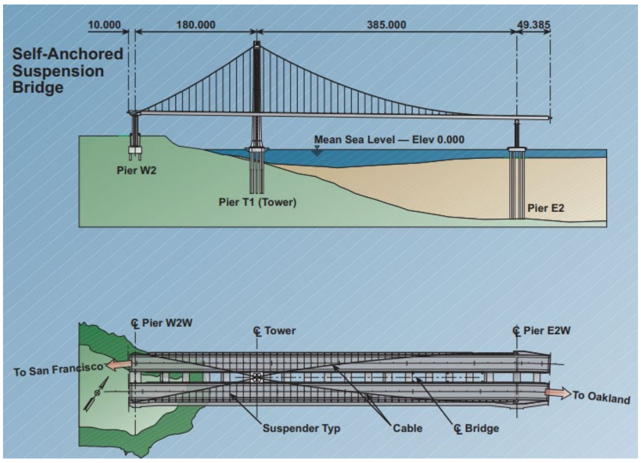

Figure 16. Cross section of Oakland Bay Bridge

In the end, the Design Task Force selected a self-anchored suspension bridge design, which became the longest single-pylon suspension bridge in the world. The final competition came down to self-anchored suspension span and cable span, Fig. 17.

Figure 17. Diagram of load transfer on the Oakland Bay Bridge [12].

To build a self-anchored suspension bridge, two actually have to be built, one as scaffolding to support the main form and the other, the actual bridge. In conventional suspension bridges, the pylons are built first, then the main cables are suspended between them and the bridge structure is attached to the cables. With a self-anchored suspension bridge, the process is reversed. Since the suspension cables are anchored to the bridge structure and not to the banks, at both ends of the bridge the bridge structure must be placed high above the water on a temporary structure [12]. The bridge needs truss scaffolding under the box girders for support. Also, scaffolding is needed to hold the bridge structure while it is being built. Then the cables that attach the bridge structure to the pylon are connected. Basically, two bridges are being built; a temporary structure is first built to support the roadway before the cables are installed, which is then removed.

The self-anchored form in which the cables are tied to the deck itself was necessary, because the geological conditions of the bay could not support anchoring in the very foundations of the bridge where the new East Crossing is located. As a result, a single suspension cable wraps over the tower and under the west end of the span, before wrapping again over the tower to anchor to both decks at the east end, Fig. 18 and 19. One cable is nearly 1.6 kilometers long, 8 meters wide, encircling the west end, before returning to the top of the tower to anchor at the east end. It is the longest suspension cable of any bridge in the world, with more than seventeen thousand 5 millimeter wires, each of which can support a weight of 3.5 tons [13].

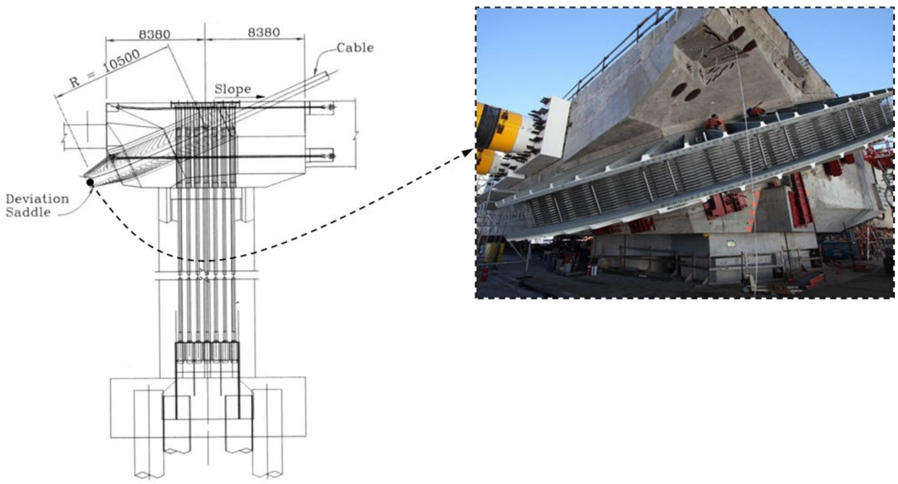

Figure 18. Detail of the saddle on the Oakland Bay Bridge [13].

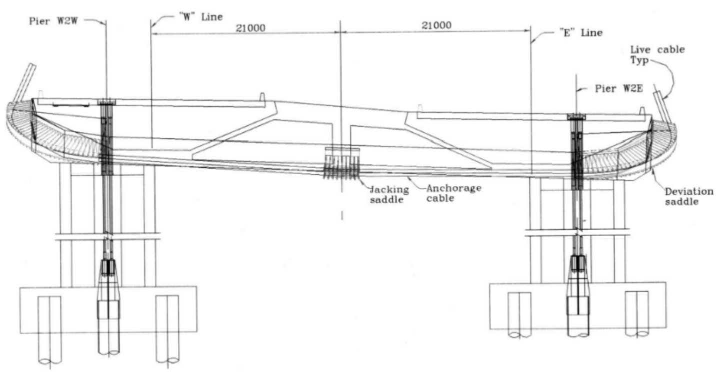

Figure 19. Cable anchorage loop [13].

5.6. BUILDING ISSUES

New concern was caused by the failure of the bridge in March 2013. Most of the large diameter bars were supposed to meet the A354BD standard, in various locations. All A354BD bars on the bridge are galvanized, as a form of corrosion protection. The second level of protection against corrosion

includes: removal of humus from the substrate, use of stainless couplings, as well as protection with certain coatings.
The A354BD type rods[1] that were used and installed in 2008. The length of these bars is from 2.7 to 5.2 meters, Fig. 20.
On March 8, 2013, a few days after the bars were stressed, 9 nuts attached to the bars were observed to have lifted approximately 5 centimeters, indicating a break in the bars. After four days, twenty more queens were found in a similar condition. After this, the stress on the bars had to be reduced to 40% of the predicted intensity, in order to avoid further escalation of the situation. Three more bars subsequently failed, bringing the total number of failed bars to 32, in a 14-day period.

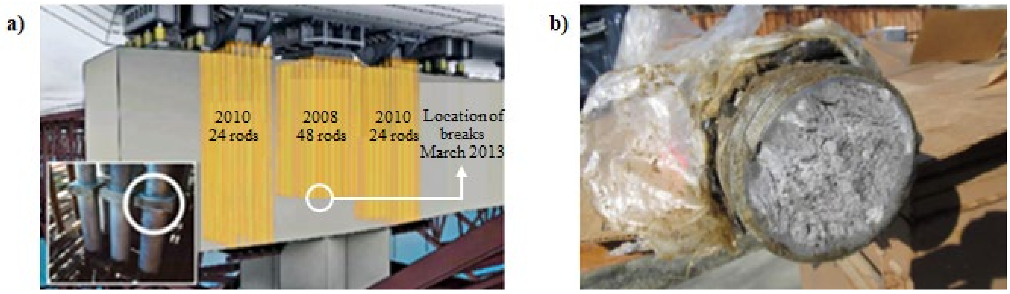

Figure 20. a) Schematic representation of the location of the rod failures; b) Appearance of the rod failures [14].

In order to investigate the cause of these fractures, a set of failed bar samples was taken for testing and analysis. Due to limited overhead clearance, the bars had to be gradually lifted and cut into 60-centimeter lengths for removal. Borescope inspection successfully photographed the lower surface of the fracture and unexpectedly revealed water and voids in the grout inside the cylinder at four out of five locations. Before completing the preliminary failure analysis, the design team made the decision to no longer rely on the remaining bars from 2008. As construction of the new design was scheduled for completion in December 2013, it was proposed to use shims to take advantage of the lateral load capacity bearings [12]. All A354BD bridge bars were identified and visually inspected again, except for the pylon foundation anchor bar. It was noted that, except for the pylon foundation anchor rod, all of the A354BD rods were supplied by the same manufacturer. Key differences between the failed 2008 bars and other bars on the bridge were identified. The 2008 rods were not subjected to magnetic particle (MT) testing on the threads, and were manufactured using a different process. In addition, a significant difference between the two groups of rods was their exposure to water. Construction photographs and a borescope examination revealed that the bottoms of the anchor rods from 2008, where the failures occurred, were exposed to standing water.

6. YAVUZ SULTAN SELIM BRIDGE

Since it was clear from the beginning that the bridge would become a symbol of the city, complex demands were presented in front of it:

- Considering that the location of the bridge is in close proximity to the Black Sea, it is necessary to ensure a navigational channel width of at least 1275 meters,
- The bridge should carry a load of up to four lanes in both directions, two railway tracks, as well as a pedestrian path on both sides of the bridge,
- The bridge should be constructed using a system of suspension bridges,
- Aesthetic conditions are of paramount importance when evaluating offers, and the bridge must not significantly deviate from the architecture of the existing two bridges over the Bosphorus,
- The bridge must be built in a short period of 36 months, plus 6 months for preparation.

The design confirmed structural efficiency and elegance. Compared to traditional suspension bridges, numerous advantages can be cited:

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[1] A354BD type rods – galvanized Ø7.62 cm (Ø3 in) rods that match the A354BD standard.

- Recognizable appearance of a suspension bridge,
- Despite heavy loads, a thin single-floor bridge structure of 5.5 meters in height was utilized, while the height of two-floor bridge structures ranges from 12 to 15 meters,
- Excellent aerodynamic shape of the structure,
- Good seismic behavior due to high damping and large rigidity,
- High limit state of serviceability with small deflections, which facilitate the functioning of the bridge,
- Good torsional properties due to high transverse stiffness caused by cross-linking cables,
- Construction process that saved time due to simultaneous construction of multiple bridge parts. [16]

6.1. BRIDGE LAYOUT DESIGN

The bridge was designed by engineer Michel Virlogeux and architect Jean-François Klein, while the construction was carried out by a consortium of the Turkish company İçtaş and the Italian company Astaldi.

Compared to traditional suspension systems, the combination of a suspension bridge and a bridge with inclined cables should lead to material savings due to the following:

- The loads carried by inclined cables require less material than with suspension cables,
- A more rational pylon height can be used because the limitation regarding stiffness in the case of a suspension system does not apply to a combined system.

When choosing a combined bridge construction assembly, it must be taken into account that the bridge beams will have to endure significant axial forces. It will prove useful to introduce pressure into the bridge beam, in addition to the pylon, which prevents the installation of expansion joints at the pylon. Since the material requirement is lower for bridges with inclined cables than for suspension bridges, the angle of cable inclination can be minimized, and it can even be beneficial to carry all loads with a system of inclined cables, where it can be applied. This leads to the formation of a system quite similar to the Dischinger system. [2]

The initial tender was released as part of a concession project. It required the design of a suspension bridge, with a main span of at least 1275 meters, whose appearance should resemble the two previously built bridges over the Bosphorus. To avoid building foundation pillars far from the shore, a solution was adopted that resulted in increasing the main span from 1275 to 1408 meters. The main obstacle of the project was an extremely tight time interval of 36 months allocated for the design and construction of the bridge. The hanging of the middle span of the bridge structure was accomplished using two rows of hangers, each anchored at a distance of 6 meters from the longitudinal axis of the bridge. Compared to the total width of the bridge of 58.5 meters, this is very small, leading to a tendency towards torsional twisting of the bridge beam. Additionally, great moving loads caused significant deflections. [17]

BRIDGE BEARING SCHEME

On most pylons, the platform is supported on isolator pendulum bearings, which are not primarily used for seismic isolation but to reduce the longitudinal displacement of the platform and bending of the pylon under heavy rail traffic, with the aim of distributing the very large longitudinal load from rail traffic over more columns (avoiding excessive pylon bending). At the expansion joints at each end of the bridge section, sliding bearings are used to resist vertical loads, as rocking bearings would cause the face to lift during longitudinal movements, which would not be compatible with railroad tracks. Transverse forces (wind and seismic forces) are resisted by vertically oriented cup bearings on the abutment and pylon.

CONSTRUCTION

The Third Bosphorus Bridge, also known as Sultan Selim I Bridge, is made as a suspension bridge, but also has inclined cables, which are bound to cable-stayed bridges. The bridge is also a high-rigid suspension bridge. By adopting a suspended structural system in the middle of the main span and a brace system in the sections near the pylons, this bridge combines the advantages of a higher bridge for the possibility of a longer span and a cable-stayed bridge that exhibits greater stiffness, which is useful for railway traffic. The platform is divided into three zones depending on the type of support: suspended cables in the stiffening zone, supports and hangers from the main cables in the transition zone, and finally only hangers in the suspended zone.

BRIDGE ISSUES DURING THE DESIGN PHASE

Large forces and deflections are two very important problems, whose solution is found in the following:

- It is necessary to re-check the allowed stresses due to increased moving loads,
- Large cable deflections are not compatible with the design and geometry of the bridge beam.

The first problem is due to moving loads, which required the cables to be tensioned at very low constant stresses to avoid exceeding the limit states. This causes a decrease in cable stiffness due to increased deflection, which further increases the risk of harmful vibration effects.

Regarding the second problem, large deflections led to the displacement of cable anchor points to the maximum possible distance, Fig. 21. To avoid cable damage, the anchor pipe diameter had to be defined so that the cable could move freely without harmful contact. Increasing the anchor pipe diameter was only possible up to a size that would fit into the geometry of the bridge beam. The decision was made to create fixed points within the anchor pipe, i.e., to move the cable rotation point away from the anchor point, which was achieved using fixed deflectors.

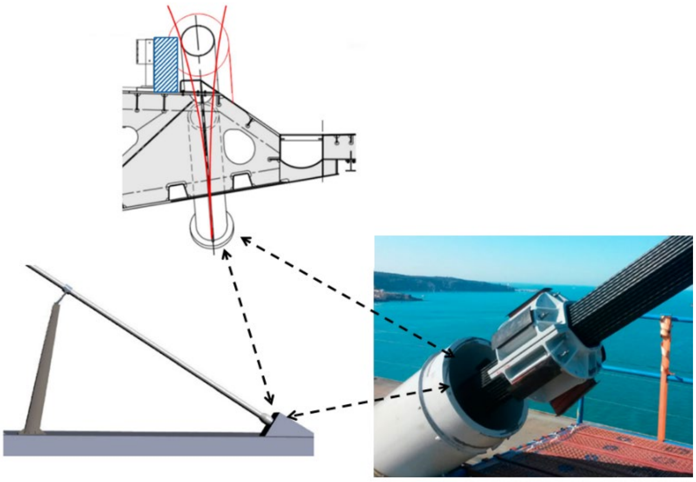

Figure 21. Representation of the location and method of cable anchoring [16].

6.2. ANCHORING BLOCKS

The anchoring blocks were excavated to a depth of almost 35 meters. The sides were supported by a stone wedge system and shotcrete concrete. 24,000 cubic meters of concrete, weighing 60,000 tons, was poured into each anchor block. The blocks stabilize the tension load caused by the main cables of the bridge. Both the Asian and European sides have anchorages with a capacity of 100,000 tons each. Together, the reinforced concrete and embankment, as a whole, have a constructive weight of each anchor block of approximately 150,000 tons. After the completion of concrete works, drainage, waterproofing and embankment works were carried out. Meanwhile, a concrete anchor block tensioned by 45,000 post-tensioning cables with a steel strength of up to 1,860 MPa was installed and the saddle distribution was ready.

6.3. BEARINGS

Pendulum isolators, also known as curved surface sliders, are a type of seismic isolation bearing. Other types include Lead Rubber Bearings (LRB) and High Damping Rubber Bearings (HDRB). Each of these types protects the supporting structures from sudden seismic ground accelerations – isolating the structure from the ground and thus significantly reducing the displacements/accelerations it is exposed to. Further key functions of seismic isolators generally include controlled dissipation of seismic energy and post-event re-centering (returning the supporting part of the structure back to its original location).

A typical isolation bearing has two spherically shaped sliding surfaces - the lower one, which enables rotation around any axis, and the upper one, which enables horizontal movements during an earthquake.

The main components are the same as a typical free-sliding spherical bearing, except that the upper sliding interface of the spherical bearing is flat, not curved, designed only to accommodate operating movements due to thermal expansion, etc, Fig. 22. The bed height increases as the upper plate (of varying thickness) moves from its central position during an earthquake. As a result, much of the work is done in raising the superstructure, thereby dissipating much of the earthquake's energy in a non-destructive manner.

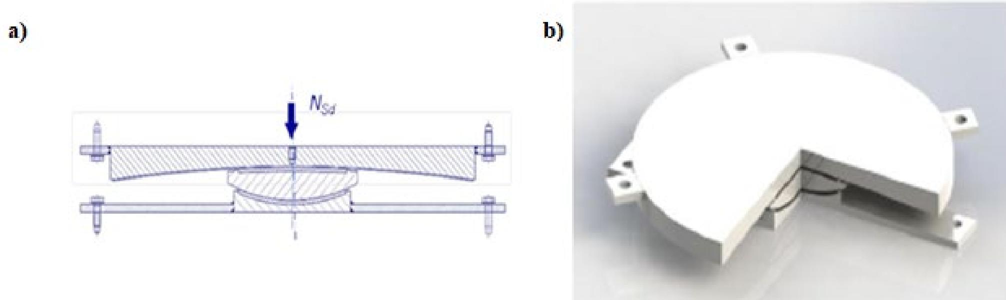

Figure 22. a) Schematic view of the spherical bearing of the bridge; b) Axonometric view of the spherical bearing of the bridge [17].

The dimensions of the pendulum bearing are primarily determined by two main parameters:

- The maximum load that can be carried, which defines the minimum area of the sliding surfaces.
- Movements that must be accommodated during operation or a seismic event.

For this construction, the following parameters were applied in the design of the largest bearings:

- Limit load power 125 MN;
- Displacement of the limit state of strength 764 mm.

The use of isolating pendulum bearings is an effective way of reducing the longitudinal movements of the suspension bridge pavement under live load, especially in the case of heavy rail traffic loads. However, if the radius of curvature of the main sliding surface of the designed bearing is low in relation to the vertical load to be supported, the design can become very inefficient and even impractical. In such cases, the spherical shape of the sliding surfaces of the bearing shell can be made cylindrical, Fig 23.

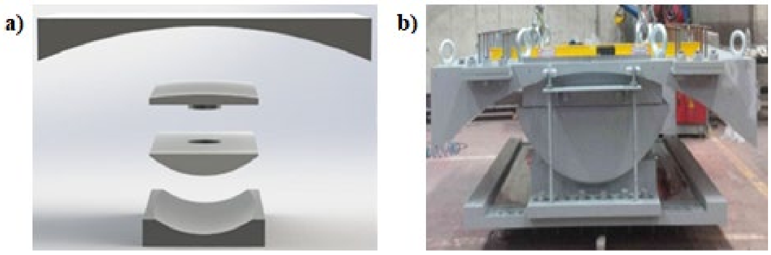

Figure 23. a) Schematic representation of the cylindrical bearing of the bridge; b) Appearance of the cylindrical bearing of the bridge [17].

6.4. BRIDGE PLATFORM

The bridge has an aerodynamic steel orthotropic bridge structure, which improves aerodynamic performance and aesthetic appearance in the main span. The spans on the shorter side are constructed using concrete that acts as a counterweight to the main span. The total length of the steel span is 1360 meters. It consists of prefabricated steel segments, each 58.5 meters wide and up to 24 meters long, Fig. 24. The steel segments are manufactured in parts, made up of 44 different panels. The bridge structure has 59 steel segments, the lightest of which is 300 tons, two segments exceed 450 tons, and the remaining 56 are 800 to 860 tons. The steel bridge segments were produced in three different places. The bridge segments were transported to the site by ship.

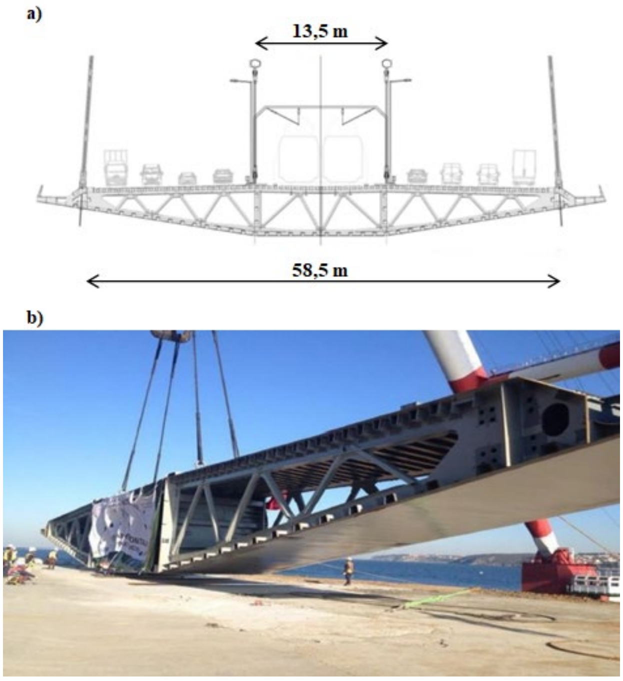

Figure 24. a) Cross-section of the Yavuz Sultan Selim Bridge's platform; b) Appearance of the Yavuz Sultan Selim Bridge's platform [16]

6.5. PYLON

The pylons are A-shaped. Each pylon consists of two cylindrical reinforced concrete shafts underground and two triangular legs. The height of the pylon is 322 meters, which is a world record for a suspension bridge. The thickness of the concrete wall of 1.5 meters at the base is reduced to 1 meter at a height of 208 meters. The legs of the towers are interconnected, and the concrete transverse beam is located at a height of 61 meters, just below the level of the bridge structure. After their completion, a bridge structure was placed on it. The height of the supports between the pylons is 11 meters at the ends, and 6.5 meters in the middle.

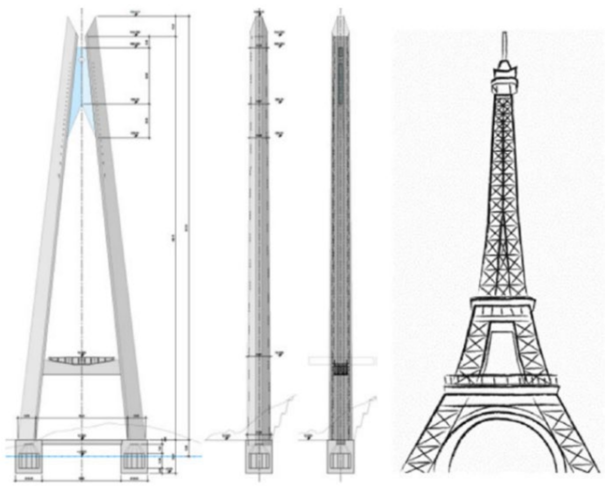

Figure 25. Pylon height comparison (Eiffel Tower and Yavuz Sultan Selim's pylon) [16]

Anchor boxes for fixing the cables are placed in the pylons of the bridge from a height of 208 meters to 304 meters above sea level. There are a total of 176 anchor boxes in the four arms of the pylon bridge, i.e. 44 per leg. The heaviest of them weighs 65 tons.

6.6. CABLE

The mixed suspension system consists of three main parts:

- 176 holders (stiffeners) of cables,
- Hanging (main) cables with a length of 2420 meters,
- 34 pairs of vertical hangers, which support the central part of the span structure from hanging cables.

TENSIONING CABLES

176 stiffening cables were used, with lengths ranging from 154 to 597 meters and diameters between 225 and 315 millimeters. Each cable consists of 65 to 176 strands and each strand has 7 wires with a diameter of 5.2 millimeters. The strength of the wire is 1960 MPa. Each tower leg has 22 cables on the land side, which anchors 22 cables on the main span side.

One end of the stiffening cables is connected to the anchorages in the connecting pipes, which are located on the edges of the steel bridge segments, while the other end is connected to the anchor boxes in the pylons.

MAIN CABLES

Two main cables with a total weight of 12,882 tons were built, produced in a specialized factory in South Korea in less than a year. The main cables carry 34 steel segments, each weighing up to 860 tons. A total of 68 hangers weighing about 170 tons with a strength of 1860 MP. The main span cables have a diameter of 723 millimeters and consist of 113 strands. The main cable with a diameter of 752 millimeters and 122 strands extends from the side. Each strand has 127 galvanized wires with a diameter of 5.4 millimeters, which are arranged in a hexagonal pattern.

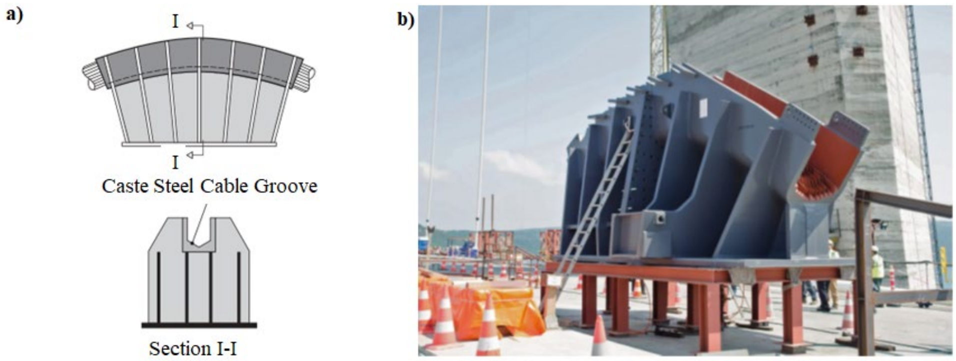

Figure 26. a) Schematic view of the saddle with a cast iron groove; b) Appearance of the saddle with a cast iron groove [2] [15]

Figure 27. Building process [15]

HANGERS - PWS (PARALLEL WIRE SYSTEM)

Hangers are vertical cables that support the bridge structure by means of main cables in the transition zone and suspension zone. In the transition zone, 11 bridge deck segments are also supported by stiffening cables. In the suspended zone, the steel parts of the bridge are directly supported. The bridge contains a total of 68 hangers, length from 13 to 106 meters, diameter from 100 to 175 millimeters, total weight of 171 tons, strength of 1770 MPa.

7. DISCUSSION

This paper is written with an idea of analyzing and comparing, mainly, suspension bridges and cable-stayed bridges. The historical retrospective acknowledges different ideas and encountered problems that have occurred during design phase, as well as building phase.
Different aspects can be taken into account when we're talking about bridges and their purposes:

- Efficiency of solutions,
- Used materials,
- Economical aspect,
- Political aspect.

The main subjects of the paper, as mentioned earlier, are suspension bridges, as well as cable-stayed bridges. Different systems are used for different objectives, depending on many factors, such as soil mechanics, seismic activity, surrounding architecture etc. That's why, in the selection process, engineers encounter various obstacles.
When we talk about differences between girder bridges and cable supported bridges, main takeaways are:

- Girder beams need much more structural material to span the same distance as cable supported bridges.
- Main supporting points in girder bridges are located under the roadway, while main supporting points in cable supported bridges are located high above the roadway, on the pylon.
- In cable supported bridges, continuation of the main cables is required outside the main supporting points, so the tension in the cables can be transfered to the anchoring blocks on the ground.

From this comparison, the decisive advantage of cable supported bridges lays in the low consumption of structural material. Since this advantage only grows with span increase, it is obvious and only logical solution to use cable supported designs for greater spans.
As for the Oakland Bay Bridge, it is one of the modern marvels. The self-anchored suspension system was chosen over cable-stayed variants, as seen in the paper above. The main reason was the 385 meters wide chanel passage that had to be maintained, as well as inability to anchor the main cables, related to the bad geological conditions.
The Third Bosphorus Bridge encountered different obstacles, since it was provided very tight time window to execute all phases. The bearing system combines suspension bridge with the cable-stayed bridge, allowing for great spans and rigidity needed for railway bridges, respectfully to the mentioned types.

8. CONCLUSION

Today, suspension bridges represent one of the oldest and most common types of bridges. Bridges can be divided according to the type of construction, as well as according to the corresponding spans, so beam and arch bridges are more suitable for short spans, cable-stayed bridges for medium-long spans and suspension bridges for very long spans.
With the development of high-quality steels, which were used for the production of cables, the construction of bridges with inclined cables began to become more frequent. Cable-stayed bridges are usually anchored by themselves and thus create suitable solutions, especially in locations where the soil conditions are not favorable for foundations. An example of a cable-stayed bridge is the Sultan Selim I Bridge in Istanbul, Turkey. The need to stiffen the bridge by means of long, high-tension cables caused the creation of an entirely new construction method called the hybrid system, thus ushering in a new era of bridge construction. In addition to the new construction method, it is necessary to analyze the seismic resistance of this bridge, which is an extremely important feature, taking into account that the bridge is located in the seismic zone of the XI category, which is

characterized by strong earthquakes. The solution was found in the use of bearings with dampers, which isolate the structure from a rigid connection with the ground, reducing movements. Two versions of bearings were used, spherical and cylindrical.

The suspension bridge construction system has developed and changed throughout history. Modern suspension bridges date from the 18th century. The choice of the span significantly affects the price of the bridge, and it is necessary to carefully approach the choice of the span, considering that the irrational dimensions of the span lead to unnecessary financial expenses. Suspension bridges can be anchored to the shore or to themselves, forming a self-anchored variant of the bridge. Self-anchored bridges are bridges that do not require additional horizontal anchoring, as is the case with cable-stayed bridges or girder bridges. The reconstruction of the San Francisco-Oakland Bay bridge is reflected in the replacement of the seismically vulnerable part of the bridge with a self-anchored variant of the suspension bridge. The need for reconstruction became apparent after the 1989 Loma Prieta earthquake, which highlighted the bridge's susceptibility to seismic action. During the design and construction, numerous challenges were overcome, such as maintaining the required width of the shipping channel, which caused the need for a larger span. The asymmetric variant with one pylon represents the optimal solution, which in itself represents an engineering challenge, considering that it is necessary to provide a balance of internal forces in each part of the bridge. Seismic impacts, which caused the collapse of the previous bridge, were suppressed by the installation of seismic dampers and a specific support system of the bridge structure.

The objective of this paper is to simplify the complex engineering hidden in the background of these critical objects, as well as to inspire engineers to take on the challenge of exploring different possibilities and solutions and to avoid designing boring and, in some cases, less efficient objects.

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47
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ROUTE OF SOUTH SECTION OF BUDVA BYPASS - REVIEW OF PRELIMINARY DESIGN OF ORGANIZATION AND TECHNOLOGY CONSTRUCTION

Abstract

The Budva bypass, spanning approximately 30 kilometers, is divided into three distinct sections: North, Middle, and South. The Terms of reference required the preparation of a Preliminary design for the construction elements of all structures along the section and route. The Southern section, which is the subject of this article, begins at the end of the Middle section in Vrijesno. The route of the Southern Section goes through the hilly hinterland above the Budva coast, from Kamenovo to Petrovac. In Petrovac, it is connected to the main road M-2 Petrovac-Sotonići-Virpazar via the intersection "Petrovac". The total length of the Southern section is 8.56km. There are five bridges and one tunnel in this route. There are, also, retaining structures and slope protection, conection routes and deviations, one interchange, and noise protection walls on this section of bypass. In this article, parts of Preliminary Design of organization and technology construction are showned. Network plan structure, approximate estimation of the duration of the works, approximate cost estimation, and approximate cash flow estimation during construction are presented.

Keywords: organization, technology, construction, route, bypass

ТРАСА ЈУЖНЕ ДИОНИЦЕ ОБИЛАЗНИЦЕ БУДВА – ПРЕГЛЕД ИДЕЈНОГ ПРОЈЕКТА ОРГАНИЗАЦИЈЕ И ТЕХНОЛОГИЈЕ ГРАЂЕЊА

Сажетак

Обилазница око Будве, дужине приближно око 30км, подијељена је на три дионице: Сјеверну, Средњу и Јужну. Пројектним задатком је предвиђена израда Идејног пројекта изградње свих објеката на дионици и трасе. Јужна дионица обилазнице, која је предмет овог рада, почиње на крају Средње дионице у Вријесну. Траса Јужне обилазнице пружа се кроз брдовито залеђе Будванске обале, од Каменова до Петровца. У Петровцу се спаја са главном трасом регионалног пута М-2 Петровац – Сотонићи - Вирпазар преко раскрснице „Петровац“. Укупна дужина Јужне дионице обилазнице Будва је 8.56 km. На траси ове дионице се налази пет мостова и један тунел. Такође, на овој дионици се налазе потпорни зидови, заштите косина, приступни путеви и девијације, једна петља и зидови за зажтиту од буке. У овом раду су приказани дијелови Идејног пројекта организације и технологије грађења. Структура мрежног плана, приближна процјена трајања радова, приближна процјена коштања и приближан ток новца током грађења су презентовани.

Кључне ријечи: организација, технологија, грађење, траса, обилазница

1. INTRODUCTION

Throughout the project documentation development, current regulations, guidelines, methodologies, strategic plans, and reports were employed as reference materials. [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17]

The route of the Southern section begins at the end of the Middle section in the zone of the settlement Vrijesno. The route is then placed through the hinterland of the coast through Čelobrdo, Marovići. In the Tudorovići zone, the route enters a tunnel about 3 km long. After exiting the tunnel, the route over a series of bridges leads to the main road M-2. The connection of the Bypass with the main road is designed through the connecting road on which a toll ramp is organized. The connecting road is connected by a highway with a roundabout. The connecting road and the bypass intersect with a interchange, with four direct ramps.

Due to the cutting of the existing road network, one deviation was designed.

2. ROUTE

2.1. TYPICAL CROSS SECTION

The typical cross section of a road is designed based on specified velocities, and the widths of various elements are determined accordingly. For the main alignment (Figure 1.) with a design velocity of 100 km/h, the elements and their respective widths are as follows:

- traffic lanes 4x3.50m
- edge strips 4x0.35m
- dividing belt min 3.00m
- shoulder 2.00m
- berm 1.25m
- grid 0.9m
- inflow-outflow strip 3.50m.

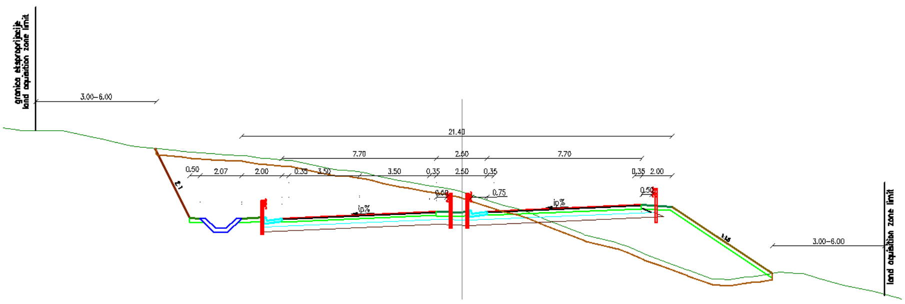

Figure 1. Typical cross section of main alignment

The Terms of References require the dividing strip to be at least 3.00 meters wide, and according to TEM standards (Trans-European standards and recommended practice), this width includes edge strips. Therefore, the width of the dividing strip according to TEM is calculated as 2.5 + 2x0.35 = 3.2 meters, which meets the required minimum width.

The minimum transverse slope of the road is 2.5%, and the maximum in the curve is 7,0%.

2.2. BOUNDARY ELEMENTS OF PLAN AND PROFILE

The plan and profile elements have been determined by considering the designated design speed, adhering to the standards of neighboring countries, and aligning with TEM.

Table 1. Elements of plan and profile

		label	regulation	design
Layout plan	Minimum radius of horizontal curvature	min R	450m	500m
	Minimum radius of the horizontal curvature in the counter-slope	min R	3000m	-
	Minimum transition curve parameter	min A	180	250
	Maximum direction length	max L	2000m	710m
Longitudinal profile	Maximum longitudinal slope	max in	5%	3.15%
	Minimum longitudinal slope	min in	0.5 %	1%
	Minimum radius of convex roundness (in = 0%)	min Rv konv	9000m	15000m
	Minimum radius of concave curvature	min Rv konk	4000m	8000m

The geometric layout of the bypass route has been intricately designed in accordance with the established boundary elements of the plan and profile. Apart from facing highly complex terrain conditions, the design was significantly shaped by the necessity for numerous structures, including tunnels and bridges. Due to this complexity, especially with the goal of separating the axes within tunnels, the axis and elevation of the right and left lanes of the bypass were independently defined on two subsections. Simultaneously, a shared axis and elevation were maintained on two other subsections.

Furthermore, compliance with professional requirements, such as ensuring a maximum height distance between the right and left lanes in tunnels (in the range of 2.5-3 meters as per transverse evacuation connection conditions), as well as considerations outlined in the Layout plan of tunnels and bridges, played a role in limiting the ability to have a more autonomous guidance of the axis and elevation for the right and left lanes.

2.3. LAYOUT

The elements of the horizontal geometry of this variant are designed for Vr = 100km/h. The minimum applied radius on the open route is 500m, and in the tunnel 1000m.

There are two deviations and one interchange named “Petrovac” in the main route. The "Petrovac" interchange is an uneven rhombus-type intersection with a roundabout.

The intersection of the connecting road and the M-2 highway is designed as a roundabout. A toll ramp has been designed on the connecting road.

2.4. LONGITUDINAL PROFILE

The grade of the main direction was designed with a maximum longitudinal slope of 3.15% on a length of 1545m.

2.5. BRIDGES AND TUNNELS

The locations where the bridges commence and terminate are strategically selected to establish an optimal connection between the bridge structures and the surrounding terrain while ensuring a rational placement of supports. The choice of modern bridge construction technologies is deliberate, focusing on those readily available and proven in the domestic market and neighboring countries. This approach aims to facilitate the involvement of local construction companies in the Project's implementation.

The main route incorporates five designed bridges, each assigned specific chainages and lengths, as outlined in the following table (Table 2.):

Table 2. Bridges lenght

Bridge	Start L/R	End L/R	Length L/R
1	-/3077	-/3734	-/657
Krastavac	6626/6627.75	6654/6789.75	28/162
Vukovici	6977/6994	7364/7471	387/477
Zukovica	7849/7848	7949/7976	100/128
Petrovac	8242/8242	8314/8314	72/72
Total			587/1496

The total length of the bridges of main route is 2083m.

Given the current stage of Project development, where precise data on geological and geotechnical soil conditions are not yet available, the commencement and conclusion points of the tunnel have been strategically chosen. This selection aims to ensure an ample height for the superstructure in the portal zones, allowing for flexibility in adapting to potential variations in soil conditions.

In the case of the bypass route, one tunnel has been designed (Table 3.).

Table 3. Tunnel lenght

Tunnel	Start L/R	End L/R	Length L/R
Tudorovici	3665/3742	6607/6620	2942/2878

The total length of the tunnel is 5820m.

3. TECHNICAL AND TECHNOLOGICAL SOLUTIONS FOR MAIN ROUTE CONSTRUCTION

The analysis gave technical and technological solutions for the construction of the main alignment. A significant emphasis was placed on recommending a high level of mechanization for carrying out earthworks, with manual labor being suggested only in specific situations where necessary.

For reinforced concrete works, the proposal is to utilize pre-machined reinforcement produced off-site and transported as completed elements to the installation location. Concrete production is planned at a concrete batching plant and is then transported using machinery for both external and internal transport. The casting process involves the use of traditional formwork, crafted from high-quality chipboard or steel. It's important to note that the specific choice of mechanization is not within the scope of this analysis. This decision will be influenced by adopted work methods and construction technology, as well as factors such as the existing state of mechanization, the financial standing of the contractor, market conditions for machinery, the condition of personnel, and the ability to maintain the machines.

3.1. DETERMINATION OF THE ANNUAL ALLOCATION OF HOURS FOR WORK EXECUTION

The calculation of the annual working days for work execution considers variations in weather conditions, specific work methodologies during different seasons, and takes into account public holidays.

3.2. MATERIALS PROCUREMENT

The materials required for the execution of works on the open route will predominantly be sourced from Montenegro or neighboring countries, and the procurement plan is outlined as follows:

- Cement will be delivered from Serbia and Albania to the site by trucks.
- Aggregate will be delivered from Montenegro to the site by trucks.
- Additives for concrete will be delivered from Serbia to the site by trucks.
- Steel will be delivered from the Federation of Bosnia and Hercegovina, Serbia, or Turkey to the site by
- trucks.
- Fuel will be delivered from Montenegro or the surrounding countries to the site by trucks.

- Equipment arriving from the port Bar will be transported by vehicles to the site. The remaining equipment arriving from surrounding countries will be transported by trucks to the site.
- Asphalt will be delivered from the asphalt base (in Montenegro) to the site by trucks.

3.3. CONCEPT OF WATER AND ELECTRICITY SUPPLY

Water required for construction will be supplied through a mobile water tank, supplemented by the use of local water sources. Initially, electricity for the construction site will be generated through generators. Following the completion of power lines, the site will then receive electricity through the substation.

3.4. CONSTRUCTION SITE PLAN

The construction site necessitates strategic planning for the arrangement of temporary structures such as offices, dining rooms, worker cloakrooms, toilets, water tanks, and machinery parking. Additionally, there is a requirement to organize transportation for workers commuting to and from the construction site from their respective locations.

3.5. WORKS ON THE OPEN ROUTE

The plan for the open route involves the segmentation of main activities into two categories: earthworks and road construction works.

4. NETWORK DIAGRAM STRUCTURE

Using the predetermined work positions essential for project completion, an initial list of activities was created (Figure 2.). This list was formulated using the MS Project 2013 software package. Activities in the list are interlinked with links representing the sequential order of operations during work execution. The interconnected activities collectively form the structure of a network diagram. This planning approach is based on the network planning technique. The overall number of activities in the network diagram structure is 22, with 4 activities identified on the critical path.

ID	i	Outline Number	Task Name	Duration
1		**1**	**CONSTRUCTION OF THE ROUTE/IZGRADNJA TRASE**	**960 days**
2		**1.1**	**Construction of the main route/Izgradnja glavne trasa**	**760 days**
3		1.1.1	Trasa/Route	760 days
4		1.1.2	Potporni zidovi/Retaining walls	360 days
5		1.1.3	MSE i kosine/MSE and slopes	450 days
6		1.2	Vezni put/Link road	150 days
7		**1.3**	**Denivelisana raskrsnica Petrovac/Interchange**	**220 days**
8		1.3.1	Trasa/Route	220 days
9		1.3.2	Naplatna rampa/Toll station	150 days
10		**1.4**	**Devijacija 1/Deviation 1**	**90 days**
11		1.4.1	Trasa/Route	90 days
12		1.4.2	Potporni zid/Retaining wall	70 days
13		1.5	Saobracajna signalizacija i oprema/TSE	150 days
14		1.6	Zastita od pozara/Fire protection	60 days
15		1.7	Pejzazno uredjenje/Landscape	75 days
16		**1.8**	**Instalacije/Installations**	**920 days**
17		1.8.1	Hidrotehnicke instalacije/Hydrotechnics	660 days
18		1.8.2	Elektroinstalacije jake struje/High voltage	670 days
19		1.8.3	Elektroinstalacije slabe struje/Low voltage	440 days
20		1.8.4	Sistem nadzora i upravljanja saobracajem/TCMS	210 days
21		**1.9**	**CONSTRUCTION OF PAVEMENT/IZRADA KOLOVOZNE KONSTRUKCIJE**	**210 days**
22		1.9.1	Construction of pavement/Izrada kolovozne konstrukcije	210 days

Figure 2. List of activities

In the Figure 3 the network plan is shown.

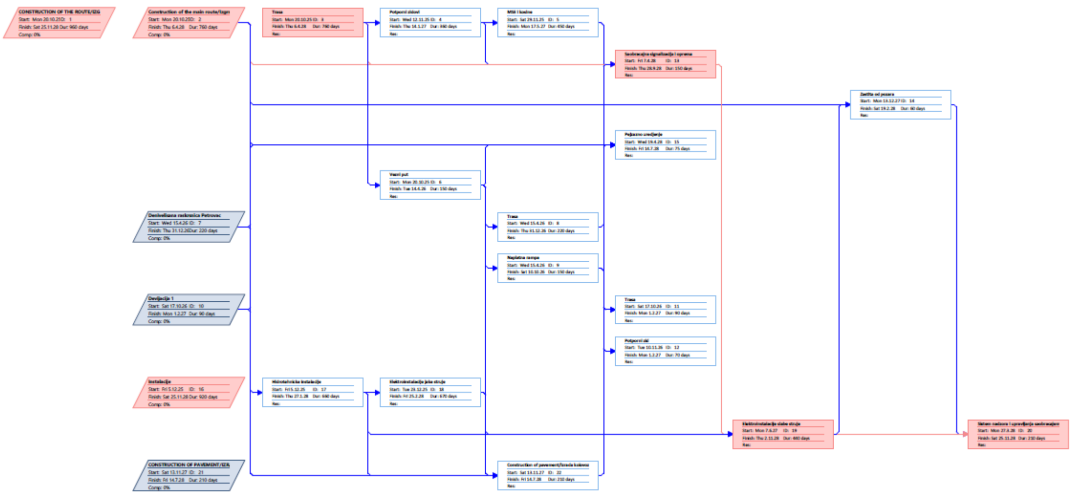

Figure 3. Network plan

5. APPROXIMATE ESTIMATION OF THE DURATION

The work schedule entails operating six days a week, with a nine-hour daily shift, including a one-hour break. Public holidays are designated as non-working days. The duration of activities was estimated considering the work volume outlined in the Preliminary Designs Bill of Quantities (BoQ). The deadline for completing all activities was calculated based on the constructed network diagram. Construction commencement is slated for October 20, 2025. The construction duration spans 960 working days, culminating in the project's completion on November 25, 2028. The project timeline is visually presented in the Gantt Chart (Figure 4).

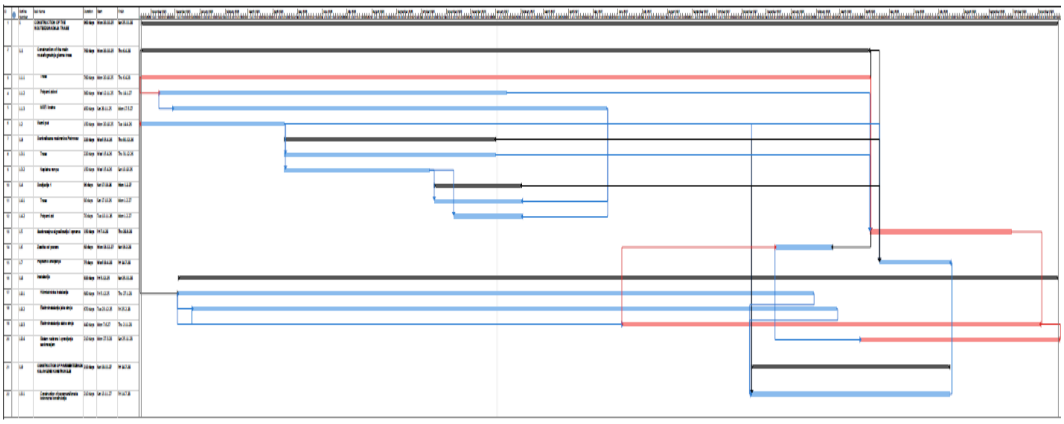

Figure 4. Gantt Chart

6. APPROXIMATE COST ESTIMATION

An approximate cost estimate was derived from the unit prices provided in the Preliminary Design of the main route. The total construction costs, excluding unforeseen works and VAT, sum up to €77,596,023.77.

The total sum represents the sum of the costs of the execution of the mentioned work:

- Construction of the main route with associated retaining walls, MSE and slopes
- Interchange Petrovac with toll station
- Deviation 1 with associated retaining walls
- Traffic signalization and equipment
- Fire protection
- Landscape

- Instalation (hydrotechnichs, high and low voltage, Central and distance traffic control and management system)
- Construction of pavement

7. APPROXIMATE CASH FLOW ESTIMATION

The peak construction costs are anticipated in December 2026, reaching €4,013,280.03, while the lowest costs are expected in November 2028, totaling €71,494.49.
Determining the center of gravity of the investment involves analyzing the diagram and cumulative cost curve, revealing that the center of gravity falls in November 2026.
In addition to cash flow estimates, cost diagrams were crafted based on the type of work, illustrating the percentage participation of each work category in the overall costs. The highest cost is attributed to the Construction of the main alignment, amounting to €46,501,201.90, constituting 59.93% of the total costs. Conversely, the lowest cost is related to Fire protection, totaling €1,869.99, with a minimal percentage participation of 0.002%.

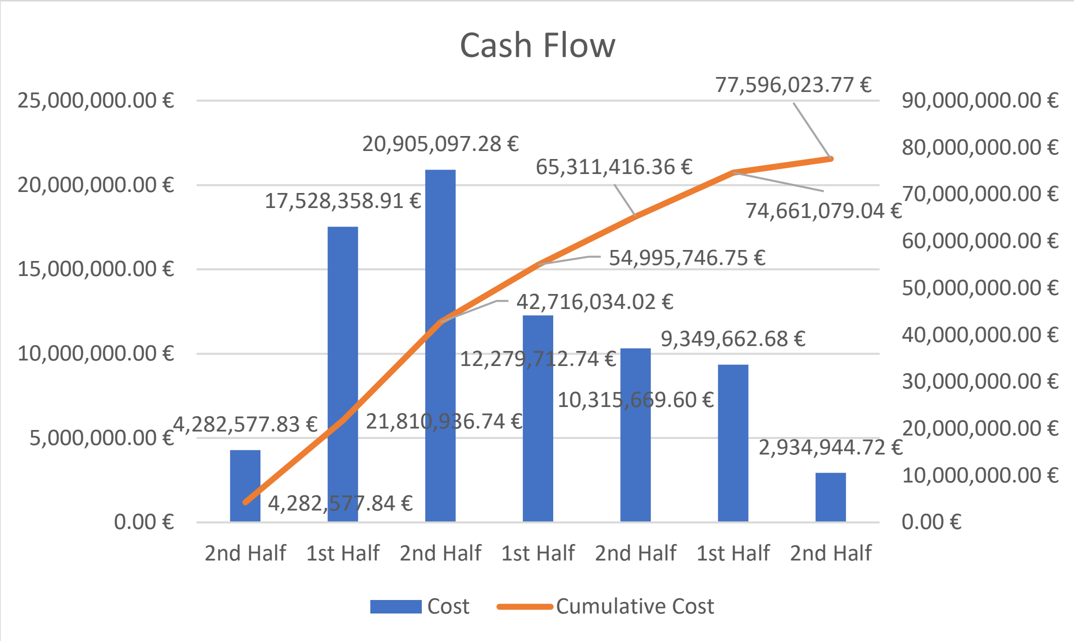

Figure 5. Cash Flow

8. CONCLUSION

The Budva Bypass is about 30 km long and consists of three sections: North (about 8 km long), Middle (about 13 km long) and South (about 9 km long).
The Southern section, which is the subject of this article, begins at the end of the Middle section in Vrijesno. The route of the Southern Section goes through the hilly hinterland above the Budva coast, from Kamenovo to Petrovac. In Petrovac, it is connected to the main road M-2 Petrovac-Sotonići-Virpazar via the intersection "Petrovac". The total length of the Southern section is 8.56km.
Following a comprehensive analysis, proposed were technical and technological solutions for the construction of the main route..The initiation of the project involved creating an initial list of activities based on predetermined work positions deemed crucial for project completion. This list was generated using the MS Project 2013 software package, with activities linked together to represent the sequential order of operations during work execution. The interconnected activities collectively constitute the structure of a network diagram, employing the network planning technique. The entire network diagram structure comprises 22 activities, with 4 activities identified on the critical path.
The completion timeline for all activities was determined using the constructed network diagram. Construction is scheduled to commence on October 20, 2025. The project's duration encompasses 960 working days, concluding with its completion on November 25, 2028.

A rough cost estimate was generated based on the unit prices outlined in the Preliminary Design of the main route. The total construction costs, excluding unforeseen works and VAT, amount to €77,596,023.77.

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48
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STUDY OF LONG-TERM WATER SUPPLY IN THE AREA OF MUNICIPALITY OF TEŠANJ, BOSNIA AND HERZEGOVINA

Abstract

This paper examines the issue of water supply in the municipality of Tešanj, which has been identified as crucial for many years due to the indispensable nature of water as a basic resource necessary for life. The available capacity of the Kraševo-Jelah-Tešanj central water supply system is 47 l/s. By calculating the daily water demand in the area, we determine a water deficit of 51.11 l/s, which needs to be addressed. The analysis and synthesis of data during the preparation of the study leads to the proposition of an artificial aquifer recharge system as a solution to the long-term water supply problem in the mentioned area.

Keywords: water supply, water demand, water deficit, artificial aquifer recharge.

СТУДИЈА ДУГОРОЧНОГ ВОДОСНАБДИЈЕВАЊА НА ПОДРУЧЈУ ОПШТИНЕ ТЕШАЊ, БОСНА И ХЕРЦЕГОВИНА

Сажетак

У овом раду анализиран је проблем водоснадбијевања општине Тешањ, који се због неизаставног сегмента воде, као основног ресурса неиопходног за живот, издваја као најзначајнији већ дужи низ година. Расположиви капацитет централног вововодног система Крашево-Јелах-Тешањ јесте 47 l/s, рачунајући дневне потребе за водом на предметном подручју, долази се до податка о дефициту воде од 51.11 l/s, које је потребно надомјестити. Анализа и синтеза података током израде студије доводи до система вјештачког прихрањивања издани, као рјешења проблема дугорочног водоснадбијевања на наведеном подручју.

Кључне ријечи: водоснадбијевање, потребе за водом, дефицит воде, вјештачко прихрањивање издани.

1. INTRODUCTION

The issue of water supply in the municipality of Tešanj has persisted for many years and remains one of the most significant challenges. The Kraševo-Jelah-Tešanj central water supply system currently operates with a total capacity of 47 l/s at minimum yield. It's important to note that the Kraševo system functions independently, and there are no current provisions for transferring water between the Kraševo and Jelah-Tešanj systems, or vice versa. Considering losses in the Central Water Supply System (CWSS), the total maximum daily water demand amounts to 98.11 l/s. Consequently, the current water deficit at the sources stnds at 51.11 l/s. This underscores the urgent need for additional water to be introduced into the system. Planning for this issue is constrained by a 30-year timeframe, with the year 2052 serving as the ultimate deadline for defining long-term water demand and devising solutions for the development of water supply systems in the Tešanj municipality area 6.[1]6.[2].

2. STUDY AREA (DESCRIPTION OF THE CURRENT SITUATION)

As part of the efforts to assess the condition of the water supply system, detailed descriptions and preliminary assessments of the transportation system, transport-distribution pipelines, surge tanks, reservoirs, and pumping stations were conducted in the research area. Comprehensive data essential for developing the hydraulic model were compiled for all these structures, accompanied by the creation of a system blueprint (refer to Figure 1).

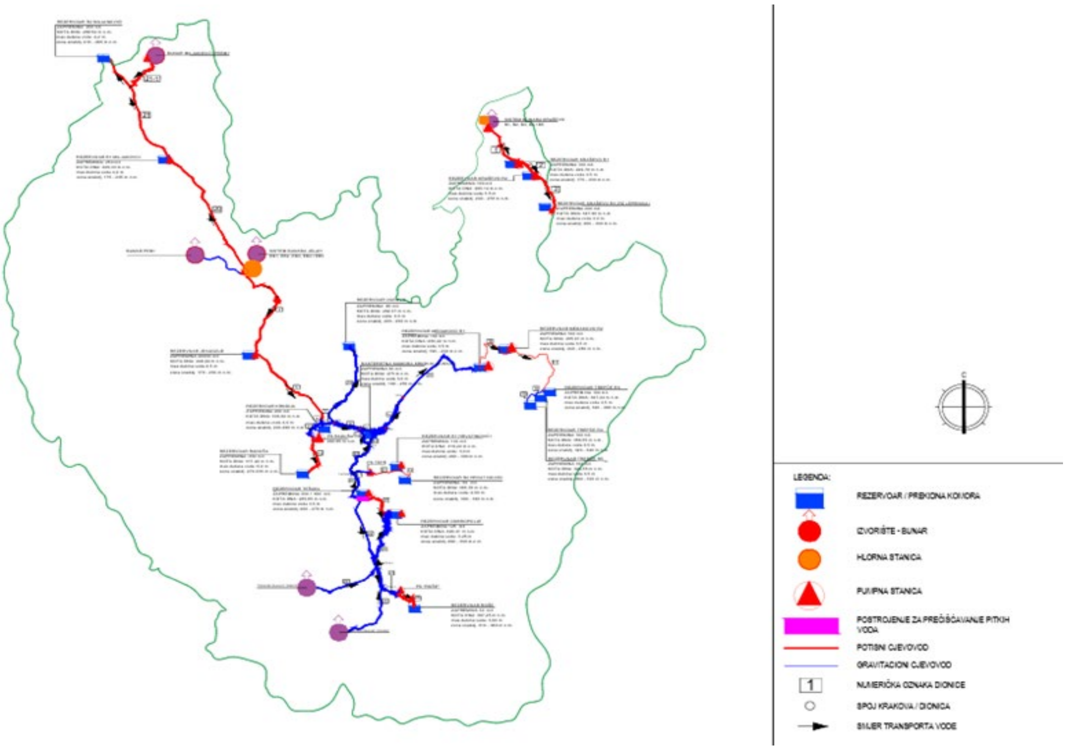

Figure 1. Overview of the Kraševo-Jelah-Tešanj central water supply system

Once the foundational infrastructure of the system was established, efforts shifted towards analyzing consumption patterns and consumer structures for each individual system. Within the entire system, special attention was given to large consumers, such as industrial entities, whose consumption was analyzed separately from that of residential areas, termed "settlement consumption." In preparing the study, consumer and supply zone data from the Geographic information system (GIS) database of Utility company "KJKP Rad"Sarajevo, were utilized. Consumption data were sourced from water meter reading reports. Water loss data were determined based on readings from the main water meters located at the entrances to the District Metered Area (DMA) zones, ensuring accurate projections 6.[3].

3. DEFINING THE PROJECTION AND CRITERIA FOR CREATING THE STUDY

As part of the process of defining projections for the study, demographic projections were initially conducted for each distribution zone within the Central Water Supply System (CWSS) as well as for local water systems. These projections were based on a thorough analysis of available data, capturing demographic trends while employing optimistic estimates.

According to estimates from 2022, the CWSS supplies water to 2,250 inhabitants through the Kraševo Water Supply System (WSS), 18,850 inhabitants through the Jelah WSS, and 5,511 inhabitants through the Tešanj WSS, totaling 26,611 inhabitants. Optimistic demographic projections anticipate that by the end of the planning period in 2052, the CWSS will supply water to 2,477 inhabitants through the Kraševo WSS, 30,138 inhabitants through the Jelah WSS, and 10,489 inhabitants, alongside 1,600 users of the Kiseljak Sports-recrestion-centar (SRC), through the Tešanj WSS. This totals 43,104 inhabitants and 1,600 users of the Kiseljak SRC.

Following the demographic analysis of the population as a consumption area, the consumption of large consumers, including industries, was analyzed. The maximum daily consumption of large consumers/industry in 2022 was 118.68 m3/day in Kraševo WSS, 1,045.00 m3/day in Jelah WSS, and 40.1 m3/day in Tešanj WSS, amounting to a total of 1,203.78 m3/day. Projecting the economic development and consequent growth in water demand, it is estimated that by 2052, 219 m3/day will be necessary for the economy in Kraševo municipality, 2,442.3 m3/day in Jelah municipality, and 60 m3/day in Tešanj municipality. Thus, by the end of the planning period, a total of 2,721.3 m3/day will be needed to supply the CWSS economy.

The maximum daily water consumption of the settlements was determined by applying consumption unevenness coefficients, which were determined based on the type of settlement for each CWSS distribution zone as well as for local water systems 6.[4].

Figure 2. Current and estimated water demand of Kraševo-Jelah-Tešanj CWSS for the planning period until 2052.

The maximum daily demand for CWSS water, accounting for losses, in 2022 is 8.99 l/s for the Kraševo system, 71.08 l/s for the Jelah system, and 18.05 l/s for the Tešanj system, totaling 98.12 l/s. By the end of the planning period, the estimated water demand with losses is projected to increase to 12.60 l/s for the Kraševo system, 149.27 l/s for the Jelah system, and 36.99 l/s for the Tešanj system 6.[5]. Consequently, the total maximum water demand with losses in the CWSS in 2052 is expected to reach 198.86 l/s. This signifies that water demand over a 30-year period is anticipated to rise by approximately 100 l/s.

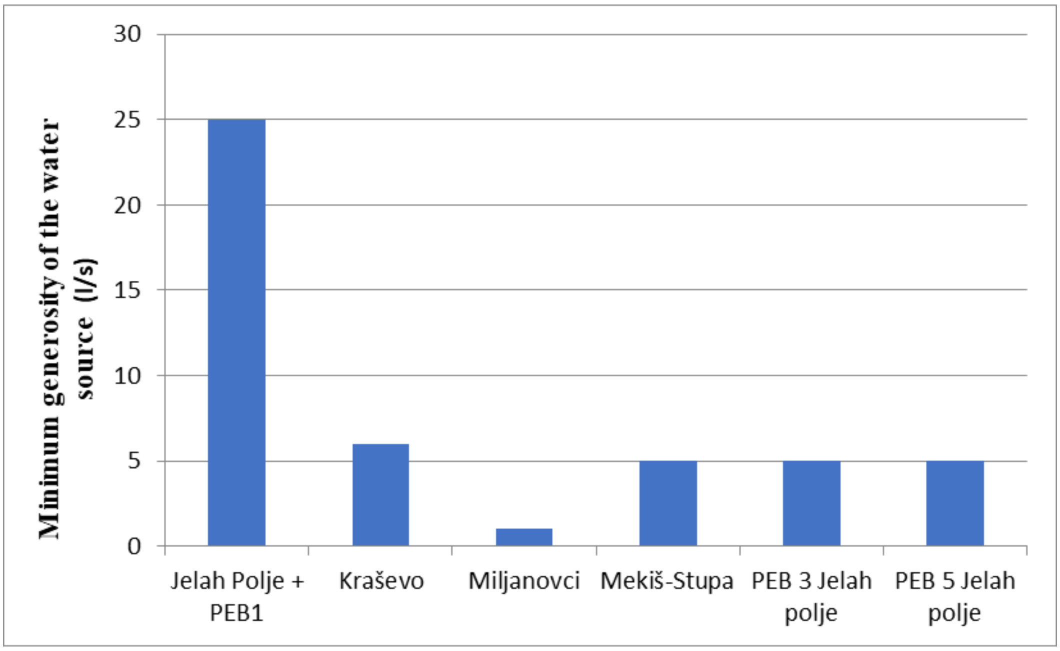

Figure 3. Current minimum yield of the water source in the Kraševo-Jelah-Tešanj sistem

4. METHODS

Based on the analysis and synthesis of data, along with previous research, the most promising location for providing additional water is the Jelah Field. Here, it's feasible to capture quantities totaling 150 l/s through artificial recharging methods. Artificial recharge involves human-induced activities where surface water is directed to infiltrate into the aquifer, leading to the accumulation of water within it. From a hydrogeological perspective, this activity results in an increase in the piezometric level within the aquifer and a subsequent rise in underground water reserves, directly contributing to an increase in the source's capacity and, potentially, an improvement in the quality of underground water 6.[6]6.[7].

Artificial recharge methods have been successfully implemented worldwide. While relatively underutilized in our region, successful applications have been observed in Niš, Požarevac, Trstenik, Sarajevo, and previously in Čačak. The primary motivations for employing artificial recharge methods stem from the following factors 6.[8]:

- compared to surface reservoirs, there are no fees for flooding the surface of the terrain, etc.
- the possibility of maintaining the piezometric level at the required height
- using the self-purifying potential of the environment during the percolation of water through the porous environment with the aim of improving water quality
- the aquifer is used as a reservoir for accumulating underground water
- the quality of underground water has advantages compared to the quality of surface water
- the possibility of pre-treatment of water and bringing the quality to the required level
- water losses are negligible compared to surface accumulations

Indeed, with artificial recharge, there's a notable increase in the general level of the water source. This elevation rise facilitates the functionality of shallower water-bearing horizons, ensuring the fulfillment of the projected capacity of the source, exemplified by the Jelah Polje source. In scenarios where there's a need to augment the source's capacity, artificial recharge enables the accumulation of the requisite water volumes. In addition, with the increase of the piezometer level at higher elevations, it is necessary to invest less electricity to overcome the additional lifting height of the well pumps 6.[9].

By employing artificial recharge, there's a reduction in the volume of subsequent water treatment required. This is because the natural filtration and purification processes that occur as water percolates through the aquifer result in improved water quality. Therefore, not only does artificial recharge serve to increase water availability, but it also contributes to enhancing the quality of water resources, leading to potential cost savings and efficiency improvements in water treatment processes downstream 6.[8].

There are several methods of artificial infiltration, categorized primarily into direct and indirect methods. Among these divisions, one notable categorization includes direct surface and direct underground infiltration methods, as well as a combined approach. For the Jelah Field and Kraševo sources, it's recommended to employ the direct surface method, considering the geological and hydrogeological characteristics of the terrain 6.[6]6.[7]6.[8].

In addition to the flooding method, other viable options include furrows and trenches, which are likely to have lesser impacts. However, the method of infiltration basins is particularly recommended. This method is widely used for artificial recharge and consists of three main components: the input side, the transport part, and the output side.

On the input side, elements are deployed to ensure that water of the required quality enters the aquifer. The transport part involves the filtration process as water infiltrates towards the water intake structure. Finally, the output side comprises the water intake structures and potentially includes treatment processes for affected groundwater.

Specifically, the entire system at the Jelah Field source would encompass:

- Surface water intake from the Usora River 6.[10]
- Raw water pumping stations
- Water pre-treatment plants
- Low-pressure pumping stations and pipelines for water transport
- Infiltration facilities
- Underground water catchment structures (tube wells combined with drains)
- Tension system for the collection and transport of captured water
- System for the treatment of captured water if necessary (chlorination)

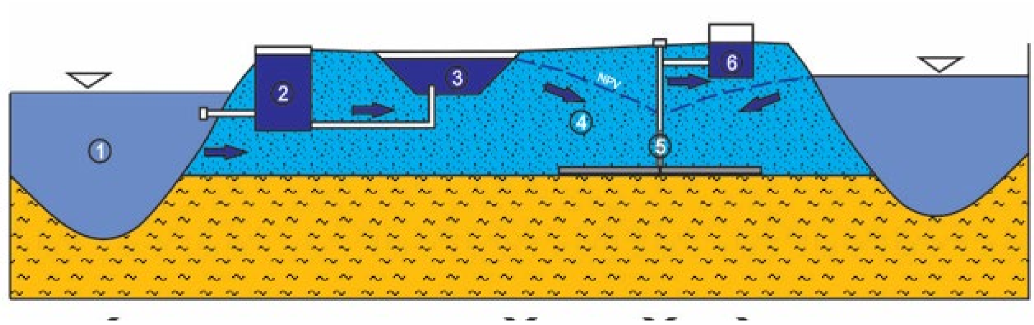

Figure 4. Schematic representation of the elements of the artificial recharge system at the source of Jelah Field (1- water intake of surface water, 2- pretreatment of water, 3- infiltration structure, 4- filtration through a porous medium, 5- source of underground water (wells and drains), 6- treatment of captured water)6.[8]

5. RESULTS AND DISCUSSION

The application of the artificial recharge method issued to the subject Tešanj municipality water supply system implies the following steps:

- Capture and treatment of minimal amounts of water from the existing springs: Jelah Field+ Exploaratory well “PEB1”, Kraševo, Miljanovci, Mekiš-Stupa and new wells “PEB3” and “PEB5” (total 47 l/s).
- Capture and treatment of additional quantities of water (total required additional quantities for CWSS, for the end of the planning period, approx. 150 l/s) at the Jelah Field site and further transport with quantities from the existing wells of Jelah Field towards reservoirs and distribution of water according to the same concept that is currently established for the distribution zones of the Jelah system. For the distribution zones of the Jelah system, additional approx. 108 l/s. The increase in the capacity of the transport and main transport-distribution, gravity and pressure pipelines/pumping stations of the Jelah system is defined according to the hydraulic model of the system and the maximum daily needs with losses for the end of the planning period 6.[11].
- Connecting the Jelah and Tešanj systems, by supplying the Tešanj reservoir (289.35 m above sea level) with quantities of water from the existing and planned catchment structures of Jelah Field. The necessary quantities of water for the distribution zones of the Jelah

system (except Miljanovci) as well as the necessary additional quantities of water would be transported by a pressure transport line from Jelah Field to the Jevadzija reservoir, and then by a re-pressure transport line from Jevadzija Reservoir to Krndija Reservoir (ground elevation 304.62 m above sea level) for the Tešanj system. From Krndija Reservoir, the transport and distribution of water for the distribution zones of the Jelah system and the transport of additional quantities of water for the Tešanj system to Tešanj Reservoir would be carried out by gravity (construction of a new transport pipeline). Additional amounts of water for the Tešanj system amount to approx. 32 l/s. The height difference at the minimum water level in Krndija Reservoir and at the inlet in Tešanj Reservoir is approx. 15 m. The increase in the capacity of the transport and main transport-distribution, gravity and pressure pipelines/pumping stations of the Tešanj system is defined according to the hydraulic model of the system and the maximum daily needs with losses for the end of the planning period 6.[9].

- By connecting the Jelah system with the Kraševo system in such a way that additional approx. 6 l/s for the Kraševo system (Kraševo Reservoir 1 (R1) zone) was transported from the planned catchment structures of Jelah Field to the Krndija reservoir and then to the Krndija interruption chamber (Bukva). Considering that with the minimum yield of the Kraševo source of 6 l/s, it is possible to provide an orderly water supply to the distribution zones Kraševo R2 and Kraševo R3 (1.81 + 4.66 = 6.47 l/s) until the end of the planning period, additional amount of water from the Jelah field catchment structures could be provided by supplying the Kraševo R1 zone from interruption chamber Bukva 6.[12].
- The increase in the capacity of the transport and main transport-distribution, gravity and pressure pipelines/pumping stations of the Kraševo system is defined according to the hydraulic model of the system and the maximum daily needs with losses for the end of the planning period 6.[13].

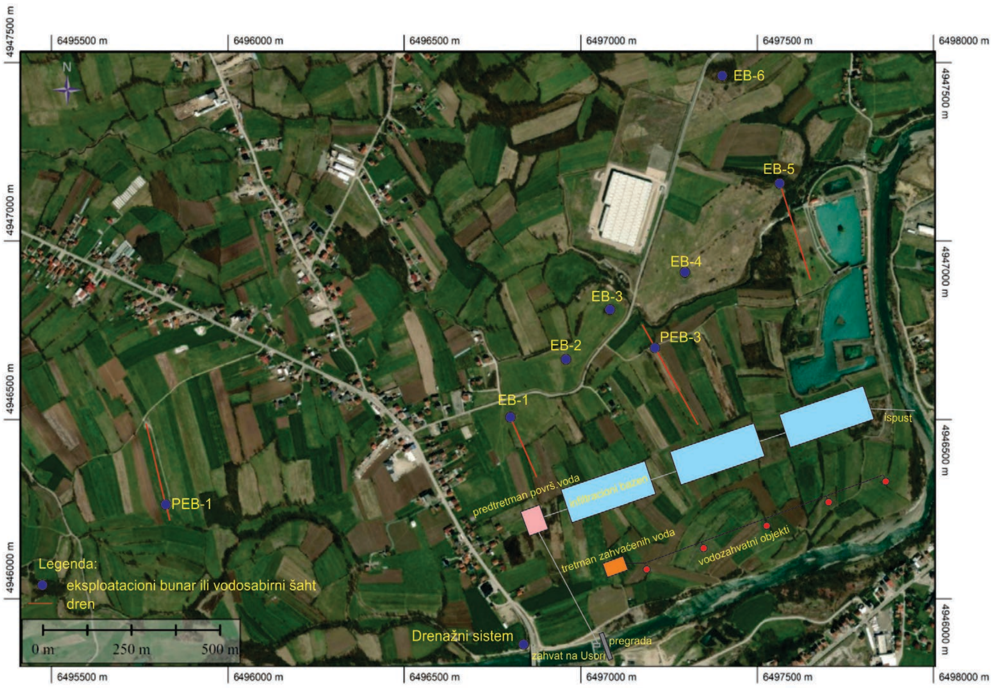

Figure 5. Presentation of the artificial recharge system at the Jelah Field source

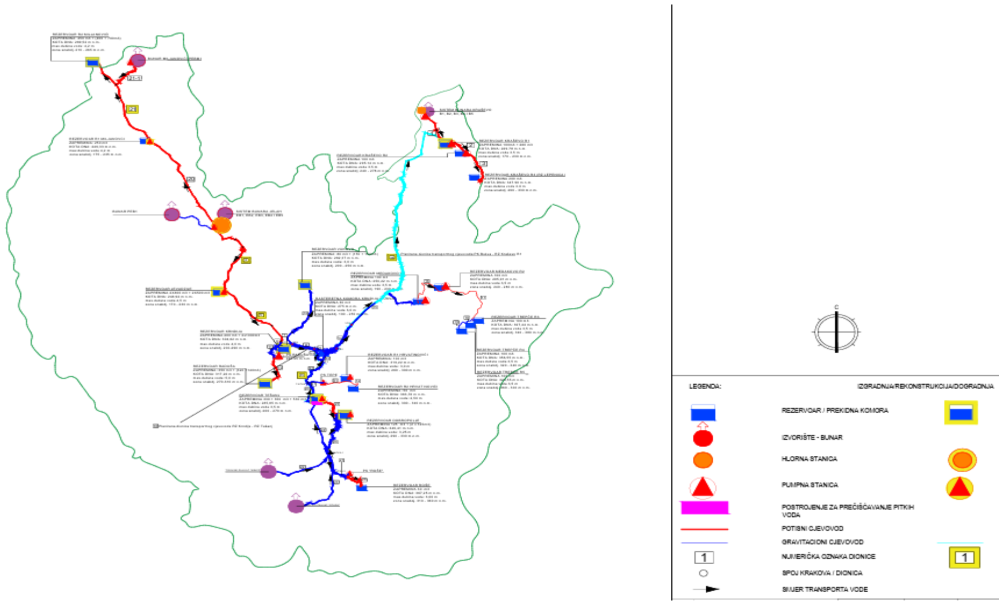

Figure 6. Planned development of the Kraševo-Jelah-Tešanj central water supply system

6. CONCLUSION

Observing the general state of the water supply system in Bosnia and Herzegovina reveals a pressing issue: an increasing number of cities and municipalities are grappling with insufficient water quantities or inadequately developed water supply systems. Insufficient investments in development and inadequate system management contribute to uncontrolled water consumption and capacity deficits. When compared with the global issue of water scarcity, particularly in terms of drinking water, it becomes evident that raising awareness about water usage is crucial in our region. Developing more centralized, extensive, and modern water supply systems is imperative, given Bosnia and Herzegovina's abundant water resources.

Many existing systems suffer from significant network losses, posing a unique challenge, especially considering that only 3% of Earth's total liquid mass is fresh water. Preserving both the quantity and quality of the natural water resources in our region is essential. Tešanj municipality faces the challenge of an insufficiently developed water supply system. Over the next 30 years, additional water quantities and system expansion and reconstruction are necessary.

Analyzing demographic trends, economic and industrial development, it's evident that there's a deficit of 100 l/s in the maximum daily water demand category for the Tešanj municipality CWSS. Among various methods to provide additional water, the study identifies water supply from the Jelah Field as a viable option. Utilizing the method of artificial recharge, up to 150 l/s can be obtained from this area. Among the types of artificial recharge, direct surface recharge of the river is deemed the most applicable for the identified source.

It's crucial to emphasize that alongside exploring new water sources, efforts must also focus on network reconstruction and expansion, particularly in areas prone to large losses and those posing health risks due to outdated materials. By addressing these issues comprehensively, we can ensure a sustainable and reliable water supply system for the future.

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49

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THE ASSESSMENT OF THE CONCRETE STRUCTURE STADIUM "SJEVERNI LOGOR" IN MOSTAR

Abstract

The paper presents the assessment of the stadium "Sjeverni logor" in Mostar, through the necessary steps in diagnosing the state of the existing structure: collection of existing documentation, inspection of the structure, testing and analysis, and assessment and decision on further action. Drawings of the stadium were made with defined damage and test points with non-destructive methods.

Destruction and classification mechanisms are performed according to EN1504. The non-destructive methods used during the examination are the rebound hammer and ultrasonic pulse velocity. At the end of this paper, the results and assessment of the condition are given, and the appropriate methods of sanctions are proposed, in accordance with EN1504.

Keywords: mechanisms of destruction, non-destructive methods, methods of rehabilitation

ДИЈАГНОСТИКА СТАЊА БЕТОНСКЕ КОНСТРУКЦИЈЕ СТАДИОНА "СЈЕВЕРНИ ЛОГОР" У МОСТАРУ

Сажетак

У раду је приказана дијагноза стања стадиона "Сјеверни логор" у Мостару, кроз неопходне кораке у дијагностицирању стања постојеће конструкције: прикупљање постојеће документације, преглед конструкције, испитивање и анализе, те процјену и одлуку о даљњем поступању. Израђени су цртежи стадиона са дефинисаним оштећенима и мјестима испитивања са недеструктивним методама.

Механизми уништавања и класификације изведени су према EN1504. Неразорне методе које су кориштене приликом испитивања су склерометар и ултразвук. На крају овог рада дати су резултати и оцјена стања, те су предложене одговарајуће методе санције, у складу са EN1504.

Кључне ријечи: механизми разарања, неразорне методе, методе санације

1. INTRODUCTION

The assessment of the construction [1] aims to provide an answer to the question of the state of the construction on the basis of measurements and research. The diagnostic procedure includes:

- Determining the current state of the entire structure and especially its individual elements
- Determining the remaining level of load capacity, usability or other essential property of the structure

The request to determine the condition of the structure can arise for several reasons, such as:

- the need for planning and designing maintenance works,
- the conversion or adaptation of the building is foreseen,
- the development of technology requires higher usage loads.

In this paper assessment based on visual inspection and in-situ tests for concrete structure stadium "Sjeverni logor" in Mostar is presented. After the inspection and conducted tests, rehabilitation measures are proposed in accordance with EN 1504.

2. THE STADIUM "SJEVERNI LOGOR" IN MOSTAR

The "Sjeverni logor" stadium is located within the USRC "Midhat Hujdur Hujka" in the Sjeverni logor in Mostar. The building has three entrances, one each on the north, east and west sides. The stadium together with the stands was built in 1996. The aerial view is presented in figure 1.

Figure 1. Aerial view of the stadium structure

It is a reinforced concrete construction, where the foundations, columns and the upper two floors of the stands are built by concreting on site, with the pillars and upper floors of the stands being monolithically connected, while the remaining floors of the stands are prefabricated concrete elements.

Due to the fact that the documentation was not adequately archived and given to the team that was working on the diagnosis of the condition of the sinking object, the dimensions and characteristics of the section were defined by visual inspection and measurements. The dimensions of the base of the building are 43.2 m x 58.5 m. The total height of the stands is 5.1 m.

The columns have a rectangular cross-section with dimensions of 60x30 cm. The total number of columns is 34. The stands consist of beams with cross-section dimensions of 100x50 cm.

The columns, together with the "stairs" and foundations, form a framework structure on which the beams rest. The connection between the monolithic and prefabricated beams is made with a layer of concrete 10 cm thick. The beams overlap each other at a width of 20 cm, and the other 80 cm rest on the "stairs". The static system of the stands is a continuous beam. On the south and west side, it is a continuous beam with 8 spans 4.50 m long, while the beams on the west and east side are spread over 5 spans of 4.70 m with an overhang up to half of the span of the opening for the entrance to the building, length 2.15 m.

3. VISUAL INSPECTION

For structures whose condition needs to be determined at some point in their existence, i.e. after they have been in use for some time, the simplest way to collect data on the structure is to study the design and construction documentation, as well as reports on previous inspections and maintenance. Of course, data should be corrected prior the usage.

Data on the original design and calculation of the structure, as well as plans of the built state, are not usually available, as is the case with this structure. In this case, a visual inspection of the structure is used to determine the dimensions of the section, the geometry of the structure, the parameters that describe the properties of the materials from which certain structural elements are made, according to the methods of diagnosing the state of the structure [2].

A visual inspection of the structure determines damage to individual structural elements, their causes, spread, and the impact on the load-bearing capacity and usability of that element and the structure as a whole. In addition, the possible existence of excessive deformations, rotations or vibrations is controlled. It is important that the inspections are aimed at evaluating the decisive factors of the safety and usability of structures, and at observing and evaluating all phenomena and changes that may lead to disruption of the specified parameters [2].

The assessment for existing buildings can be divided into following steps [3, 4]:

- Collection or reconstruction of blueprints
- Collection or reconstruction of calculations
- Building inspection
- Investigations and monitoring
- Calculations
- Evaluation and decision on further action.

A visual inspection of the structure determines damage to individual elements and their extent.

During the visual inspection of the construction, special attention was paid to [5]:

- geometry and cross-section dimensions
- appearance and differences in the color of the construction surface
- appearance of cracks, their size and arrangement
- signs of material degradation on the surface of the structure.

On the existing structure of the "Sjeverni logor" stadium, the following damages were observed during visual inspections:

- Damage caused by moisture
- Degradation
- Segregation
- Appearance of vegetation
- Corrosion of reinforcement
- Cracks
- Deterioration

Some of the observed damages are shown in the figure 2.

Figure 2. Examples of damages on construction (from left: cracks on column, corrosion, concrete separation)

After the visual inspection, new blueprints of existing condition were created, due to lack of original blueprints. On these blueprints, all observed damages were defined (figure 3). Also, visual inspection provided data on damages on construction and points of in-situ tests.

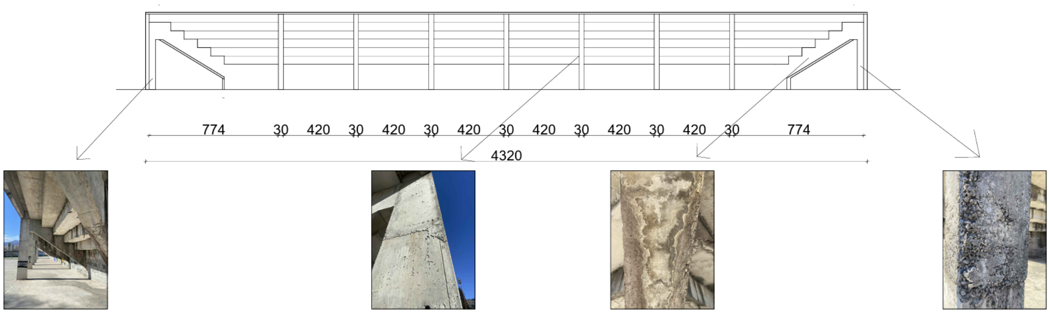

Figure 3. Example of damages defined on blueprints

4. IN-SITU TESTS RESULTS

The outer side of the stadium structure was tested with non-destructive in-situ tests. Compressive strength was measured with digital rebound hammer. Concrete quality was measured by ultrasonic pulse velocity (UPV) test.

Tests were conducted on 10 columns and 10 beams. Of these, there are two pillars each in the western and northern tribunes and three pillars each in the southern and eastern tribunes. The points are given in figure 4.

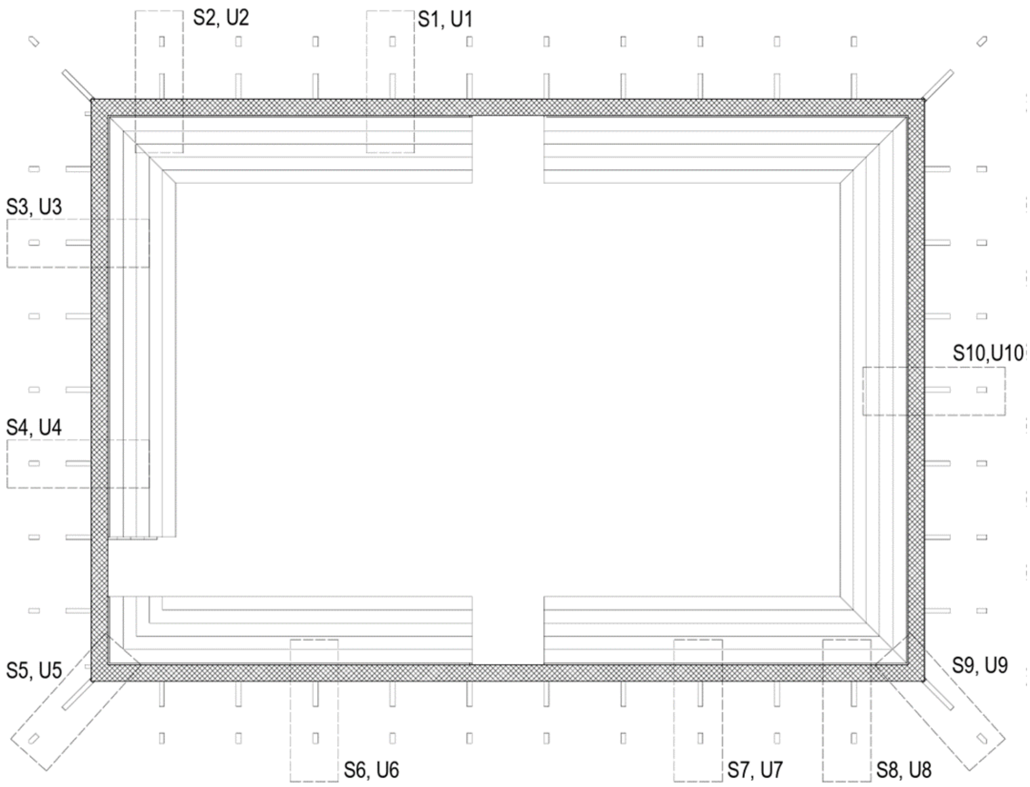

Figure 4. Selected columns and beams for in-situ tests

The rebound hammer is a method used to determine the characteristic compressive strength. The test was conducted at a total of 20 locations, with a maximum of 5 shots per test location. As a result, the mean value of the readings at the test site is taken, adjusted to take into account the direction of the rebound hammer test and the rebound hammer index is expressed as a whole number. If more than 20% of the reading differs from the mean value by more than 6 index units, the entire test spot should be discarded.

Table 1 shows the results of sclerometer measurements on the beams and columns of the stadium.

Table 1. Average in-situ tested compressive strength (MPa)

Location	Column	Beam
S1	40,36	62,76
S2	51,40	65,68
S3	56,50	54,84
S4	54,24	67,56
S5	65,05	61,08
S6	47,92	57,40
S7	56,98	52,10
S8	43,16	59,10
S9	73,60	48,71
S10	48,56	51,68
Average	53,78	58,09

Figure 5. Compressive strength tests

The UPV test is one of the non-destructive testing methods that is widely used due to the great adaptability, sensitivity and reliability of the results that can be achieved. The UPV test was applied in the same places where the sclerometer was used, i.e., on 10 columns and 10 beams. Regarding the accessibility of the test sites, a direct test method was used on all columns and beams (figure 6).

The velocity of the ultrasonic pulse in a material depends on the density and elasticity of that material. If the ultrasonic pulse encounters an inhomogeneity in the material, given the size and shape of the inhomogeneity, the ultrasonic pulse will bounce off the inhomogeneity while the remaining part of the ultrasonic energy will continue to propagate to the back of the object's surface. Ultrasonic testing of components and structures is based on the propagation of an ultrasonic pulse through the material, during which the ultrasonic pulse is subject to all the laws of propagation of sound waves.

Elastic properties such as Young's modulus of elasticity E, shear modulus G and Poisson's ratio μ can be estimated and calculated by measuring the UPV using longitudinal and/or transverse waves.

The dynamic modulus of elasticity was determined empirically (1) based on the measured ultrasonic pulse velocity [6]. To calculate the dynamic modulus of elasticity, the values of Poisson's coefficient μ= 0.20, and the density of concrete ρ= 2400 kg/m^3 were assumed.

$$E_d = v^2 \rho \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \quad (1)$$

v – velocity (km/s)
ρ – density of concrete (kg/m^3)
μ – Poisson's coefficient

Table 2 shows the results of in-situ UPV measurements.

Table 2. Average in-situ test results for pulse velocity and E_d

Location	Test	Column	Beam
S1	v (km/s)	4,20	3,41
	E_d (MPa)	38026,3	25103,3
S2	v (km/s)	4,48	2,65
	E_d (MPa)	43305,9	15170,6
S3	v (km/s)	3,68	3,89
	E_d (MPa)	29267,2	32703,0
S4	v (km/s)	4,07	2,38
	E_d (MPa)	35693,0	12225,5
S5	v (km/s)	4,20	3,41
	E_d (MPa)	38026,3	25046,3
S6	v (km/s)	4,28	4,40
	E_d (MPa)	39560,4	41795,3
S7	v (km/s)	4,32	3,55
	E_d (MPa)	40246,4	27290,5
S8	v (km/s)	4,35	4,26
	E_d (MPa)	40831,8	39112,7
S9	v (km/s)	4,38	3,55
	E_d (MPa)	41430,0	27290,5
S10	v (km/s)	4,17	4,48
	E_d (MPa)	37604,4	43435,4

Based on the standard EN 12504-4, it is concluded that the concrete is mostly medium to good quality (v=3,0 – 4,5), due to average measuring values range about 4,00 km/s.

Figure 6. Ultrasonic pulse velocity test

5. REHABILITATION

After the inspection of the "Sjeverni Logor" stadium and after the rebound hammer and UPV tests, it can be concluded that the general condition of the structure is satisfactory. Damage caused by mechanical, physical and chemical action does not affect the load-bearing capacity of the structure. But it is necessary to carry out certain repairs in order to extend the useful life of the structure. Regular maintenance is also necessary, in order to reduce the occurrence of new damages. Based on the proposed remedial measures according to EN1504, and in accordance with the categorization of damage mechanisms for the concrete construction of the stands of the " Sjeverni Logor" stadium, the following remedial measures are proposed [7]:

- Manual application of mortar

It represents an established method of local repair of damage in concrete and is most often used for the repair of smaller areas. Mortars are specified in EN 1504-3. The goal of this method is to replace poor quality concrete with new mortar or concrete.

- Modifying elements

In places where the column has cracked due to the horizontal movement of the beam, it is more economical to replace part of the structure. In such cases, it is necessary to ensure the adequate bearing capacity of the structure and the distribution of the load by means of appropriate systems for gluing or tying.

- Hydrophobic impregnation

The entry of water, including dissolved harmful substances, can be prevented by hydrophobic impregnation of concrete. In this way, significant cracks are repaired and closed.

- Impregnating

Impregnation aims to fill the pores of the concrete surface to prevent any transport of liquids or gases through the concrete surface. In addition to filling the concrete pores, a thin film of impregnation material is often additionally placed on the surface of the concrete. The result is sometimes called pore blocking.

- Surface sealing of cracks

It is done to prevent the penetration of aggressive substances into the concrete. This method is used for individual cracks or exceptional displacements of cracks that cannot be covered with coatings.

- Coatings

Surface coatings improve the surface of concrete, which becomes more resistant to certain external factors or behaves better under their influence. Small surface cracks with a displacement of up to

0.3 mm can be safely repaired and then filled. Their movement is adapted to the use of flexible coatings for bridging cracks, which are resistant to water and carbonization.

- Increasing coverage by adding mortar or concrete

This method is mostly related to the corrosion of reinforcement. If the reinforcement is not sufficiently covered with concrete, adding cement mortar or concrete reduces the aggressive effect of chemicals.

- Replacement of contaminated or carbonized concrete

This method is the traditional standard for repairing reinforced concrete. By removing the damaged concrete and re-covering the rebar, the steel is once again protected by an alkaline coating.

6. CONCLUSION

Assessment of condition of the "Sjeverni Logor" stadium in Mostar requires the necessary steps, namely: collection of existing documentation, inspection of the structure, examination and analysis of the obtained data, and assessment and decision on further action. The first step in the preliminary inspection of the construction was the measurement of the construction and the drafting of the existing state. Based on a visual inspection, the mechanisms of destruction of the structure, their causes, the spread of damage, and their effect on the structure were established. All observed damages are entered in detail in the construction database, with defined causes and proposed remedial measures according to EN 1504.

As part of the assessment, in-situ tests were performed using non-destructive methods: rebound hammer and ultrasonic pulse velcocity. Nowadays, non-destructive methods of testing materials and structural elements are increasingly used in construction, for quality control, but also for determining the constancy of properties. The advantage of non-destructive methods is that tests can be repeated in different periods on the same test sample or place, and the results are collected for the purpose of monitoring changes in properties. Testing, with a rebound hammer and UPV, was performed on 10 columns and 10 beams. With the use of a sclerometer, it was concluded that the compressive strengths of concrete at all test locations are satisfactory. When testing with the UPV method, it was concluded that the concrete is of mostly medium to good quality. This paper presents tables of the results of these tests and their analysis.

Although the mentioned destruction mechanisms do not affect the load-bearing capacity of the structure, it is necessary to repair the damage, and appropriate methods of repair are proposed, according to EN1504. Regular maintenance and repair can extend the life of the structure.

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GEODESY

ГЕОДЕЗИЈА

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INTEGRATION OF RESUNET AND YOLO ALGORITHMS INTO A UNIFIED MODEL FOR OBJECTS DETECTION

Abstract

Automatic extraction of footprints of buildings from orthophotos is a challenge in the field of remote sensing data processing. The combination of image classification and object localization tasks in this research aims to develop a new model based on ResUNet and the YOLO algorithm. By applying the proposed model and publicly available data, a high level of building extraction success of 89% is achieved. Although there is potential to improve the results by introducing other types of data, the integration of these models represents a significant step towards improving the technology of automatic extraction of buildings from orthophotos.

Keywords: ResUNet, YOLO, neural networks, deep learning, building detectio.

ИНТЕГРАЦИЈА RESUNET И YOLO АЛГОРИТАМА У ЈЕДИНСТВЕНИ МОДЕЛ ЗА ДЕТЕКЦИЈУ ОБЈЕКАТА

Сажетак

Аутоматско издвајање отисака зграда са ортофото снимака представља изазов у области обраде података даљинске детекције. Комбинација задатака класификације слике и локализације објеката у овом истраживању има за циљ развој новог модела заснованог на *ResUNet*-у и *YOLO* алгоритму. Примјеном предложеног модела и јавно доступних података, постиже се висок ниво успјешности екстракције зграда од 89%. Иако постоји потенцијал за побољшање резултата увеђењем других типова података, интеграција ових модела представља значајан корак ка унапређењу технологије аутоматског издвајања зграда из ортофото снимака.

Кључне ријечи: ResUNet, YOLO, неуронске мреже, дубоко учење, детекција зграда

1. INTRODUCTION

Accurate and up-to-date information about buildings plays an essential role in many fields such as urban planning, environmental protection, real estate management, disaster risk assessment and many other fields [1], [2]. Such information is invaluable for modern society and city management, so it is not surprising that in recent years, with the rapid development of urban areas, automatic building extraction has become an important topic of scientific research [3], [4].

Remote sensing offers a large number of high-resolution sensors that record a wealth of information about objects on the ground. Therefore, remote sensing data provide significant support in the field of object classification and detection within urban areas [5]. The high spatial resolution of aerial and satellite images gives the possibility of distinguishing different objects in urban areas and enables the extraction of information about individual objects.

The manual method of collecting information about individual buildings, although it has high accuracy, is very expensive and time-consuming work, and cannot meet the requirements for quickly extracting and updating information about buildings in large areas. Using high-resolution images and modern image processing algorithms [6], [7], buildings can be accurately identified and classified based on their characteristics, such as roof shape, size, color, etc. However, this raises some new challenges in automatic object extraction due to the diversity of building features and complex environments [8]-[10]. First of all, buildings have significant differences in size, shape, height and function, and also have large variations in high resolution images caused by lighting, viewing angle, obscuration of the building by other objects and shadows [1]. Urban scenes consisting of spectrally similar objects such as roads, buildings and other artificial objects also make it difficult to accurately detect buildings [11].

Although this task has received a lot of attention in the scientific community, most approaches use additional data, such as point clouds, multispectral imagery, height information of objects and terrain (DSM, DEM), etc. This data, while important, is usually too expensive or unavailable for most cities around the world. Therefore, improving the accuracy and efficiency of automatic building extraction from high-resolution images is still a challenging task that is the focus of many researches [12], [13].

Traditional methods for extracting buildings from remote sensing images mainly involve image classification based on pixel features or image objects. Methods that rely on pixel features generally use the information of a single pixel for its classification. Initially, most studies used conventional machine learning techniques to process relevant objects by manually selecting features [3]. Machine learning methods such as K-Means [14], Support Vector Machines [15], Random Forest [16] and others were used for pixel analysis and classification. However, these methods ignore the relationship between neighboring pixels and do not use spatial information about objects. The results of this classification are prone to the influence of "salt and pepper", which results in blurred boundaries of separated buildings. Also, all these methods require prior knowledge, and their poor generalization capabilities due to manual feature selection may cause inaccurate results [8].

Detecting buildings from aerial and high-resolution satellite images is a complex task, partly due to the huge amount of data, i.e. of pixels to be processed, which often makes it challenging to handle large datasets in a fast and efficient manner, even with modern computing frameworks [17]. To deal with this challenge, new superpixel segmentation algorithms have been proposed and developed that group pixels to create contextually meaningful regions, leading to better processing efficiency while preserving important information [18]. However, the classification accuracy is highly dependent on the image segmentation results, and the segmentation scale is difficult to determine. Therefore, problems such as over- or under-segmentation are frequent occurrences, which can significantly affect the quality of the final result.

Due to the increase in computing power and the availability of large data sets, deep learning methods have emerged as successful tools for solving many tasks in the field of computer image processing. Deep learning has a strong generalization ability and the ability to efficiently express features [19]. It bridges the semantic gap, integrates feature extraction and image classification, and omits data pre-processing, such as image segmentation, through an end-to-end hierarchical construction method [5]. It can also automatically perform hierarchical feature extraction on massive raw data, reduce human labeling and reduce labor costs [5].

Deep learning, with convolutional neural networks (CNN) as a representative, is an automated artificial intelligence technique that has emerged in recent years, specialized in learning general patterns from large data sets, as well as exploiting the learned knowledge to solve unknown problems [20]. Deep learning has been successfully applied and rapidly developed in areas such as image classification, object detection, semantic segmentation, and instance segmentation.

Convolutional neural networks have a strong capacity to extract information from spatial context, and their automated learning mechanism allows for reuse [21]. All of the above, CNN is widely used on remote sensing images for object classification and detection.

Some of the key advantages of CNN-based image classification algorithms are that they provide solutions that offer greater generalization capabilities [22]. They also perform object-based classification, ie. they take into account features that characterize entire image objects, thus reducing the "salt and pepper" effect that affects conventional classifiers. CNNs can not only automatically extract features from raw image data, but also obtain semantic information level by level, which has resulted in great success in image classification tasks [23].

In 2015, Long et al. [24] proposed a fully convolutional network (FCN), the first end-to-end semantic segmentation method implemented in neural networks. Although FCN has achieved good results in building extraction, it does not consider the relationship between pixels. It also mainly focuses on global and ignores local features, resulting in poor results. However, most subsequent deep learning network models have been improved and innovated based on this model, i.e. many scholars have proposed some deepened and improved networks, such as U-Net [25], SegNet [26], etc. U-Net is one of the most commonly used network models for image segmentation tasks that belongs to one of the FCN variants. In recent years, many image segmentation algorithms have used U-Net as the original network model for segmentation.

In addition to the mentioned models for classification and segmentation, in the field of computer image processing there are algorithms for object detection that are also based on CNN. Object detection is the process of automatically finding and localizing objects of interest in images or videos. This process includes recognizing the presence of certain objects, as well as determining their locations and bounding boxes in the image or video. There are two basic types of algorithms for detecting objects in images using deep learning, namely two-level and one-level networks [21]. Two-level networks first identify potential regions that contain objects and then classify the image based on those regions. Examples of these algorithms include R-CNN (Region Based Convolutional Neural Networks) and Fast R-CNN. However, their disadvantage may be slower image processing. On the other hand, single-stage networks such as YOLO (You Only Look Once), SSD (Single Shot Detector), and similar ones perform object detection in a single step, which makes them more efficient than two-stage networks [27].

In the studies published so far that dealt with the classification of buildings and other objects on remote sensing images, a large number of different strategies are found. Jovanović et al. in the paper [12] propose a U-Net model for identifying changes in buildings in order to update the existing record of buildings. This study shows that the proposed model performed well in the identification of objects, but it also gives a lot of false positives, i.e. objects that do not belong to the building class are placed in that class. These results, using only very high-resolution images containing RGB and NIR bands, showed object identification accuracies ranging from 84% to 88%. In the paper [28], Chen et al. have proposed the Res2-Unet model to improve detection performance and generate accurate building boundaries. However, even this model is not able to distinguish individual roads from buildings. Kokeza et al. in their paper [29] test the possibility of using different publicly available datasets for training neural networks, and then test the ability of the model to generalize to the area of interest. The evaluation of the results showed that the models trained with publicly available datasets do not meet the required accuracy for updating cadastral maps in the study area. Much better results were achieved using orthophoto images, made from data obtained using UAV, for neural network training. Farajzadeh et al. in their work [30] investigate the ability of U-Net architecture with ResNet to extract building footprints from UAV-based orthophotos and digital surface models (DSM). Experiments highlight the effectiveness of height information for detecting and extracting building footprints with significant improvements in accuracy from 89% to 97%.

Donghang et al. [31] performed fast and accurate airport detection on remote sensing images using YOLO. Pham et al. in paper [32] introduce an improved single-stage detection model based on deep learning, called YOLO-Fine. This detector is designed to be capable of detecting small objects with high precision and high speed, enabling further real-time applications. Ma and others [27] implemented the detection of collapsed buildings using the YOLO algorithm. However, some results were characterized by incorrect bounding boxes.

Given the outlined challenges, the automatic extraction of building footprints, the outer surface of the building roof, from high-resolution orthophotos is one of the most challenging tasks in this field. Due to the aforementioned problems, when extracting objects, the tasks of image classification and localization of objects from the image must be combined, i.e. image classification is used to predict the class of an object in an image, and object localization is used to locate one or more objects present in an image and locate them using a bounding box. In response to these challenges, this paper proposes an enhanced building extraction method leveraging ResUNet and YOLO algorithms. In this proposed method, the ResUNet model acts as a feature extractor, while the YOLO algorithm is employed for object detection. The primary objective is to develop a novel model aimed at enhancing the efficiency and accuracy of object detection, thus advancing the technology of automatic building extraction from remote sensing data.

2. MATERIALS AND METHODOLOGY

2.1. METHODS

Within this case study, the authors proposed a workflow for the automatic extraction of buildings based on data generated on the principles of remote sensing. The suggested steps are shown in Figure 1.

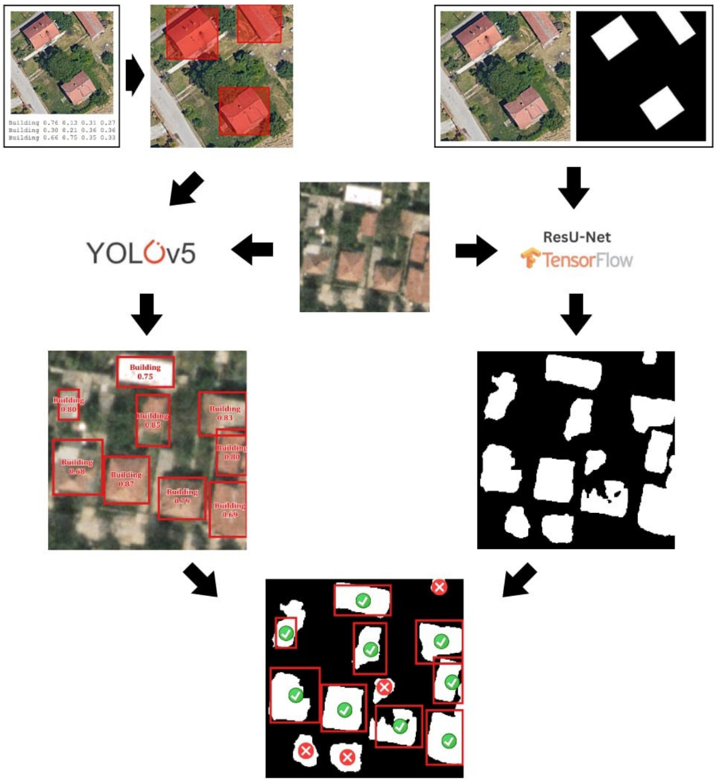


Figure 1. Flow chart of research method

As the analysis of the literature found that ResUNet achieves much better results in the classification of satellite images than the U-Net architecture, this architecture was used as the basis for the classification of buildings in this paper. Since a certain number of false positives can be expected as a result, i.e. objects that are wrongly classified as buildings, in order to overcome this problem, a single-level YOLO network is used, which will be able to filter the obtained classification results in a fast and very simple way and thus localize only the objects of interest.

2.1.2. RESUNET

The problem of segmentation of satellite images represents a major challenge in remote sensing. In the last few years, algorithms based on convolutional neural networks have been developed with the aim of segmenting satellite images. The most common way of performing semantic segmentation is the use of convolutional neural networks because they achieve very good results, and one of the most famous architectures used is U-Net, which has a coder-decoder type structure. U-Net is a type of Fully Convolutional Network that was originally applied to medical image analysis, but later found application in many other fields, one of which is the classification of satellite images. U-Net is a special type of Fully Convolutional Network that merges low-level and high-level feature maps for better object localization.

Figure 2 is an illustration of the original U-Net architecture, with the downlink on the left and the uplink on the right. Max pooling operations reduce map sizes but increase the number of channels. In the expansive path, the sampling is followed by a convolution and the number of channels is halved so that the output has the same dimensionality as the input.

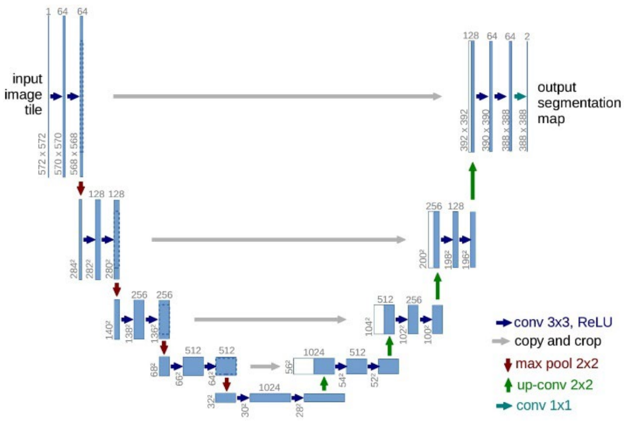


Figure 2. Original U-Net architecture [25]

ResUNet is a Deep Residual U-Net developed by Zhengxin Zhang et al. [33] for semantic segmentation. This architecture was originally applied to road extraction from high-resolution remote sensing imagery. Later, it found application in other areas such as segmentation of brain tumors, segmentation of human images and many others. The architecture of this model (Figure 3) consists of an encoding network, a decoding network and a bridge that connects these networks, just like U-Net. ResUNet is a fully convolutional neural network designed to achieve high performance with fewer parameters, and it represents an improvement on the existing U-Net architecture by taking advantage of both the U-Net architecture and Deep Residual Learning.

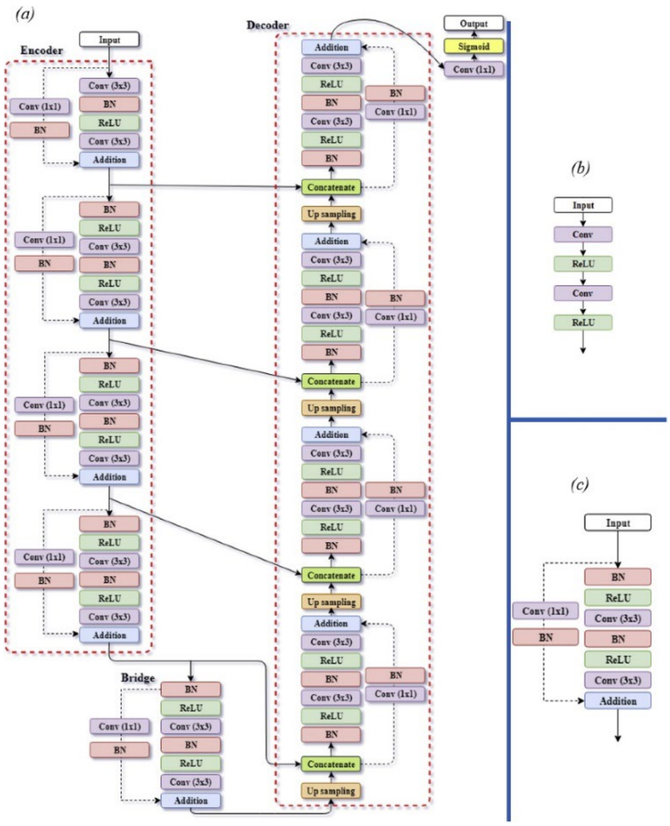


Figure 3. Architecture ResUnet [34]

Figure 3-b and Figure 3-c show the building block used in conventional U-Net and ResUNet, respectively. U-Net uses two convolutional layers (Conv) in the building block, each followed by a ReLU activation function. In the case of ResUNet, these layers are replaced by a residual block that uses batch normalization (BN), activation functions (ReLU) and convolutional layers (Conv). This combination of U-Net architecture and residual learning brings two advantages [33]:

- the residual unit facilitates network training,
- hopping connections within the network facilitates information dissemination without degradation.

2.1.3. YOU ONLY LOOK ONCE (YOLO)

The YOLO model is faster than the R-CNN family models, so it is commonly used in various real-time tasks, for example, object detection in videos. The YOLO model was first presented in 2015 by Redmon et al. [35]. R-CNN's key difference is that YOLO was the first to build a fast real-time object detector and it involves a single neural network trained end-to-end [36]. This algorithm differs from other object detection algorithms in that it "looks" at the image only once. The algorithm applies a single neural network to the entire image simultaneously predicting the probability that the object belongs to a certain class and the bounding boxes that determine its location in the image. Unlike two-stage detection network algorithms, YOLO treats target detection as a regression problem and simultaneously obtains target bounding boxes and the probability of object presence in the bounding box.

The boundary frame can be described by four descriptors:

- center of frame,
- frame width,
- height,
- a parameter that refers to the class to which the object belongs.

The version of YOLO used in this work is YOLOv5 developed by Ultralitics. The difference between YOLOv5 compared to previous models is that YOLOv5 uses a cross-level partial network (CSPNet) [37] as the backbone of the model and a path aggregation network (PANet) [38] as the backbone for feature aggregation. These new improvements provide better feature extraction. The architecture of the model is presented in Figure 4.

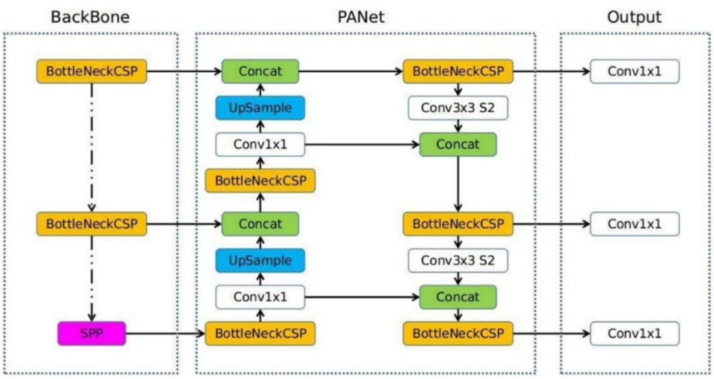


Figure 4. Overview of YOLOv5 architecture [36]

YOLOv5 provides different network models with different configurations and parameter sizes (Figure 5). It contains five different network models YOLOv5n, YOLOv5s, YOLOv5m, YOLOv5l and YOLOv5x. The YOLOv5n model is the simplest, while the YOLOv5x model is the most complex. The larger the network, the more parameters that can be adjusted to get better performance, but this also means more time to train the model.

Figure 5. YOLOv5 different model sizes [36]

2.2. DATA COLLECTION

For a practical evaluation of the effectiveness and generalization performance of the model proposed in this paper, two publicly available datasets were used: the WHU aerial imagery dataset and the WHU satellite imagery dataset [39]. These datasets contain buildings of various types, shapes and sizes. The WHU aerial imagery dataset covers an area of 450 square kilometers in Christchurch, New Zealand and contains 187 000 buildings. The data set consists of 8 189 images with a resolution of 512×512 pixels, and the spatial resolution of the images is 0.3m [40]. Using this data, YOLO and ResUNet were trained, and testing of previously trained models was performed on orthophoto images of the area of interest, i.e. of the city of Novi Sad. These orthophoto images were generated using aerophotogrammetry methods with LEICA CAMERA RC 30 camera, with the longitudinal and transverse overlap of 60% and 25% respectfully.

3. RESULTS AND DISCUSSION

3.1. SEGMENTATION AND CLASSIFICATION

The input data for training the ResUNet model is composed of pairs of images (image and mask), as shown in Figure 6. Before training the ResUNet model, the input WHU data set is divided into two parts in the ratio of 80-20%. This step is necessary so that in the process of training the neural network, a quantitative assessment of the model can be obtained, which tells how well the network is trained to work with data that did not participate in the training.

Figure 6. An example of a pair of input data used for training

In order to avoid overtraining the network, which can cause poor object identification, an early stop parameter was used in the training phase. Stopping the training is defined at the moment when the accuracy rating on the validation data starts to decrease, i.e. if in the three next epochs from the moment when the highest accuracy is reached, better results are not obtained, the training is interrupted, otherwise the training will go up to a maximum of 50 epochs. As a result of applying early stopping, it was obtained that the number of epochs required for training the ResUNet model is 20, while the accuracy of the model is 96.58%. In the following diagram (Figure 7) the curve of the model's accuracy rating obtained in the process of training the neural network can be seen.

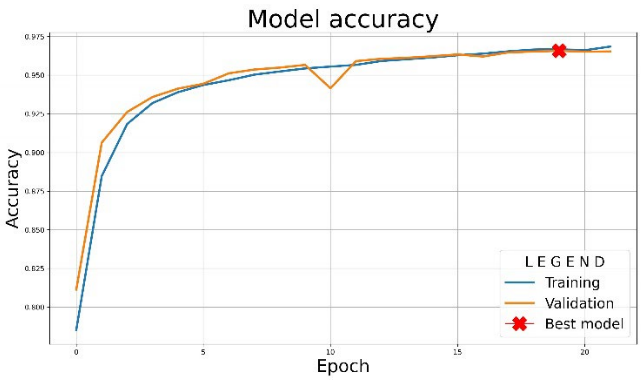
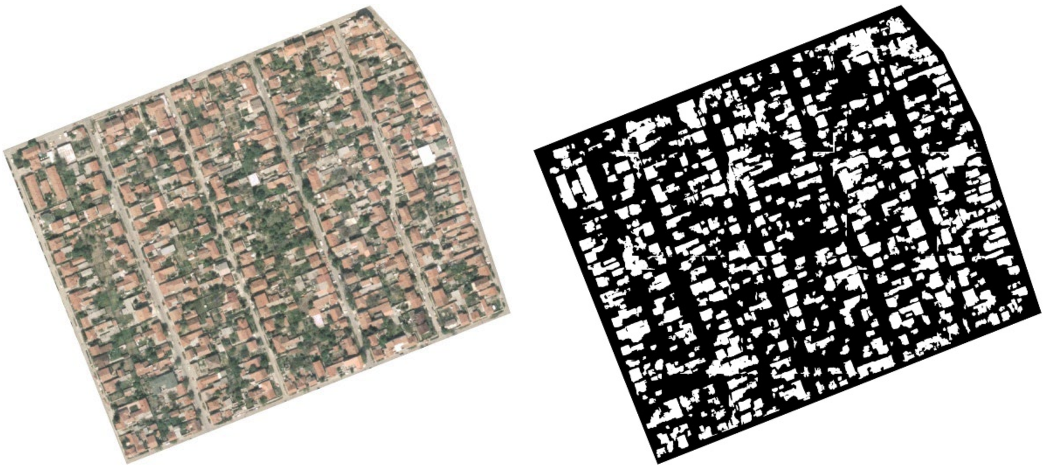


Figure 7. ResUNet model accuracy

After the completion of the training phase, the trained building identification model was applied to a new data set (orthophotograph of Novi Sad) in order to examine the possibility of knowledge transfer. As the model is applied to the input data, the result are raster images representing probability maps with a range of (0, 1), with 0 as the lowest probability of a building's existence and 1 as the highest probability of a building's existence. The next step represents the definition of the probability threshold value, based on which the buildings will be identified. The threshold value used in this paper is 0.5. Although it is expected that the slightly lower limit value chosen in this way will give many more false positives (objects that are not buildings and are classified in that class), it was deliberately chosen in order to cover all objects with certainty, i.e. in order to avoid the occurrence of false negatives (objects that exist but have not been identified), while false positives will be removed by integrating these results with the YOLO results. The results obtained using the ResUNet model on the test area are shown in Figure 8.



a) *b)*

Figure 8. Orthophoto of parts of Novi Sad (a) and ResUNet model results (b)

From the results obtained using the ResUNet model (Figure 8-b), it can be seen that there is a large number of false positives, which was expected since a slightly lower threshold value was chosen for the identification of buildings, as previously explained. However, large number of false positives should not be seen as a problem since the goal was to completely include all objects on the analyzed area not regarding the potential occurance of false positives that will be filtered through YOLO algorithm.

3.2. OBJECT DETECTION

In order to detect buildings using the YOLO algorithm, the WHU data had to be adapted to the YOLO algorithm. What YOLO requires as training input is a dataset containing images and the coordinates of the bounding boxes of the objects in that image. The file structure with bounding boxes consists of five values that respectively refer to the class of the object, the coordinates of the center of the box, the width and the height of the bounding box, as shown in Figure 9.

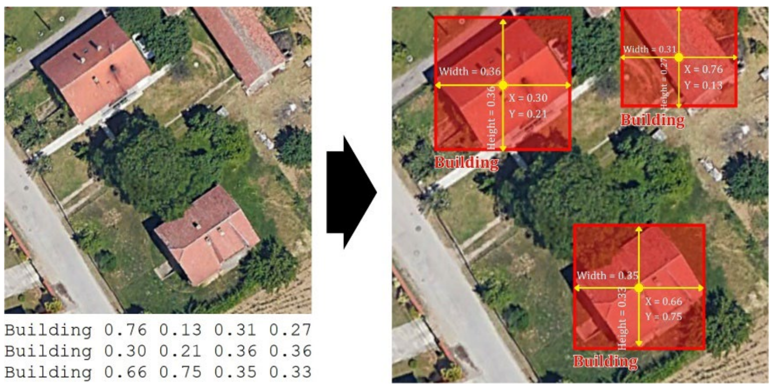


Figure 9. An example dataset for training the YOLO algorithm

During the training of the YOLOv5l network model, the maximum number of epochs is set to 50, with the fact that in the end the model from the epoch in which the highest accuracy is achieved is used for object detection. As with the ResUNet model, the division of the input data set into two parts in the ratio of 80-20% was used, in order to obtain the accuracy of the model during training. Performance was evaluated based on Precision, Recall and mAP (mean Average Precision) metrics when IoU (Intersection over Union) was 0.5 (50%) and 0.95 (95%). The next figure (Figure 10) shows graphs of metric curves during training.

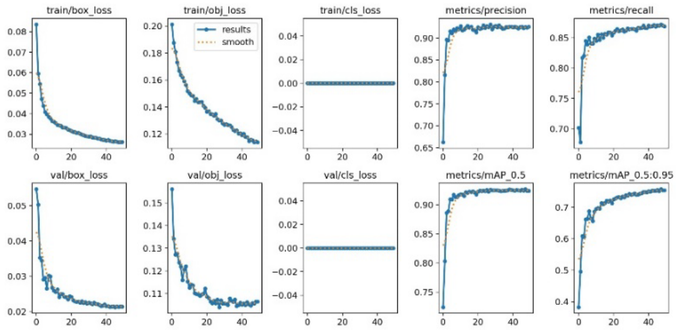


Figure 10. Graph of Precision, Recall, and mAP as YOLO training progresses

After evaluation, the model with the best accuracy obtained in 47 epochs and had a Validation Precision score of 0.93, Recall score of 0.87, as well as mAP score of 0.93 and 0.76 for @0.5IoU and @0.95IoU, respectively. This result confirms the effectiveness of this approach in correctly predicting objects. After completing the training phase, the trained building detection model was applied to the same data set as ResUNet (orthophotograph of Novi Sad). The results of object detection using the previously trained YOLO model in the test area are shown in the following figure.

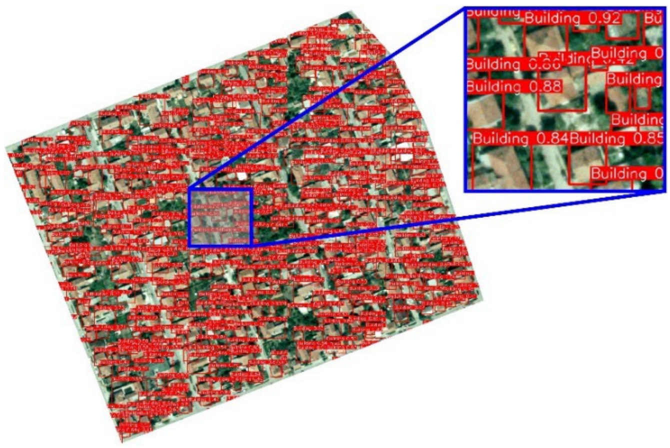


Figure 11. Building detection using the YOLO algorithm

The results of building detection using the YOLO algorithm (Figure 11) show a very high relative accuracy (percentage of the existence of objects within the boundary frames), but as with the ResUNet model, there are a certain number of false positives.

3.3. INTEGRATION RESUNET AND YOLO

The solution to the aforementioned problems regarding the presence of false positives in the results of segmentation, classification, and object detection lies in merging these results before drawing final conclusions. As can be concluded from the individual results (Figure 8 and Figure 11), while YOLO demonstrates the capability to detect objects more accurately (with a significantly lower false detection rate), it lacks the ability to differentiate their shapes like ResUNet, which yields a considerable number of false positives. Consequently, to retain the most crucial information from both models by integrating the results, it becomes feasible to enhance the accuracy of object detection and extract their shapes and positions more precisely.

An example of a correctly mapped building is given in Figure 12-detail A, where it can be seen that the building is correctly detected and that the boundaries of the object are preserved in the segmentation process. By crossing the results, the large number of false positives present in the ResUNet results is eliminated (Figure 12-detail B). As said YOLO gives much less false positives, so eliminating ResUNet polygons that are not inside the bounding box solves this problem. In this way, 81 polygons were removed (polygons detected only by ResUNet). False positives from YOLO results are also eliminated in the same way, i.e. all bounding boxes that do not contain ResUNet polygons are removed (Figure 12-detail C). In this way, 14 polygons were removed (polygons detected only by YOLO). The problems encountered by this methodology are given in Figure 12-detail D and E. In the first case (detail D) both models detected the existence of an object in a place where it is not present on the ground, while in the second case (detail E) neither ResUNet nor YOLO were able to detect the existence of the object. The reason for the appearance of these errors may lie in the differences, both in the shape and size of the objects in the images, as well as in the brightness and angle of the recording of the WHU data set for training and the orthophoto plan of Novi Sad used for testing. The number of false negatives, such as detail E in Figure 12, in the analyzed area is 38 objects, while the number of false positives, such as detail D in Figure 12, is 40 objects. These results can be considered successful, given that knowledge transfer was applied due to the lack of training data in the analyzed area, so it can be said that the proposed model copes well with new data.

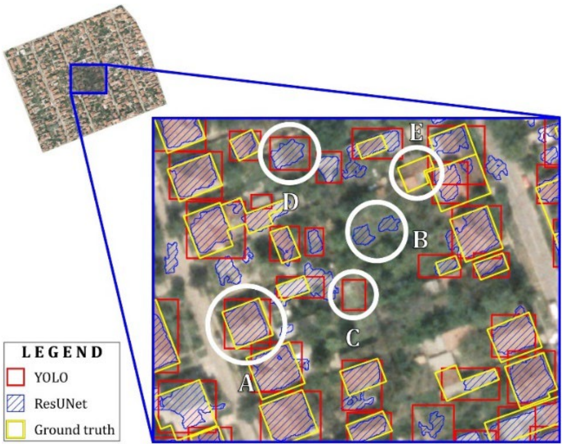


Figure 12. Analysis of the obtained results

One of the major problems this method is faced with is shown in Figure 13-detail F. Namely, in the case of the existence of buildings located next to each other, none of the used models is able to identify those buildings as separate entities, i.e. two individual buildings. Therefore, solving this problem as well as the problem with irregularly mapped edges of buildings, which is particularly pronounced in irregularly shaped buildings (Figure 13-detail G), is imposed as the primary goal of improving the proposed model.

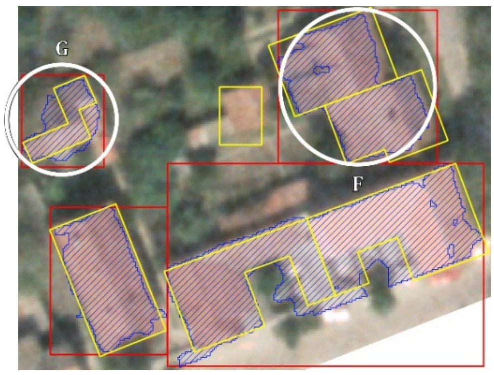


Figure 13. Problems in the results of the proposed model

In the end, it can be concluded that out of 367 buildings located in the analyzed area, 327 buildings were correctly identified. Accordingly, the percentage of success of the proposed methodology for the detection and extraction of buildings of 89% represents a very good basis for obtaining results quickly.

4. CONCLUSION

Traditional methods have proven to be insufficiently fast and efficient when extracting buildings from high-resolution images. With the development of deep learning technology, such as convolutional neural networks (CNN), new opportunities have opened up for automatic object detection and classification on remote sensing data. Models such as ResUNet and YOLO represent advanced techniques that have achieved high accuracy in object segmentation and detection. However, despite these advances, existing models face challenges in extracting buildings, such as shadows, different textures, and orientation of buildings.

The integration of ResUNet and YOLO represents a new approach that combines the strengths of both models to overcome these challenges. The ResUNet model, based on the idea of fully convolutional networks (FCN), has the ability to extract spatial information from the image, while the YOLO algorithm enables fast and efficient object detection. The combination of these models enables a better understanding of the image context and a more accurate detection of buildings even in complex scenes.

One of the goals of this paper was to examine the use of knowledge transfer, i.e. training models with publicly available data, and applying such trained models to new data. This approach significantly speeds up the time of obtaining results because there is no need for prior preparation of training data, and also solves the problem of availability of training data. In both cases (ResUNet and YOLO) it was shown that knowledge transfer is an applicable method that gives satisfactory results. As it can be concluded from the results shown (Figure 8 and Figure 11), in both cases there is a certain number of false positives that need to be eliminated and a significantly smaller number of false negatives. The very fact that the number of false negatives is very small indicates that knowledge transfer is applicable for this kind of object classification and detection.

Therefore, by using these two models together, one can eliminate false positives from the results and thus improve the accuracy, in such a way that the information about the shape and dimensions of the objects will be obtained using ResUNet, and for the verification of those results and the elimination of noises, the results of the YOLO model will be used. Based on the results thus obtained, the authors come to the conclusion that the extraction of buildings was performed with a high accuracy of 89%, especially if one takes into account the speed of obtaining results, which was obtained thanks to the use of publicly available data for training.

If necessary, the accuracy of the model could be increased by using some more publicly available data for training, in order to cover as many possible scenarios and diversity in the type, size, shape and texture of building roofs as possible. In this way, the problem of false negatives could be solved, i.e. not recognizing objects that exist on the ground. Another important source of information would be the DSM, which would significantly improve the results, but up-to-date data on the heights of objects are usually not available.

The issues encountered by the proposed model include the inability to identify adjacent buildings as separate units and difficulties in extracting building edges, resulting in the appearance of fuzzy edges. The process of building edge extraction is influenced by various factors, such as the complex appearance of the object, the capturing angle, glare, shadows, etc. The integration of ResUNet and the unique YOLO model for object detection represents a significant advancement in the technology of automatic building extraction from remote sensing data. Furthermore, these aforementioned challenges will guide future research directions and represent crucial issues that need to be addressed in order to achieve fully automated object mapping using orthophoto imagery.

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51

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TESTING METHODS WITH DIFFERENT DEGREES OF SAMPLING IN DETERMINING SYSTEMATIC INFLUENCES AND MEASUREMENT UNCERTAINTIES OF LINEAR MEASURING DEVICES

Abstract

This work tested several procedures to determine the linear measuring device's systematic influences and measurement uncertainty. Three methods were developed that differ in the degree and density of sampling during measurement and were compared with the existing method used for calibrating linear measuring devices in the Metrology Laboratory accredited for calibrating angle and length, Institute of Geodesy and Geoinformatics, Faculty of Civil Engineering, in Belgrade. The goal is to determine the possibility of introducing these methods into the calibration process without violating the accuracy and precision measures and to meet the assumed measurement uncertainty requirements of measuring devices and equipment.

Keywords: measurement uncertainty, systematic influence, precision, linear measuring device

ТЕСТИРАЊЕ МЕТОДА РАЗЛИЧИТОГ СТЕПЕНА УЗОРКОВАЊА КОД ОДРЕЂИВАЊА СИСТЕМАТСКИХ УТИЦАЈА И МЈЕРНЕ НЕСИГУРНОСТИ ЛИНЕАРНИХ МЈЕРИЛА

Сажетак

У овом раду тестирано је неколико поступака за одређивање систематских утицаја и мјерне несигурности линеарних мјерила. Развијене су три методе које се разликују у степену и густини узорковања приликом мјерења и поређене су са постојећом методом која се користи за еталонирање линеарних мјерила у Метролошкој лабораторији акредитованој за еталонирање мјерила угла и дужине, Института за геодезију и геоинформатику, Грађевинског факултета, у Београду. Циљ је утврдити могућност увођења ових метода у поцес еталонирања линеарних мјерила, а да се не наруше мјере тачности, прецизности и да се задовоље претпостављени захтјеви мјерне несигурности мјерила и опреме.

***Кључне ријечи**: мјерна несигурност, систематски утицај, прецизност, линеарна мјерила*

1. INTRODUCTION

Linear measuring devices represent equipment used by many beneficiaries for various needs and, as such, should satisfy the appropriate properties. The linear measuring devices used are ribbons, measuring tapes, measuring rods, levelling rods and rulers. The measuring devices can be materialised from glass, steel or other materials, on which the dimensions are marked with lines of a certain thickness. When checking the measuring devices, sampling and reading the marked division on the devices is done according to a specific procedure and with appropriate equipment. The task of this work is to determine and check the optimal sampling density that would satisfy the assumed quality.

All measurements were made in the Metrology Laboratory accredited for the calibration of angle and length gauges, Institute of Geodesy and Geoinformatics, Faculty of Civil Engineering, in Belgrade, according to the method given in the Working instructions for calibration of leveling bars, rulers, measuring bars and measuring tapes and is in accordance with the standard ISO 17123-1 - Optics and optical instruments - Field procedures for testing geodetic and surveying instruments — Part 1: Theory. The measuring system used for the calibration of rulers, i.e. all linear measures, consists of an HP 5508A laser interferometer and a measuring bench on which the interferometer and mesuring device is placed [1].

In this paper, several methods were tested, which differ in the degree and density of sampling during measurement, for determining the systematic influences and measurement uncertainty of linear measuring devices. A measuring ruler with a length of 500 mm was used for these purposes.

This research can be presented through the following steps:

- Presentation of linear measuring device and measuring systems located in the Metrology Laboratory of the Institute of Geodesy and Geoinformatics of the Faculty of Civil Engineering in Belgrade;
- Elaboration of various methods of precise determination of systematic influences and measurement uncertainty of linear scales and sampling and reading of the marked division on the scale according to a specific procedure and in the appropriate number of repetitions;
- Assessment of measurement parameters and recording of the existence of systematic influences and determination of measurement uncertainty for all projected sampling combinations;
- Testing hypotheses about the equality of dispersions and the equality of expected values;
- Display of the obtained results and determination of the optimal sampling solution according to the given measurement procedure;

2. EQUIPMENT: LINEAR MEASURING DEVICE AND MEASURING SYSTEMS

The linear measuring device used for this experiment is a metal ruler with a length of 500 mm (Figure 1). The division was carried out on both sides in two different proportions. For this test, a division performed on a scale of 1:1000 was used, where dashes indicate millimetres, and numbers show centimetres. Crucial for the choice of this ruler was the material from which it was made (metal with a low degree of deformity) and the high quality of the engraved division.

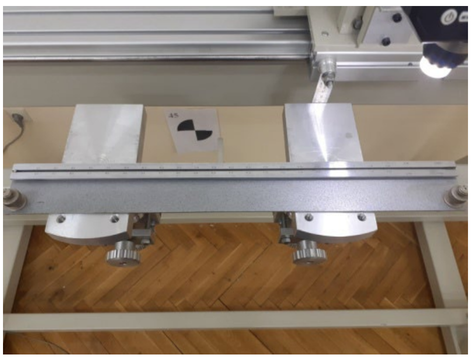


Figure 1. Measuring device - a metal ruler with a length of 500 mm

The measuring system used for ruler calibration consists of an HP 5508A laser interferometer (Figure 2) and a measuring bench (Figure 3) on which the interferometer and measuring device are placed. The measuring bench is designed to ensure precise positioning and system stability. The interferometer is placed on sliding tracks consisting of prisms that serve for precise positioning and adjustment of the device. The division reads with a digital reader and a microscope (Figure 4).

Figure 2. HP 5508A laser interferometer

Figure 3. Measuring bench

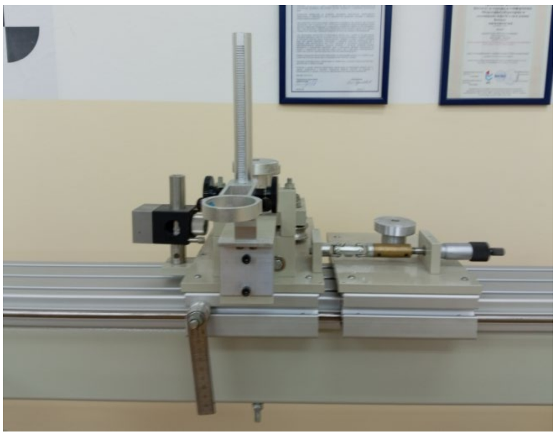


Figure 4. Digital reader - microscope

During the measurement, data on the temperature of the working environment and the temperature of the material of the measuring device are taken using sensors:

- HP 10757B, which measures the temperature of the ruler material,
- And the HP 10751B sensor that measures the air temperature of the working environment (laboratory).

In addition to the above data on temperatures, information on the humidity of the air in the laboratory is taken from the thermohygrometer Mastech (MS6508) in order to monitor the state of the atmospheric conditions in the laboratory [1].

Table 1 shows the basic characteristics of the measuring equipment.

Table 1. Characteristics of measuring equipment

R. no.	Name	Manufacturer	Type	Ser. number	Measuring range	Uncertainty
1	Measuring bench	-	-	-	(0 – 6000)mm	-
2	Laser interferometer	Hewlett Packard	HP 5528A	2532A02 552	Up to 15 m	5*10-7
3	Air temperature sensor	Hewlett Packard	HP 10751B	-	(0 – 40) °C	0,50 °C For the range (15 – 25) °C
4	Air pressure sensor	Hewlett Packard	HP 10751B	-	(517,2 – 775,7) mmHg	1,40 mmHg For the range (15 – 25) °C
5	Material temperature sensor	Hewlett Packard	HP 10757B	-	(0 – 40) °C	0,10 °C

2.2. INSTALLATION OF MEASURING EQUIPMENT AND LINEAR MESURING DEVICE

The laser interferometer is placed on the interferometer plate of the work bench, where it is connected to the power supply, as well as to the sensors HP 10757B and HP 10751B. After placing the prisms of the interferometer, on the fixed and movable support of the workbench, the interferometer is switched on, after which the process of achieving the optimal temperature begins for the correct operation of the interferometer laser (the time period for achieving the optimal temperature is never longer than 5 minutes). After reaching the optimal temperature, the laser and prisms are adjusted in order to establish the interferometer's operation.

Figure 5. Installation of the ruler on the measuring bench

The setting is performed as follows:

The plate on the laser head is turned to block the laser return beam. It is checked whether the red dot on sight (crosshair) moves when the slide is moved from one end to the other end of the rail of the measuring bench. If the red dot moves then alignment is done until the red dot rests on the crosshairs of the laser head when the carriage is moved from one end of the bench rail to the other.

The ruler is placed on the measuring bench, that is, on the supports of the linear measuring device of the measuring bench, parallel to the direction defined by the prism supports located on the rail of the measuring bench (Figure 5). After installation, the ruler is levelled using the workbench's measuring device support ruler. Then, using the binoculars of the measuring bench, the unique focus of the binoculars along the entire length of the ruler additionally ensures the levelling.

3. PROPOSED MEASUREMENT METHODS AND MATHEMATICAL BASIS OF PROCESSING MEASUREMENT RESUTS

The measurement procedure is performed as follows:
The lengths between the zero line (partition) and the other subdivision lines of the scale, including the last subdivision line (partition), are measured. The number of measuring points depends on the length of the measuring scale of the measuring devices, in this case the ruler. The length is measured from the zero division to each meter division. For measuring tapes over 5 meters long, every meter is measured.
To determine the central line of each division of the ruler, the middle of the division (full division line) coincides with the microscope's crosshair. The positioning system is set from one coordinate axis (reticle axis) placed in the division's central line or at the beginning of the division (Figure 6). Five measurements are taken at each measurement point.

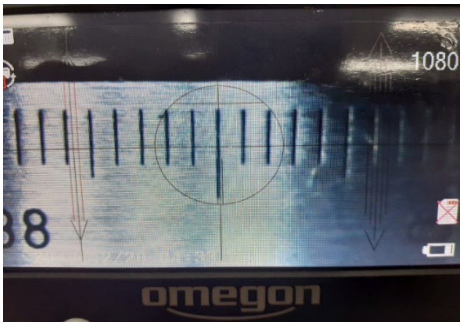


Figure 6. Coincidence of the reticle with the edge of the division

In our case, for testing purposes, we used four sampling methods:
Method 1 - For the first and last decimeter (dm) measure every centimeter (cm) and for the first and last centimeter (cm) measure every millimeter (mm).
Method 2 - Every cm was measured
Method 3 - For the first and last dm, measure every cm
Method 4 – Every odd cm was measured

3.2. PROCESSING OF MEASUREMENT RESULTS

Processing of measurement data implies application of statistical calculations to the results. For each measurement point, the mean value and standard deviation are calculated. The mean value of the measurement at each point is calculated using the expression [2], [3]:

$$\bar{C} = \frac{\sum_{i=1}^{5} C_i}{5} \tag{1}$$

where C_i represents the measurement of one subdivision.
The standard deviation is calculated according to the expression (ISO 17123-1) [2]:

$$\sigma_C = \sqrt{\frac{\sum_{i=1}^{5}(\bar{C}-C_i}{4}} \tag{2}$$

After that, the deviation of the measured value from the nominal value is calculated as:

$$\Delta C_i = \bar{C}_j - C_{j\,nom}, j = 1, n \tag{3}$$

where n depends on the length of the ruler.
A diagram of differences is drawn based on the nominal values of the ruler and the corresponding deviations measured from those nominal values. The nominal values of the scale are applied on the

X-axis of the diagram, and the deviation values on the Y-axis. After drawing the difference diagram on the chart, the equalising right of deviation from the nominal values is illustrated in the form:

$$Y = a * X + b \tag{4}$$

Determination of the unknown parameters of the equation of the line is done by adjustment according to the least squares method. This determines the unknown parameters of lines a and b and their standard deviations. Mathematical statistics methods decide whether the parameter a equals zero in the confidence interval 1-α. Null hypothesis: a = 0 is accepted if the following condition is satisfied:

$$|\mathrm{a}| \leq S_a * t_{1-\frac{\alpha}{2}}(\mathrm{v}) \tag{5}$$

where $t_{1-\alpha/2}$ is the quantile of the student distribution depending on the number of degrees of freedom (v). Otherwise, the null hypothesis is rejected, and the parameter a has the value determined by the adjustment.

3.3. MEASUREMENT UNCERTAINTY

3.3.1. MATHEMATICAL MODEL OF MEASUREMENT

The expression for the mathematical model of measurement can be written in the following form [4]:

$$e = l_m \cdot (l + \alpha_m \cdot \theta_m) - l_{LI} + e_{dif} + e_{cos1} + e_{cos2} + e_{dz} + e_a \tag{6}$$

Where:
e - deviation (measurement result) at 20°C,
l_m - the length of the path between the reference position and the measurement position,
α_m - linear temperature expansion coefficient of the instrument,
θ_m - deviation of the instrument temperature from 20°C,
l_{LI} - corrected length indicated by LI,
e_{dif} - error in the difference between the current and initial division mark readings of the instrument,
e_{cos1} - cosine error in measurement due to misalignment of the instrument (expected value is 0), e_{cos2} - cosine error in measurement due to misalignment of the laser beam (expected value is 0),
e_{dz} - dead zone error (expected value is 0),
e_a - error caused by angular deviation of the telescope (expected value is 0).

3.3.2. THE STANDARD UNCERTAINTY OF THE ESTIMATE OF THE INPUT QUANTITY AND THE COMBINED STANDARD UNCERTAINTY OF THE MEASUREMENT

The standard measurement uncertainty according to EA-4/02 is:

$$U_c^2(\mathrm{e}) = c_{lm}^2 \cdot u^2(l_m) + c_{\alpha m}^2 \cdot u^2(\alpha_m) + c_{\theta m}^2 \cdot u^2(\theta_m) + c_{l_{LI}}^2 \cdot u^2(l_{LI}) + c_{e_{raz}}^2 \cdot u^2(e_{raz}) + c_{e_{cosl}}^2 \cdot u^2(e_{cosl}) + c_{e_{cos2}}^2 \cdot u^2(e_{cos2}) + c_{e_{mp}}^2 \cdot u^2(e_{mp}) + c_{e_a}^2 \cdot u^2(e_a) \tag{7}$$

Where c_i are the partial derivatives of the function (7):

$$c_{l_m} = \frac{\partial f}{\partial l_m} = 1 + \alpha_m \cdot \theta_m \approx 1; \theta_{max} = \pm 1°C \tag{8}$$

$$c_{\alpha_m} = \frac{\partial f}{\partial \alpha_m} = \theta_m \cdot l_m \tag{9}$$

$$c_{\theta_m} = \frac{\partial f}{\partial \alpha_m} = \alpha_m \cdot l_m \tag{10}$$

$$c_{l_{LI}} = \frac{\partial f}{\partial l_{LI}} = -1 \tag{11}$$

$$c_{e_{raz}} = \frac{\partial f}{\partial e_{raz}} = 1 \tag{12}$$

$$c_{e_{cosl}} = \frac{\partial f}{\partial e_{cosl}} = 1 \tag{13}$$

$$c_{e_{cos2}} = \frac{\partial f}{\partial e_{cos2}} = 1 \tag{14}$$

$$c_{e_{mp}} = \frac{\partial f}{\partial e_{mp}} = 1 \tag{15}$$

$$c_{e_a} = \frac{\partial f}{\partial e_a} = 1 \quad = 1 \tag{16}$$

The standard uncertainties of the input values are calculated (evaluated) for the applied equipment and method, as well as for assumed measurement conditions.

a) Uncertainty of the path length between the reference and measurement positions $u(l_m)$.

This uncertainty arises due to compensating for the change in the speed of light in external conditions compared to the speed of light in a vacuum. Determination of external ambient conditions is performed using HP 10751 sensors. For a temperature interval that remains constant in the laboratory, ranging from (15 – 20)°C, and according to the manufacturer's specifications, the measurement uncertainty due to the compensation of the speed of light is:

$$u(l_m) = (1.5 * 1)\mu m, \text{ for 1 in meter.} \tag{17}$$

b) Uncertainty of the linear coefficient of thermal expansion $u(\alpha_m)$

As rulers are made of different materials, their thermal expansion coefficients vary. The measuring instruments under examination are made of invar, fibreglass, or steel, each having thermal expansion coefficients in the range of (1 - 12) µm/m°C. The deviation interval of the change in thermal expansion coefficients is $\pm 1 \times 10^{-6}$ °C^{-1}.

The standard uncertainty, assuming a rectangular distribution, is:

$$u(\alpha_m) = \frac{1*10^{-6} \cdot C^{-1}}{\sqrt{3}} = 0.58 * 10^{-6} \cdot C^{-1} \tag{18}$$

c) Uncertainty of the temperature deviation $u(\theta_m)$

The standard uncertainty of temperature measurement for the used HP 10757 sensor is 0.1 °C, i.e.:

$$u(\theta_m) = 0.10 \cdot {}^\circ\mathrm{C} \tag{19}$$

d) Uncertainty of the LI indication $u(l_{LI})$

The standard uncertainty for this type of device has a value:

$$u(l_{LI}) = (0.1 * 1)\mu m, \text{ for 1 in meter.} \tag{21}$$

e) Uncertainty due to the error in reading the current and initial division mark of the measuring instrument $u(e_{dif})$

The calibration procedure involves forming the difference in readings between the values at individual positions of the measuring instrument and the initial values (zero, starting point, on tapes and rulers, or the first decimeter on leveling sticks). When reading both values, there is a reading error with a measurement uncertainty $u(e_{cur})$ at individual (current) positions of the measuring instrument and $u(e_{ref})$ at the initial (reference) value. Since the measurements are taken under the same conditions and by the same metrologist, it can be considered that the measurement uncertainties of reading are the same, i.e., $u(e_{cur}) = u(e_{ref}) = u(e_{reading})$. The total measurement uncertainty of the reading difference then amounts to:

$$u(e_{diff}) = u(e_{reading}) * \sqrt{2} \tag{22}$$

The measurement uncertainty of the reading is determined by a statistical estimate from measurements carried out by two individuals, each doing 60 readings individually at the reference point. The measurement uncertainty of the reading is determined separately for levelling sticks and separately for rulers and measuring tapes due to the different qualities of the division application. The standard deviation of these measurements, accepted as the standard uncertainty, is:

$$s = u(e_{reading}) = 0.24\ \mu m \text{ - for leveling sticks and} \tag{23}$$

$$s = u(e_{reading}) = 1.97\ \mu m \text{ - for rulers and measuring tapes.} \tag{24}$$

Accordingly, it follows:

$$s = u(e_{diff}) = 0.34\ \mu m - \text{for leveling sticks} \tag{25}$$

$$s = u(e_{diff}) = 2.79\ \mu m - \text{for rulers and measuring tapes.} \tag{26}$$

f) Uncertainty caused by cosine error $u(e_{\cos})$ (for laser and ruler)

The maximum expected value of the standard uncertainty due to cosine error, according to the manufacturer's specification, is:

$$u(e_{cos}) = (0.03 * 1)\mu m, \text{ , for 1 in meter.} \quad (27)$$

g) Uncertainty caused by dead zone $u(e_{dz})$

This component is negligible in the specific case.

h) Uncertainty caused by Abbe error $u(e_a)$

This component is caused by different angles of the telescope and the LI reflector along the measurement path. In specific lighting conditions, this error is not pronounced, i.e., its value is considered to be 0.

In tables 2 and 3, values for the standard uncertainties of input quantity estimations for the lower limit of the measurement range 1 mm and 1000 mm for rulers and measuring tapes are presented.

Table 2. Standard uncertainties of input quantity estimations for the lower limit of the measurement range (1 mm) for rulers and measuring tapes.

Quantity	Estimated Quantity	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
l_m	1 mm	0.0015 µm	normal	1	0.00150 µm
α_m	11°C	0.58×10^{-6} °C^{-1}	rectangular	0.05 °C^{-1}	0.00032 µm
θ_m	0°C	0.1°C	normal	0.58×10^{-6} °C^{-1}	0.00006 µm
l_{LI}	1 mm	0.0001 µm	normal	1	0.00100 µm
e_{diff}	1 mm	2.79 µm	normal	1	2.79000 µm
e_{cos1}	$0.03*10^{-6}$ µm	0.00003 µm	normal	1	0.00003 µm
e_{cos2}	-	-	-	-	-
e_a	0	0.0 µm	uniform	1	0.00000 µm
				Total:	2.79291 µm

Table 3. Standard uncertainties of input quantity estimations for the upper limit of the measurement range (1000 mm) for rulers and measuring tapes.

Quantity	Estimated Quantity	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
l_m	1000 mm	1.5 µm	normal	1	1.500 µm
α_m	11°C	0.58×10^{-6} °C^{-1}	rectangular	0.05 °C^{-1}	0.317 µm
θ_m	0°C	0.1°C	normal	0.58×10^{-6} °C^{-1}	0.058 µm
l_{LI}	1000 mm	0. 10 µm	normal	1	1.000 µm
e_{diff}	1000 mm	2.79 µm	normal	1	2.790 µm
e_{cos1}	$0.03*10^{-6}$ µm	0.03 µm	normal	1	0.030 µm
e_{cos2}	-	-	-	-	-
e_a	0	0.0 µm	uniform	1	0.000 µm
				Total:	5.695 µm

According to all the above, the **combined standard uncertainty** estimation of input quantities under the best possible measurement conditions can be expressed by the equation (calculated from tables 2-3):

$$u = 2.79\ \mu m + 5.695 * 10^{-6} * l_{\mu m} - \text{for rulers and measuring tapes.} \quad (28)$$

In accordance with EA-4/02, the expansion factor k=2 is used for calculating the **expanded uncertainty**:

$$u = 5.58\ \mu m + 11.39 * 10^{-6} * l_{\mu m} - \text{for rulers and measuring tapes.} \quad (29)$$

4. MEASUREMENT RESULTS, ASSESSMENT OF SYSTEMATIC INFLUENCES AND MEASUREMENT UNCERTAINTIES OF THE LINEAR MEASURING DEVICES

As previously described, a Laser Interferometer was used for testing methods to determine systematic influences and measurement uncertainties of linear measuring devices.

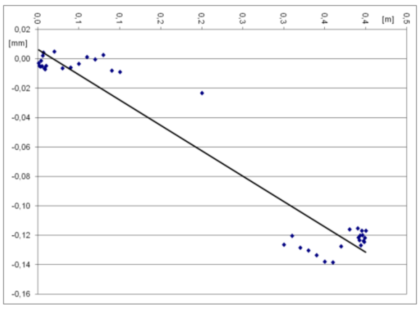
After positioning the interferometer prism on the fixed and movable supports of the workbench, turning on the interferometer, and achieving the optimal temperature for the correct operation of the laser interferometer, measurements or sampling were performed on the ruler described in Chapter 2, Figure 1.

The lengths between the zero line (subdivision) and other division lines of the measuring devices were measured, including the last division line (subdivision). To determine the central line of each subdivision of the measuring devices, the coincidence of the midpoint of the subdivision (full division line) with the crosshair of the telescope's reticle was achieved. The positioning system is set from a single coordinate axis (reticle axis), which is aligned with the central line of the subdivision or the beginning of the subdivision. Five measurements were performed at each measurement point.

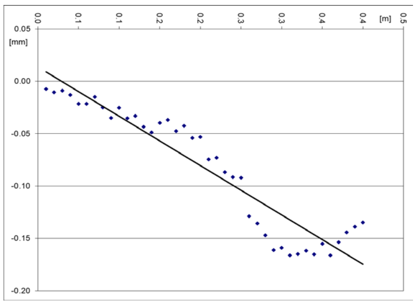
In our case, for the testing purposes, we used four sampling methods:

- Method 1 - For the first and last decimeter (dm), every centimeter (cm) was measured, and for the first and last centimeter (cm), every millimeter (mm) was measured. A total of 40 samplings were performed with five coincidences each, resulting in a total of 200 measurements.
- Method 2 - Every centimeter (cm) was measured. A total of 40 samplings were performed with five coincidences each, resulting in a total of 200 measurements.
- Method 3 - For the first and last decimeter (dm), every centimeter (cm) was measured. A total of 22 samplings were performed with five coincidences each, resulting in a total of 110 measurements.
- Method 4 - Every odd centimeter (cm) was measured. A total of 20 samplings were performed with five coincidences each, resulting in a total of 100 measurements.

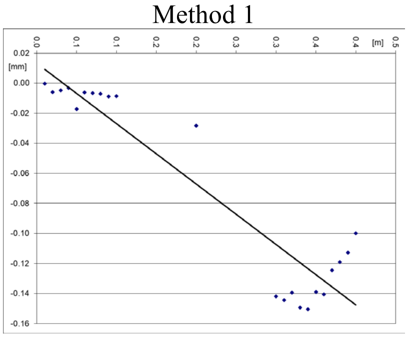
The following measurement graphs were obtained based on the measured values (Figure 7). The graphs show different degrees and densities of levelling sampling for all four applied methods.



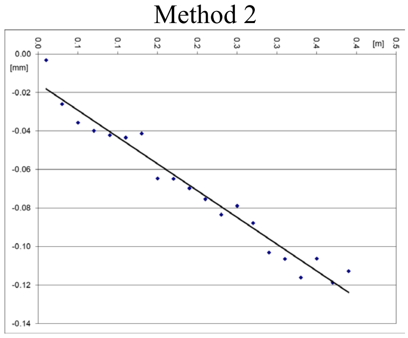
Method 1



Method 2



Method 3



Method 4

Figure 7. The degree of sampling of the ruler

The measurement results were processed using the least squares adjustment method. The parameters for the addition constant, multiplication, and expanded measurement uncertainty for measurements with the interferometer have been calculated.

These results are presented in Table 4 for all four methods, and Table 5 represents their differences. Table 6 contains standard deviations and measurement deviations from the mean value.

Table 4. Parameters for the addition constant, multiplication, and expanded measurement uncertainty for measurements with the interferometer.

Method	Addition constant [mm]	Multiplication	Expanded measurement uncertainty of the reading u(r) [mm]	Expanded measurement uncertainty of other influences u(odher) [mm]
1	0.0063	0.99965528	0.008	0.000029
2	0.0134	0.99952976	0.013	0.000054
3	0.0134	0.99959825	0.018	0.000068
4	-0.0152	0.99972140	0.006	0.000027

Table 5. Differences in the obtained results.

Method	Differences of additions constants [mm]	Differences of multiplication constants	Differences of readings u(r) [mm]	Differences in other influences u(odher) [mm]
1-2	*0.007*	*0.00012552*	*0.005*	*0.000025*
1-3	*0.007*	*0.00005703*	*0.010*	*0.000039*
1-4	*0.022*	*0.00006612*	*0.002*	*0.000002*
2-3	*0.000*	*0.00006849*	*0.005*	*0.000014*
2-4	*0.029*	*0.00019164*	*0.007*	*0.000027*
3-4	*0.029*	*0.00012315*	*0.012*	*0.000041*

Table 6. Values of standard deviation.

Method	Mean value of standard deviation [mm]	The mean value of the deviation [mm]
1	0.006	-0.064
2	0.008	-0.083
3	0.006	-0.071
4	0.006	-0.071

Based on the calculated results, according to Table 2, the following conclusions can be drawn:

- The highest addition and multiplication constants values are obtained using Method 4 and are -0.0152 mm and 0.99972140, respectively.
- The smallest value of the addition constant is obtained using Method 1 and is 0.063 mm, while the smallest value of the multiplication constant is obtained using Method 2 and is 0.99952976.
- The total expanded measurement uncertainty of interferometer measurement (influence of reading uncertainty and other influences) is the smallest when using Method 4, and the largest when using Method 3.

Regarding the differences in the results obtained using different methods, and according to Table 3, we can conclude:

- The largest difference in addition constants is between Method 2 and 3 and Method 4, amounting to 0.029 mm, while the smallest is between Method 2 and Method 3, and it is 0 mm.
- Between Method 2 and Method 4 is the largest difference of multiplication constants (0.00019164), and the smallest between Methods 1 and 3 (0.00005703).

- The largest difference in the total expanded measurement uncertainty (for both parameters) is between Methods 3 and 4 (0.012 mm and 0.000041 mm), while the smallest is between Methods 1 and 4 (0.002 mm and 0.000002 mm).

Table 3 shows that:

- the mean value of the standard deviation is the highest with Method 3, while it is the same with the other methods i
- the mean value of the deviation is the highest with Method 2, while it is the lowest with Method 1.

As seen previously, maximum differences in additional constants occur at the hundredth part of a millimetre, specifically when differences involving measurement data according to Method 4 are considered. This is somewhat justified, considering that the fourth method has the smallest number of measurements. Differences between other methods are in the order of thousandths of a millimetre. A similar situation applies to differences in multiplication constants.

However, to make a final judgment about the quality of the proposed methods, it is necessary to perform testing of dispersions and expected measurement values.

4.2. TESTING HYPOTHESES ABOUT THE EQUALITY OF DISPERSIONS AND THE EQUALITY OF EXPECTED VALUES

We will test the equality of dispersions to verify whether the application of the new methods yields measurement results with the same accuracy as the results obtained by Method 1, which is used as the fundamental method in such examinations. We will use the F-test to test the hypotheses:

$$H_0: \sigma_1^2 = \sigma_2^2$$
$$H_a: \sigma_1^2 \neq \sigma_2^2 \tag{30}$$

with test statistics [5]:

$$F = \frac{m_A^2}{m_B^2} \tag{31}$$

where are they:

$m_A^2 = \max(m_1^2, m_2^2)$ and $m_B^2 = \min(m_1^2, m_2^2)$ evaluation of dispersions σ_1 and σ_2 and $F = |H_0 F(f_B, f_A)$, with degrees of freedom f_A and f_B, so the decision of the test is:

$$F < g \text{ - accepted } H_0 \tag{32}$$

where is

$$g = F_{1-\alpha}(f_B, f_A) \tag{33}$$

with significance level α.

The results of the testing are presented in tables 7, 8 and 9.

Table 7. Values of the test statistics for comparing the equality of dispersions for Method 1 and Method 2.

	Method 1	Method 2	Test decision
n	40	40	F<g H_0 is accepted - EQUAL DISPERSIONS
σ^2_0	0,000033486	0,000057738	
σ_0	0,006	0,008	
f	39	39	
F	1,724		
$g_{0,95}(39,39)$	1,704		

Table 8. Values of the test statistics for comparing the equality of dispersions for Method 1 and Method 3.

	Method 1	Method 3	Test decision
n	40	22	$F<g$ H_0 is accepted - EQUAL DISPERSIONS
σ^2_0	0,00003349	0,00003395	
σ_0	0,006	0,006	
f	39	21	
F	1,014		
$g_{0,95}(21,39)$	1,833		

Table 9. Values of the test statistics for comparing the equality of dispersions for Method 1 and Method 3.

	Method 1	Method 3	Test decision
n	40	20	$F<g$ H_0 is accepted - EQUAL DISPERSIONS
σ^2_0	0,000033486	0,000031250	
σ_0	0,006	0,006	
f	39	19	
F	1,072		
$g_{0,95}(39,19)$	2,029		

Considering that equal dispersions are obtained for all three comparisons, we can assume that the results obtained by using Method 2, 3, and 4 have the same accuracy as the results obtained by Method 1. This means that the density, i.e., the degree of sampling in these methods, does not compromise accuracy.

As dispersions from the previous testing are equal, and results for additive and multiplicative constants are obtained from the adjustment, we will perform a test of equality of their expected values, assuming that observations belong to normally distributed sets, according to the expression [5]:

$$Z = \frac{d}{\sigma_d} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \approx N[0,1] \tag{34}$$

where σ_1 and σ_2 are known dispersions and $\overline{X}_1$ i $\overline{X}_2$ are parameter estimate values a_1 and a_2. Parameters a_1 and a_2 represent estimated additive or multiplicative constant values from two compared methods. Like testing dispersions, we will take Method 1 as the reference and test the other three.

The test hypothesis is:

$$H_0: a_1 = a_2$$
$$H_a: a_1 \neq a_2 \tag{35}$$

The test decision is then:

$$|Z| \geq q \tag{36}$$

and reject H_0 and a_1 is not equal to a_2, where q is:

$$q = Z_{1-\frac{\alpha}{2}} \tag{37}$$

Based on the previous, we obtained results presented in Tables 10 and 11.

Table 10. Results of the test of equality of expected values of the additive constant

Additive constant	Method 1/ Method 2	Method 1/ Method 3	Method 1/ Method 4
Z	-1,798	-1,271	7,440
$q_{0,99}$	2,576	2,576	2,576
Test decision	Z < q – H_0 is accepted and $a_1=a_2$ is valid	Z < q – H_0 is accepted and $a_1=a_2$ is valid	Z > q - we reject H_0 and $a_1=a_2$ does not hold

Table 11. Results of the test of equality of expected values of the multiplication constant

Additive constant	Method 1/ Method 2	Method 1/ Method 3	Method 1/ Method 4
Z	0,032	0,010	-0,023
$q_{0,99}$	2,576	2,576	2,576
Test decision	Z < q – H_0 is accepted and $a_1=a_2$ is valid	Z < q – H_0 is accepted and $a_1=a_2$ is valid	Z < q – H_0 is accepted and $a_1=a_2$ is valid

According to the values obtained from Tables 10 and 11, the following conclusions can be drawn: there is no significant difference in measurement results using these methods, except in the case of determining the addition constant using Method 4. For all other cases, it is considered that the values of the addition and multiplication constants are obtained with satisfactory accuracy.

5. CONCLUSION

In this study, several procedures for determining systematic influences and measurement uncertainties of linear measuring instruments were tested. Three methods were developed, differing in the degree and density of sampling during measurements, and they were compared with the existing method used for calibrating linear measuring devices in the Metrology Laboratory accredited for angle and length calibration at the Institute of Geodesy and Geoinformatics, Faculty of Civil Engineering, in Belgrade.

After conducting measurements, sampling, data processing, and performing appropriate statistical analyses, it can be concluded that Method 1, which also represents the standard procedure for testing the precision of linear measuring instruments, provides the best results. However, other methods do not lag behind in terms of accuracy. Method 4 yields poorer results in determining the addition constant, while Method 2 and Method 3 can be reliably used as alternatives to Method 1. For all other cases, it is considered that the values of the addition and multiplication constants are obtained with satisfactory accuracy.

Considering the time and number of measurements expended, and based on the obtained results, Method 3 can be considered the optimal solution for such tasks.

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52
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STEPGRAD
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THE CENTRE OF CIRCLE DETERMINATION BY GEODETIC MEASUREMENTS

Abstract

The problem of circle's centre determination by using geodetic data is related with influences of inevitable errors as a result of measurement process as well as with the issue of model's influence itself. In this research the experiment was conducted with aim to find out the influence of measurements error and the influence of model for centre of circle determination. The two centres of two different centres were determined by direct measurements and with the model based on the points belonging to the circle. The difference between centres determined by direct measurements and circles' centres determined from the model is actually the models' influence. Obtained results showed high concordance between the centeres determined both with measurements and model.

Keywords: accuracy, precision, statistical hypothesis testing

ОДРЕЂИВАЊЕ ЦЕНТРА КРУГА ГЕОДЕТСКИМ МЕТОДАМА

Сажетак

Одређивање центра круга геодетским методама повезано је са утицајем неизбјежних грешака у процесу мјерења као и са утицајем самог модела одређивања центра.У овом истраживању спроведен је експеримент са циљем да се одреди утицај грешке модела и утицај грешака мјерења на одређивање центра круга примјеном геодетских метода мјерења. Разлика између центра круга одређеног на основу директних мјерења и центра круга одређена на основу модела указује на утицај модела. Добијени резултати указују на високу сагласност између центара добијених директним мјерењем и центара добијених на основу модела.

Кључне ријечи: тачност, прецизност, тестирање статистичких хипотеза

1. INTRODUCTION

The circle and its center determination are often issue in mechanical engineering. Mechanical elements are usually made on the machine lathe, and it is considered that elements produced in this manner are of quite accurate dimensions. However, because of different influences every element is produced with some deviations. If the dimensions are inside predefined tolerances, they are considered to satisfy required level of quality. Otherwise, the elements must be remedied or repaired. The control of produced mechanical element's geometry is the issue of geodetic domain mostly caused by the increasing accuracy and efficiency of contemporary geodetic technologies. Also, the model of least squares for data processing commonly used in geodesy is appropriate for center and radiuses of circle determination.

In most cases when the circle's center and radiuses are required, measurements provided by mechanical engineering equipment either do not provide possibility for center determination or are very expensive. Geodetic technologies and methods provide possibility for "ideal" center and radiuses determination on the base of the measured points around the circle on the high level of accuracy and efficiency.

The geodetic methods for determining circle's center and radiuses were utilized and proven in practice where the high accuracy was required [1, 2]. Furthermore, it was proven that it is possible to obtain high accuracy of zenith angles when the lines of sights are short [3]. This research was provided to find out the possible accuracy of circle's center determination from the points located on the circle's line by comparison with the circle's center determined on the base of measurements.

2. MATERIALS AND METHODS

The data (coordinates of points) for circle's center determination were obtained by measurements which were adjusted by the means of least squares [4]. There were measured points located on two circles. Each circle was approximated with twelve points and their centers were marked also. The data are given in table 1.

Table 1. The coordinates of points on the circles and their centers determined by measurements[m]

Point N°	y (1st circle)	x (1st circle)	y (2nd circle)	x (2nd circle)
0	10.3155	10.0000	10.9239	9.9660
1	10.3595	9.9880	10.9499	9.9592
2	10.3913	9.9558	10.9689	9.9404
3	10.4028	9.9118	10.9759	9.9146
4	10.3910	9.8678	10.9692	9.8887
5	10.3586	9.8359	10.9502	9.8697
6	10.3147	9.8241	10.9243	9.8625
7	10.2711	9.8361	10.8985	9.8693
8	10.2389	9.8685	10.8793	9.8882
9	10.2273	9.9127	10.8722	9.9141
10	10.2393	9.9566	10.8791	9.9400
11	10.2716	9.9887	10.8981	9.9590
12 (y_c^0, x_c^0)	10.31511	9.91217	10.92411	9.91430

The model for centers determination is as follows:

$$R_i = \sqrt{(y_i - y_c)^2 + (x_i - x_c)^2} \tag{1}$$

where:

- R_i – radius,
- y_i - y coordinate of ith point,
- x_i - y coordinate of ith point,
- y_c - y coordinate of circle's center (unknown) and
- x_c - x coordinate of circle's center (unknown).

Linearization of equation (1) leads to:

$$R_i + v_i = R_0 + \frac{\partial R}{\partial y_c}|_{y_c=y_c^0}\Delta y_c + \frac{\partial R}{\partial x_c}|_{x_c=x_c^0}\Delta x_c \tag{2}$$

$$\frac{\partial R}{\partial y_c} = -\frac{y_i - y_c^0}{\sqrt{\left(y_i-y_c^0\right)^2+\left(x_i-x_c^0\right)^2}} \tag{3}$$

$$\frac{\partial R}{\partial x_c} = -\frac{x_i - x_c^0}{\sqrt{\left(y_i-y_c^0\right)^2+\left(x_i-x_c^0\right)^2}} \tag{4}$$

After forming the linear equation system, we obtain twelve equations and have only two unknowns. The solution is obtained by the means of least squares model:

$$[vv] = min \tag{5}$$

$$v = Ax + f \tag{6}$$

$$x = -(A^TA)^{-1}A^Tf = -N^{-1}A^Tf = -Q_xA^Tf \tag{7}$$

where:

$$Q_x = \begin{bmatrix} q_{yy} & q_{yx} \\ q_{xy} & q_{xx} \end{bmatrix}$$

$$f = \begin{bmatrix} R_0 - R_1 \\ \dots \\ R_0 - R_{11} \end{bmatrix}$$

$$x = \begin{bmatrix} y_c \\ x_c \end{bmatrix} = \begin{bmatrix} y_c^0 + \Delta y_c \\ x_c^0 + \Delta x_c \end{bmatrix}$$

$$P = E = \begin{bmatrix} 1 & \dots & 0 \\ \dots & \dots & \dots \\ 0 & \dots & 1 \end{bmatrix}$$

Q_x is cofactor matrix, f is vector of free terms, x is vector of unknown circle's center coordinates and P is matrix of weights. The approximate value of radius R_0 is obtained as follows:

$$R_{0_i} = \sqrt{(y_i - \bar{y})^2 + (x_i - \bar{x})^2} \tag{8}$$

$$\bar{y} = y_c^0 = \frac{1}{12}\sum_{i=0}^{11} y_i\,; \quad \bar{x} = x_c^0 = \frac{1}{12}\sum_{i=0}^{11} x_i$$

$$R_0 = \frac{1}{12}\sum_{i=0}^{11} R_{0_i}$$

The root mean square errors of obtained circle's center coordinates is calculated as follows:

$$m_{y_c} = m_0\sqrt{q_{yy}} \tag{9}$$

$$m_{x_c} = m_0\sqrt{q_{xx}} \tag{10}$$

Final values of circle's radiuses were obtained by following formula (1).

Statistical hypotheses about equality of circle's measured and determined center equality are tested by following student's test statistics:

$$t_y = \frac{\delta y}{m_{\delta y}} = \frac{y_c - y'_c}{\sqrt{m_{y_c}^2 + m_{y'_c}^2}} = t_{1-\alpha;f} \tag{11}$$

$$t_x = \frac{\delta y}{m_{\delta y}} = \frac{x_c - x'_c}{\sqrt{m_{x_c}^2 + m_{x'_c}^2}} = t_{1-\alpha;f} \tag{12}$$

where:
- t_y, t_x – test statistics for equality of circle's centers obtained from original measurements (adjusted measurement from geodetic network) and circle's centers obtained from points on the circle,
- y_c, x_c – circle's center coordinate determined from the points on the circle,
- y'_c, x'_c – circle's center's coordinate determined from the direct measurements,
- $m_{y_c}^2, m_{x_c}^2$ – mean square errors of the y_c, x_c coordinates, respectively,
- α – level of significance ($\alpha = 0.05$) and
- f – degrees of freedom.

3. RESULTS AND DISCUSSION

Geodetic measurements were provided in a room under artificial light. For the measurement the total station was utilized with following measuring uncertainties:
- $\sigma_p = 0.5''$ for directions,
- $\sigma_Z = 0.5''$ for zenith angles and
- $\sigma_Z = 2$ mm+2 ppm for slope distances in reflector less mode.

The conditions and process of measurements are illustrated by figure 1. Utilizing proposed model (equations 1-10) the results were obtained and given in table 2.

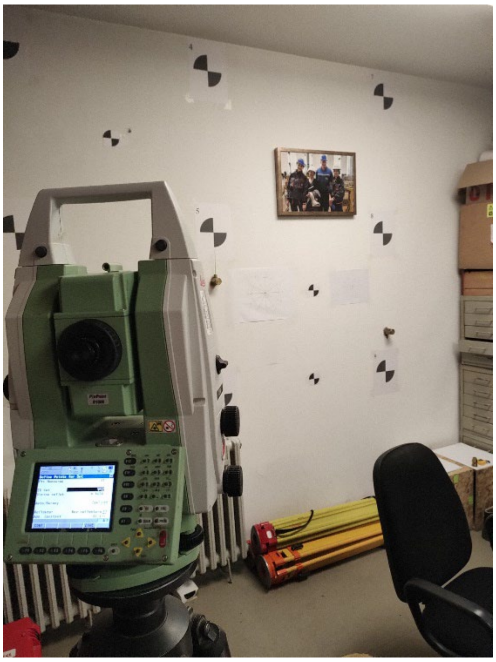

Figure 1. The conditions and total station during measurements

Table 2. The results of circles' centers coordinate determination.

Point N°	y (1st circle) [m]	m_y [mm]	x (1st circle) [m]	m_x [mm]	y (2nd circle) [m]	m_y [mm]	x (2nd circle) [m]	m_x [mm]
y_c^0, x_c^0	10.31513	-	9.91216	-	10.92413	-	9.91431	-
y_c, x_c	10.31506	0.05	9.91213	0.03	10.92410	0.04	9.91429	0.03
y'_c, x'_c	10.31511	0.02	9.91217	0.03	10.92411	0.01	9.91430	0.03

After utilization of statistical hypothesis test (formulas: 11 and 12) the obtained results are given in table 3.

Table 3. The results of hypotheses testing

Circle Nº	t_y	f	$t_{1-\alpha;f}$	H	t_x	f	$t_{1-\alpha;f}$	H
1	1.0124	10	2.2281	H_o	0.7551	10	2.2281	H_o
2	0.1771	10	2.2281	H_o	0.4365	10	2.2281	H_o

According to obtained results it is possible to state that differences between circle's centers obtained by calculation based on the measurements and circle's centers determined on the base of points belonging to the circle line are equal in statistical sense. This fact allows the statement that it is possible to determine the center and radiuses of circles on the high level of reliability by geodetic methods in case when the points are regularly distributed on the circle and when they are determined from very short distance.

An interesting observation is that root mean square errors are quite small of hundredths of millimeter levels. This could be the consequence of more accurate measurements than it was declared measurement uncertainties or because of quite short distances between control and measured points on the circles. This finding deserves further research because it opens a possibility of utilizing geodetic methods for determining the dimensions of mechanical engineering elements at the high level of accuracy requirements.

4. CONCLUSION

The experiment in this research was designed to simulate the real situation in which could appear in geodetic professional practice for determination circle's center and radius. Two circles were drowned, printed, and put on the wall. After that the geodetic measurements were provided from two control points with measurements of directions, zenith angles and distances. After measurements the adjustment of measured values was provided, and circles' centers were determined. In the second stage the centers of circles were determined by utilizing the points belonging to circle and their equality was tested by the means of student's statistics. According to the results of statistical hypothesis testing it was proven the equality of the circles' centers. Also, the high accuracy of obtained results for circles' centers determination deserve further investigation.

LITERATURE

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53

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THE INFLUENCE OF GEODETIC BASE QUALITY IN ROAD DESIGN

Abstract

This paper analyzes the impact of the quality of geodetic base, i.e., the method of obtaining spatial data for the purposes of road design. Quantities of earthworks, shape and size of the road body obtained by designing the road on geodetic base obtained from different sources (LiDAR scanning, topographic maps, and Open-source data) are compared to demonstrate the significance of selecting the type of spatial data used as a basis for design and the method of their collection.

Keywords: geodetic base, earthwork volume, DEM (Digital Elevation Model), LiDAR, NASA SRTM, ASTER GDEM, Global Mapper, topographic map, Civil 3D

УТИЦАЈ КВАЛИТЕТА ГЕОДЕТСКЕ ПОДЛОГЕ ПРИЛИКОМ ПРОЈЕКТОВАЊА САОБРАЋАЈНИЦА

Сажетак

У овом раду анализиран је утицај квалитета геодетске подлоге односно начин добијања просторних података за потребе пројектовања саобраћајница. Поређене су количине земљаних радова, облик и величина трупа саобраћајнице добијени пројектовањем саобраћајнице на геодетску подлогу добијену из различитих извора (Lidar снимањем, топографске карте и из Open-source података) у сврху показивања значаја одабира типа просторних података који се користе као основ за пројектовање и начина њиховог прикупљања.

Кључне ријечи: геодетска подлога, волумен земљаних радова, DEM, LiDAR, NASA SRTM, ASTER GDEM, Global Mapper, топографска карта, Civil 3D

1. INTRODUCTION

Geodetic bases are crucial aspects in any process of design, planning and construction of infrastructure, such as roads, bridges, buildings and other facilities. These bases constitute a set of information describing the geographical characteristics of a particular area, such as terrain, elevation, position of objects and parcel boundaries. During planning, they enable engineers to analyze the terrain and identify optimal locations for construction projects. In the design phase, they are used to create digital terrain models, facilitating precise design and adaptation of structures to the terrain. During construction, these bases are necessary for laying foundations, monitoring work progress and quality control. Given the importance of geodetic bases in the design process, it is crucial to gather, process and analyze them utilizing cutting-edge technologies and standards within the realm of geospatial sciences 6.[1]6.[2].

The lack of clear legal regulations regarding the mandatory use of specific geodetic bases in the design process poses a problem in many legal systems. This legal oversight can lead to inconsistent and unequal standards in the application of geodetic bases in the planning and construction of infrastructure projects. Additionally, the absence of specific guidelines can result in different interpretations and practices in different geographic areas, which can affect the quality, accuracy, and efficiency of the project. To overcome these shortcomings, establishing clear and comprehensive legal frameworks that prescribe standards and guidelines for the use of geodetic bases in design can be essential. These laws should define the types of data that must be used, data quality standards, procedures for their collection, processing and storage, as well as the obligations of professionals involved in the planning and construction process. Such a legal framework would not only ensure consistency and transparency in the application of geodetic bases but also ensure that the latest technologies and best practices in the field of surveying are integrated into the planning and construction process of infrastructure projects. By establishing clear legal guidelines, it is possible to improve the entire design process. The Planning and Construction Law of Bosnia and Herzegovina contains requirements for utilizing topographic maps, current georeferenced orthophoto bases, and certified cadastral-topographic plans in the development of planning documentation 6.[3].

One of the studies that addressed a similar issue is Comparison of digital terrain models based on topographic maps and remote sensing products 6.[4]. Within this research, various methods of data collection for creating a digital terrain model were analyzed. Various factors influencing the quality of geodetic bases were considered, including data collection methods, measurement accuracy and information processing procedures. The research results clearly indicate a relationship between the quality of geodetic bases and the precision of design. High-quality geodetic bases enable engineers to accurately identify terrain characteristics and adjust road designs, contributing to more efficient and safer road construction. Based on the results obtained from comparing four different methods of data collecting for creating a digital terrain model (DTM), it was concluded that LiDAR technology is the most detailed and highly efficient method for gathering high-precision data for DTM generation 6.[4]. The paper titled Improvement of the quality of geodesic support for road reconstruction emphasized the importance of enhancing geodetic support in the road reconstruction process6.[5]. Various approaches and techniques of geodetic research were analyzed with the aim of ensuring accuracy and reliability during road infrastructure reconstruction. Special emphasis was placed on identifying necessary changes to standards and regulations to ensure efficient and modern utilization of geodetic methods for improving the quality and safety of road projects 6.[5]. The case study Belgrade-South Adriatic Highway explores the application of MLS (Mobile Laser Scanning) and ALS (Airborne Laser Scanning) technologies in the mapping and analysis of road infrastructure along the stretch of highway connecting Belgrade and the South Adriatic 6.[6]. The MLS technology was used for detailed scanning of the road network using mobile laser scanners mounted on vehicles. It has been demonstrated that this technology enables rapid and precise data collection about terrain, surfaces and objects along the highway. ALS technology employs aircraft equipped with laser scanners to enable aero photogrammetric scanning of a wider area along the road route. This technology allows quick collection of high-quality three-dimensional terrain data, creation of digital elevation models and identification of potential road hazards. The result of this research showed that the combination of MLS and ALS technologies provides a comprehensive insight into the state of road infrastructure on the Belgrade-South Adriatic highway 6.[6].

Most research in this field points to the common conclusion that geodetic bases have a significant impact on the estimation and preliminary cost of earthworks during design. Specifically, this study analyzed earthworks that require significant financial resources and time. The subject of the study is a section of the planned roadway Bihać-Cazin-Velika Kladuša-Republic of Croatia located in the Una-Sana Canton, also known as the Euro Region or the Emerald of Bosnia and Herzegovina.

2. STUDY AREA

In this research, the selected project was used to highlight variations in the obtained results, given that the use of bases from diverse sources can result in significant differences in required works. The primary goal of constructing this roadway is to improve transport quality and traffic safety through the development of adequate road infrastructure. The Una-Sana Canton, containing the municipalities of Bihać, Cazin and Velika Kladuša, is located in the northwest part of Bosnia and Herzegovina. The total area of the canton is 4,841 square kilometers, making up 8.2% of the total area of Bosnia and Herzegovina, with a total population of approximately 305,000. Due to its geographical location and proximity to the Republic of Croatia, it is suitable for the development of roadways. It is situated along significant transportation corridors connecting Europe, the Mediterranean and the Middle East, offering substantial developmental opportunities for Bosnia and Herzegovina. The canton boasts a network of regional, local and arterial roads, as well as European routes connecting it with the Republic of Croatia 6.[7]. The starting point of the section is within the vicinity of the Maljevac border crossing. Statistical data indicate that the area of the Una-Sana Canton comprises 333.1 km of arterial roads, 507.7 km of regional roads, local roads and streets in settlements and cities. Unclassified roads are the most prevalent, accounting for 48.77%, followed by local and regional roads at 29.42%, regional roads at 12.83%, and arterial roads at 8.98%. The road infrastructure is over 30 years old, justifying the need for the construction of new roads. The area slated for the construction of the new roadway is also the area with the highest incidence of traffic accidents in the Una-Sana Canton, with 36.2% occurring in the city of Bihać, 22.3% in the city of Cazin, and 17% in the municipality of Velika Kladuša.

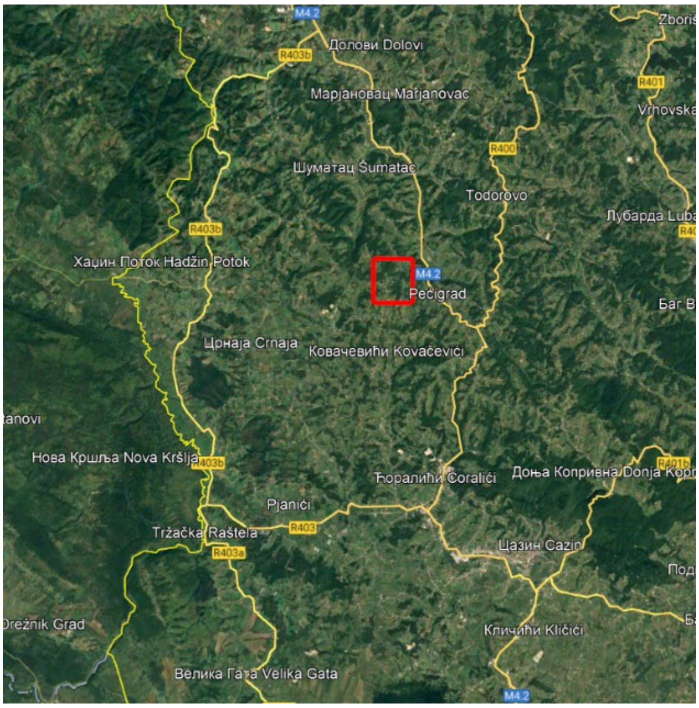


Figure 1. Study area

3. DATA ACQUISITION

Data acquisition for the specified study area involved three datasets obtained from different sources. The first dataset comprises a digital elevation model generated using LiDAR technology, i.e., aero photogrammetric scanning. The digital elevation model provides a raster representation of elevations i.e. a data matrix. The accuracy of these models depends on various factors. The simple data structure and wide availability have made them a popular tool for land characterization 6.[8].

The second dataset includes contours obtained by digitizing a topographic map, while the third dataset contains contours obtained from open sources.

First, we will provide a more detailed description of the data acquisition process for the first dataset. Through point cloud classification, points related to the ground, i.e., the terrain of the study area, were separated, which were then used to form the digital elevation model. Point cloud data was collected using the Riegl VQ-1560II sensor in combination with the Applanix AP60 inertial system, mounted on the gyro-stabilized platform Somag GSM 4000, thus maintaining the mounted camera, scanner and inertial unit in the desired orientation. This method of sensor orientation was employed due to the use of a crewed aircraft for flight execution, which was necessary due to the size of the work area. The result of LiDAR scanning is a point cloud with a density of more than 10 points per square meter. The characteristics of the sensor used are described in detail in Table 6.[9].

Table 4. Characteristics of the LiDAR system and integrated sensors

Specification of the laser scanner	
Instrument type	Riegl VQ-1560II
Scanning mechanism	Rotating polygonal mirror
Number of laser sources	2
Scanning angle	60°– effective 58°
Scanning mode	Parallel scanning lines per channel, intersecting scanning lines between channels
Frequency	from 2x 150kHz to 2x 2000kHz
Scanning speed	40-600 lines/second
Accuracy	20mm
Laser wavelength range	Near-infrared
Laser classification	Class 3B
Beam divergence	≤ 0.18 mrad @ 1/e ≤ 0.25 mrad @ 1/e2
Specification of the inertial system	
System	Applanix AP60
Type	IMU 57- Ri
Accuracy of the inertial unit: Roll Pitch Heading	 0.0025° 0.0025° 0.005°
Spatial accuracy	<0.05m horizontal <0.10m vertical
Specification of gyro-stabilized platform	
Platform	SOMAG
Type	GSM 4000
Angular stabilization range: Roll Pitch Drift	 ≤ ± 8.8° ≤ ± 7.0° ≤ ± 25.0°

Data obtained by manual digitization of a topographic map were chosen as a second data source. This is a process in which geographic data are manually recorded or drawn to create a digital version of cartographic data. Naturally, preference is given to automatic digitization since manual digitization requires significant time and human resources and can often result in errors or inconsistencies in the data 6.[10]. Topographic maps at a scale of 1:25,000 from 1980 were used, which were issued by the Republic Geodetic Authority Sarajevo, Cartography Institute "Geokarta," Belgrade 1980.

The third dataset represents a terrain model obtained from contours from open-source using the Global Mapper software environment. This is an advanced Geographic Information System (GIS) software that provides a wide range of tools for processing spatial data. The dynamic terrain visualization of Global Mapper supports the import and processing of elevation data and terrain visualization in 3D format, thus it was chosen for obtaining the terrain model. Global Mapper utilizes publicly available NASA SRTM (Shuttle Radar Topography Mission) and ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) elevation models. The ASTER GDEM is distributed free of charge to users worldwide by METI and NASA through the Earth Remote Sensing Data Analysis Center (ERSDAC) and the NASA Land Processes Distributed Active Archive Center (LP DAAC), as a contribution to the Global Earth Observing System of Systems (GEOSS). Images are captured across 14 spectral bands utilizing three distinct telescopes and sensor systems 6.[11]. The resolution of these available data is approximately 30 meters 6.[13].

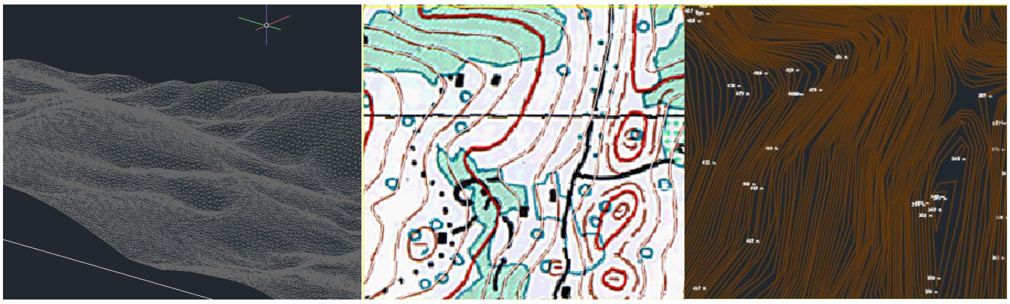
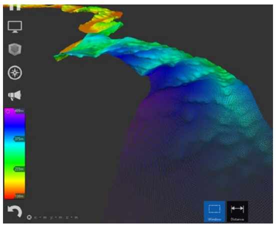
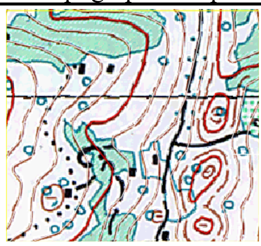
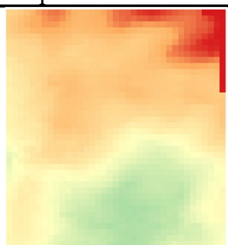


Figure 2. Used datasets (TIN network created from LiDAR data - left, part of a topographic map - middle, contours from open-source data - right)

In the following table, input data for various data acqusition methods are presented base on different criteria.

Table 5. Comparison table of data sources for different criteria 6.[14]

Criteria for comparison	**Data collection methods**		
	LiDAR point cloud	Topographic map	Open-source data
1. Data source			
2.Resolution	5mx5m	25mx25m	30mx30m
3. Density	10 points per square meter	equidistance 10 m	equidistance 5 m
4. Accuracy	< 0,05 m horizontal < 0,10 m vertical	± 3,7 m horizontal ± 2,0 m vertical	30m horizontal 20m vertical

4. METHODOLOGY

On three created datasets representing digital terrain surfaces of the study area, for the purpose of result comparison, a simplified version of a roadway with a total width of 20 meters was designed, with planned slope inclinations in cuts and fills of 1:1.5. Based on the design, digital surfaces of the roadway with slopes were generated relative to the three sets of data, i.e., three digital terrain surfaces.

The results refer to the analysis of excavation and embankment volumes (cut/fill factor), i.e., the total volumes of earthworks required for constructing the roadway corridor projected onto each dataset. The created digital roadway surfaces with slopes served as the comparison surface relative to the corresponding terrain surfaces (Base surface), and then were utilized for generating volume surfaces within the Civil 3D software environment. The primary purpose of volume surfaces is to calculate material quantities and analyze terrain. The data on material quantities from the created volume surfaces is used as part of the results of this study.

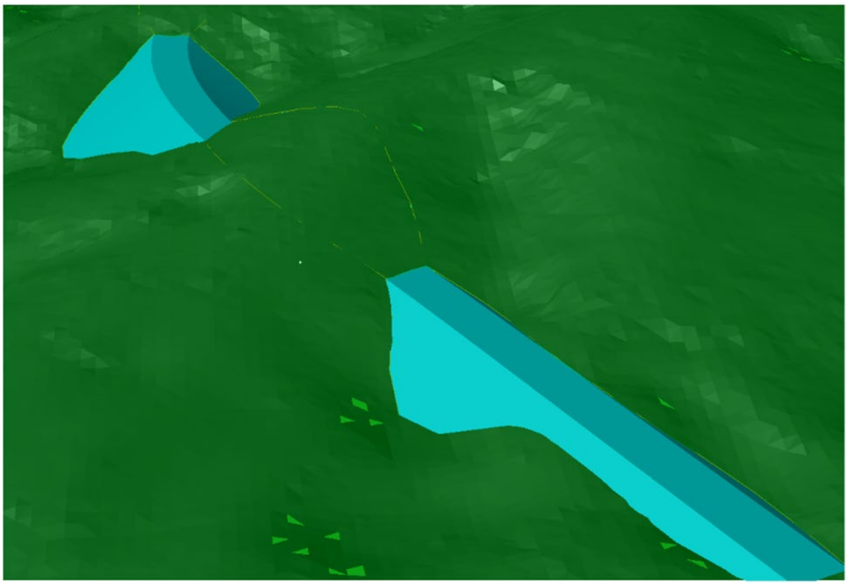


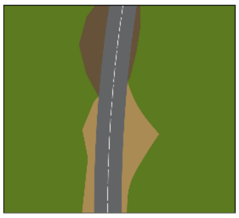
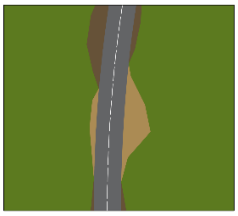
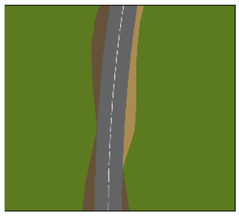
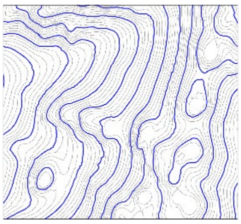
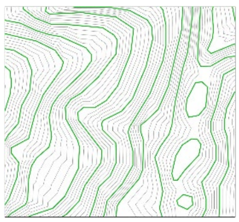
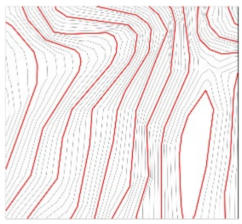
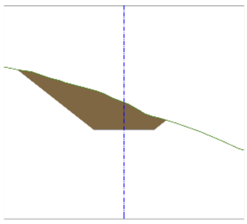
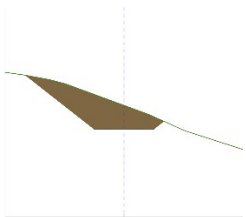
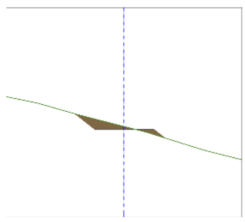
Figure 3. Projected roadway alignment onto the digital terrain surface.

5. RESULTS AND DISCUSSION

By comparing the created models, differences in the roadway alignment are observed, especially in the model formed using open-source data. Roadway models generated using LiDAR datasets and topographic maps show similarities along most of the route, which is expected considering that the contours of the isolated study area segment also exhibit similarity. Nevertheless, when comparing the quantities of earthworks, i.e., the volumes of embankments and excavations, differences in the results of 6% are noted.

When comparing the model generated using LiDAR data with the model based on open-source data, a significant difference in results, up to 30%, was noticed, mainly due to the resolution of the open-source elevation model. In the depiction of the roadway alignment on the isolated characteristic segment of the study area, a clear difference in the crest line of the cut and the toe of the embankment is observed. Additionally, elevation representations, or contours obtained from all three datasets, are shown for the same segment, revealing a lack of detailed representation of relief plasticity that directly affects the results.

Table 1. Shape of the characteristic section of the roadway alignment and the total volume of earthworks

		LiDAR	Topographic map	Open- source data
Roadway alignment at the characteristic section of the route				
Elevation representation of the characteristic section (contours)				
Characteristic cross-section profiles of the roadway				
Volume [m^3]	Embankment	328296	282447	347611
	Cut	582237	573903	293400

6. CONCLUSION

With the constant advancement and increasing technical capabilities, the role of geodesy is evolving, becoming crucial in multidisciplinary and complex projects. Geodetic bases have a significant impact on the roadway design process, as they provide essential terrain information crucial for assessing topography, slopes, soil characteristics and other factors influencing the construction and appearance of roads. These bases are essential for setting road alignments, optimally distributing curves, as well as planning safe and functional solutions for traffic systems. High-quality geodetic bases enable engineers to efficiently identify potential obstacles, assess the impact of road infrastructure on the environment and minimize risks associated with road construction and exploitation.
Although the law contains provisions regarding the use of certain geodetic bases, it needs to be updated to adequately regulate the use of modern geodetic bases, such as high-resolution digital maps and geographic information systems. Since technology is constantly advancing, the law should more precisely define and encourage the use of the latest geodetic tools and techniques, which would enhance the planning and construction process, ensure more efficient spatial management and assist in estimating the amount of work and thus the assessment of project execution timelines and financial project frameworks.

Considering the efficiency, cost-effectiveness and quality of data collection, LiDAR systems justify their increasingly frequent use in creating precise and detailed geodetic bases for various engineering projects. By integrating different types of sensors, LiDAR enables meeting the requirements for collecting spatial information for various purposes. Research confirms that the use of high-resolution spatial data is necessary in the design phase to assess the scope of work, which directly impacts all necessary project resources. Additionally, this research demonstrates that the availability of open-source data in areas allocated for project design and construction should not imply their obligatory use.

Based on the obtained results, we conclude that the terrain model derived from open sources - Global Mapper, meets the requirements for conducting studies, previous research, general project outlines, as well as for conceptual design development. Based on the conceptual design, the scope of the project is defined, requiring higher precision. Therefore, it is essential for the geodetic base used in the development of conceptual, main, and as-built projects to meet their accuracy criteria. Considering that the research results showed a difference of 6% between data obtained through LiDAR technology and digitization of a topographic map, we can conclude that data obtained through both methods satisfy requirements of these project phases. Taking into account all the advantages such as cost-effectiveness, efficiency, reduced error potential and increased precision, priority is given to data collection through LiDAR technology.

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54
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APPLICATION OF CLOSE-RANGE UAV PHOTOGRAMMETRY IN THE DETECTION OF CRACKS ON FACADE

Abstract

The photogrammetric survey of buildings is a beneficial process to obtain accurate 3D data for facade inspection. It allows more straightforward monitoring of the state of the facade over time. An orthomosaic with an average ground sampling distance of 2.1 mm is created using close-range unmanned aerial vehicle photogrammetry. Ground control points, determined with millimeter accuracy from the geodetic network, were used for georeferencing. Resulting in an average ground control points residual of 1.6 mm. Based on the created orthomosaic, visual detection of cracks in the facade was performed. Also, an orthomosaic created with this accuracy can be a basis for automatic tools for detecting cracks on the facade.

Keywords: building facade, UAV technology, image processing, crack detection

ПРИМЕНА БЛИСКОПРЕДМЕТНЕ УАВ ФОТОГРАМЕТРИЈЕ У ДЕТЕКЦИЈИ ПУКОТИНА НА ФАСАДАМА

Сажетак

Фотограметријски премјер објеката је користан поступак за креирање 3Д модела у сврху инспекције фасаде. Омогућава једноставније праћење стања фасаде током времена. Ортомозаик, са величином пиксела у природи од 2.1 mm, је креиран примјеном блископредметне УАВ фотограметрије. Контролне тачке, одређене са милиметарском тачношћу са геодетске мреже, су коришћене за геореференцирање. То је утицало на веома малу грешку дефинисања контролних тачака која износи 1.6 mm. На основу креираног ортомозаика извршена је визуелна детекција пукотина на фасади. Ортомозаик креиран са наведеном тачношћу може послужити као подлога алатима за аутоматску детекцију пукотина на фасади.

Кључне ријечи: фасада, беспилотна летелица, обрада фотографија, детекција пукотина

1. INTRODUCTION

Monitoring and maintaining structures such as buildings and bridges is a crucial but expensive job to ensure safe operation. Traditional monitoring methods involve regular visual inspections, often requiring inspectors to assess the level of deterioration. Automating this process can significantly reduce cost and time between inspections [1]. An essential task of this inspection is to represent a building's facade, which is exposed to external environmental conditions. The crack on the facade poses is the first of the signs of the deterioration of the building, which underlines the need for regular inspections and maintenance. It is important to ensure that the facade elements and all external installations attached to the facade remain intact. Early detection of cracks can help to prevent the potential collapse of the facade and building. However, given the increasing height of buildings and the growing complexity of facade elements, inspecting a building facade is often challenging [2].

3D modeling created based on images captured by high-resolution cameras on unmanned aerial vehicles (UAVs) is becoming a popular and cost-effective alternative [3]. Recent advances in sensors and flight systems have expanded the use of UAVs in various fields, such as forestry [4], agriculture [5], surveying [6], construction [7], facade inspection [8], and various other fields. Reducing labor, time, and cost resources has enabled more frequent facade inspections [9]. When assessing the condition of the facade, the close-up images taken by the UAV are currently obtained by manual adjustment [10], and cracks in each image are identified. However, this often neglects the integration of building model information, which hinders the localization and documentation of detected facade anomalies. There is a need to integrate and manage large amounts of spatio-temporal image data from different sources to improve their accessibility and usability for automated facade inspection.

The Structure from Motion (SfM) algorithm was developed to reconstruct a surface or object by aligning tie points obtained from multiple images, where each point contains both position and color information extracted from an image [11]. The SfM algorithm produces a sparse point cloud, and the Multi-View Stereo (MVS) algorithm generates a dense point cloud. In the SfM-MVS workflow, there are two approaches to georeferencing the images. The first is direct georeferencing, which uses navigation sensors integrated into UAVs, mainly Global Navigation Satellite Systems (GNSS) [12], and the second is indirect georeferencing, which uses Ground Control Points (GCPs). In most studies, the coordinates of the GCPs are determined using GNSS rovers with the Real-Time Kinematic (RTK) method. The accuracy of the coordinate determination depends on the model and manufacturer of the instrument. Nevertheless, it can be said that the coordinates are determined with a horizontal and vertical accuracy of < 10 mm and < 15 mm, respectively [13].

Improving the accuracy of GCPs can be achieved by stabilizing a geodetic network. The accuracy within a geodetic network depends on various factors, e.g., the shape and size of the network, measurement method, used instrument, number of GCPs and measurements, degrees of freedom, and more. Accurately determining coordinates within a geodetic network can be several millimeters [14]. This approach eliminates errors that may have occurred when determining the GCPs. The standard 3D accuracy with which the GCPs are determined in software processing is given as 20 mm [15] and 5 mm [16], however, are they determined with that accuracy. The final products of UAV photogrammetry include orthomosaic, Digital Elevation Model (DEM), 3D models, or mesh and point clouds. The accuracy of orthomosaic and DEM can be expressed by the Ground Sampling Distance (GSD), which represents the distance between the centers of adjacent pixels on the ground and is calculated based on the flight altitude, distance from the terrain or object, and camera specifications (image width, sensor width, and focal length). Proper acquisition and sensor calibration should result in a model with a relative accuracy within 1-3 times the GSD value. However, the absolute accuracy of the model is somewhat lower, typically between 1-2 times the GSD value in the east and north axes and 1-3 times in the vertical axis [17].

In this paper, images of the object were taken using UAV and then processed with software that uses the SfM algorithm. Georeferencing was conducted using GCPs located on the object facade with millimeter accuracy. This accuracy was achieved using a geodetic network, appropriate instruments, and measurement methods. The final processing results consist of an orthomosaic on which cracks were detected.

2. MATERIAL AND METHODS

The procedure used in this paper is given in Figure 1. Each of the steps is explained in the following chapters.

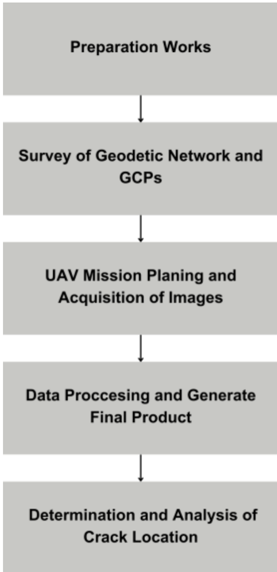
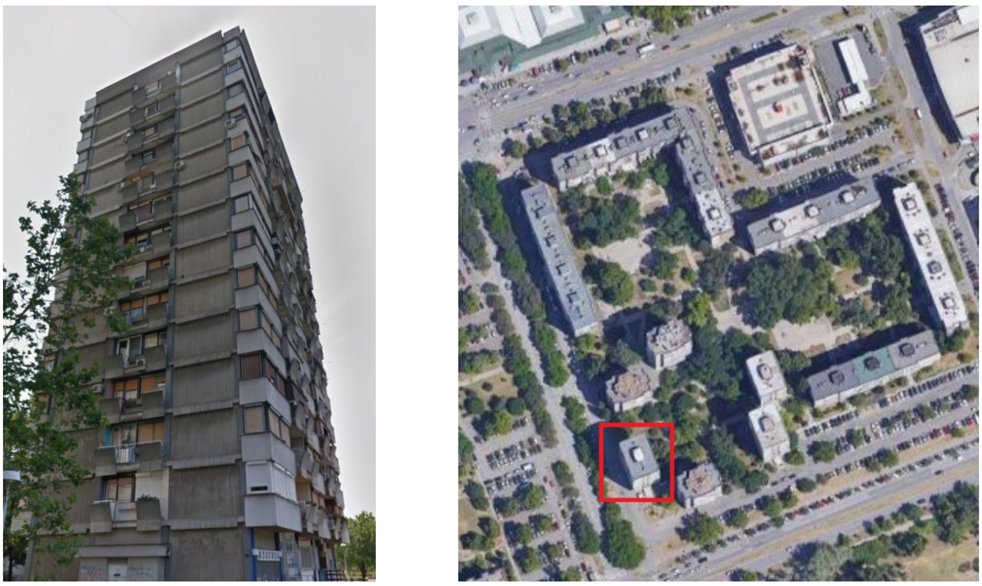


Figure 1. Workflow

2.2. OBJECT INSPECTION

The UAV dataset was acquired in the urban area of Novi Sad, Serbia, approximately 45°14' 27" N and 19° 50' 17" E. The case study focused on the northwest facade of a high-rise (13-storey) residential building built in 1972. The location of the study area and building is depicted in Figure 2. From the first to the 13th floor, the northern facade of the building is identical in appearance, with windows on the left and right edges of the building and a terrace in the middle of each floor. While on the ground floor in the middle of the building, there is an abandoned transformer station.

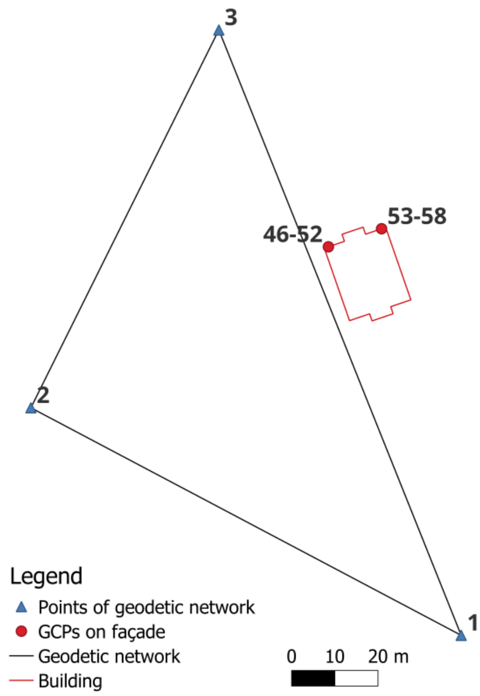


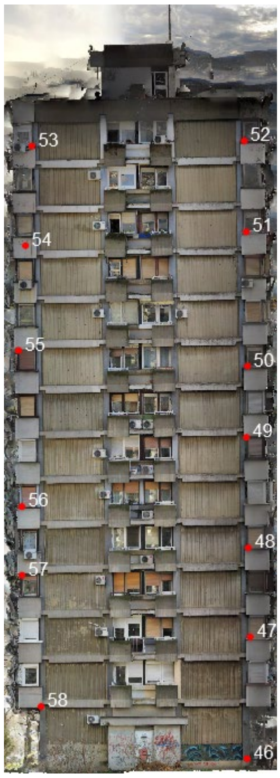
a) *b)*

Figure 2. a) Northwest facade of the object (from Google Maps-Street View©) b) location of the object in urban building block (from Google Maps©)

2.3. ESTABLISHMENT OF GEODETIC NETWORK AND GCPS

To determine the GCPs coordinates with millimeter accuracy, the geodetic network with 3 points (1–3) and 13 GCPs on the facade (46–58) is stabilized, as depicted in Figure 3a and Figure 3b. The GCPs on the facade represented existing characteristic details such as screws, point damage, or corner of a concrete block. The measurements were conducted on the same day as the UAV survey to obtain reliable information about the observations. A total of n=96 observations were performed (32 horizontal directions, 32 zenith angles, and 32 slope distances). Measurements between the points of the geodetic network were executed using one repetition in both faces of the instrument and prism as reflectors. All GCPs on the object were measured from point 3 in two repetitions on both faces of the instrument with non-prism mode. Observations of horizontal directions, slope distances, and zenith angles were carried out using the *Trimble S5* robotic total station with standard deviations σ_α=2″, σ_d=1 mm + 2 ppm prism and σ_d=2 mm + 2 ppm non-prism, and σ_Z= 2″ [18]. The number of unknown parameters was u=51 (48 unknown coordinates and three unknown orientations), with a defect datum of the geodetic network de=4. The degrees of freedom (f=n−u+de) amounted to 49. Approximate coordinates of geodetic network points were determined using the GNSS RTK method in the MGI / 1901 Balkans zone 7 coordinate system (EPSG: 3909). The Gauss-Markov adjustment model with the least squares method is used to adjust the geodetic network. This model constitutes a linear or linearized mathematical model dealing with functional and stochastic components, defining relationships between stochastically realized observations and unknown parameters of geodetic networks. The datum is defined with a minimal trace on all geodetic network points (1-3). The coordinates and standard deviations of all points are given in Table 1. Table 2 shows the measures of central tendency and dispersions of geodetic network points and GCPs standard deviation.





a) *b)*

Figure 3. a) Geodetic network and b) location of GCPs on the facade

Table 1. Coordinates and standard deviation of geodetic network points and GCPs

Point	E [m]	N [m]	H [m]	σ_E [mm]	σ_N [mm]	σ_H [mm]	σ_{3D} [mm]
1	7409223.727	5011282.613	84.603	0.3	0.4	0.4	0.6
2	7409124.065	5011335.415	84.945	0.3	0.4	0.3	0.6
3	7409167.596	5011423.089	85.830	0.2	0.4	0.3	0.6
46	7409192.741	5011372.688	86.206	0.6	1.0	0.4	1.2
47	7409192.562	5011372.724	93.793	0.6	1.0	0.4	1.2
48	7409192.520	5011372.741	99.393	0.6	1.0	0.5	1.2
49	7409192.630	5011372.712	106.251	0.6	1.0	0.5	1.2
50	7409192.531	5011372.722	110.662	0.5	0.9	0.6	1.2
51	7409192.432	5011372.900	116.173	0.5	0.9	0.6	1.2
52	7409192.524	5011372.711	124.673	0.5	0.9	0.7	1.2
53	7409205.132	5011376.552	124.747	0.6	0.8	0.7	1.2
54	7409205.621	5011376.858	118.361	0.7	0.9	0.6	1.2
55	7409205.931	5011376.913	111.896	0.7	0.9	0.6	1.2
56	7409205.953	5011376.844	102.206	0.7	0.9	0.5	1.2
57	7409205.982	5011376.826	97.791	0.7	0.9	0.5	1.2
58	7409204.957	5011376.680	89.750	0.7	0.9	0.4	1.2

Table 1. Central tendency and dispersions of geodetic network points and GCPs standard deviation

	Points of the geodetic network (1-3)				GCP (46-58)			
	σ_E [mm]	σ_N [mm]	σ_H [mm]	σ_{3D} [mm]	σ_E [mm]	σ_N [mm]	σ_H [mm]	σ_{3D} [mm]
Min.	0.2	0.4	0.3	0.6	0.5	0.8	0.4	1.2
Max.	0.3	0.4	0.4	0.6	0.7	1.0	0.7	1.2
Average	0.3	0.4	0.3	0.6	0.6	0.9	0.5	1.2
Median	0.3	0.4	0.3	0.6	0.6	0.9	0.5	1.2
Range	0.1	0.1	0.1	0.0	0.2	0.2	0.3	0.0
Standard deviation	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0

2.4. UAV MISSION PLANNING AND ACQUISITION OF IMAGES

Parrot ANAFI UAV is used for collecting images, and the technical specifications are shown in Table 3. The UAV is an integrated GNSS receiver supporting both GPS and GLONASS satellites. However, UAVs with a standard GNSS receiver provide image geolocation with an expected accuracy of a few meters [19], and in urban areas, the signal is often interrupted by the buildings [20]. The coordinates are stored in the EXIF file attached to each image, expediting the processing as the software searches for tie points only in overlapping photographs relatively close to each other.

Considering the acquisition process and potential challenges posed by external elements such as terraces, power cables, and trees obstructing the facade, a manual flight mode was chosen. The flight mission involved executing flights with the camera positioned perpendicular to the facade at an approximate distance of 6 meters. Taking into the equation the distance from the facade and the technical specifications of the UAV camera, the GSD for the UAV images was calculated to be 2.1 mm. The survey's flight mission involved selecting vertical flying strips. Image overlap is 86% vertical and 89% horizontal, and 492 images were collected.

Table 2. Technical specifications of the Parrot ANAFI UAV [21]

UAV Specifications	
Size unfolded	240 × 175 × 65 mm
Weight	320 g
Max. flight time	25 min
Operating temperature range	−10 ◦C to 40 ◦C
Max. horizontal speed	15 m/s
Max. vertical speed	4 m/s
Max. transmission range	4 km with controller
Max. wind resistance	50 km/h
Satellite Positioning Systems	GPS & GLONASS
Camera Specifications	
Sensor format	6.194 × 4.646 mm
Sensor	1/2.4” CMOS
Lens	FOV 180◦
ISO range	100–3200
Image resolution	4608 × 3456 px
Focal length	4 mm
Diagonal crop	factor 7.487

2.5. DATA PROCESSING AND GENERATING ORTHOMOSAIC

After the images were collected, the Agisoft Metashape software package began processing data. The Root Mean Square Error (RMSE) reproject error using the camera optimization feature is enhanced. This process followed the methodology explained in [22], with the computation parameters listed in Table 4. Through this procedure, low-quality tie points were systematically eliminated from the sparse point cloud after the alignment of images. The reconstruction uncertainty metric identified points exhibiting poor geometric relations between cameras. Tie points with inadequate match accuracies were singled out using the projection accuracy criterion. Additionally, tie points resulting from false matches were identified and removed based on the reprojection error criterion. These selection and elimination processes were conducted iteratively. The removal of poor tie points aimed to improve the estimated internal and external orientation parameters. However, each iteration of tie point removal altered the accuracies of the remaining tie points, necessitating reoptimization of the project before proceeding.

Table 3. Computing parameters of the software

Alignment	
Accuracy	High
Generic preselection	Enable
Reference preselection	Source
Key point limit	60 000
Tie point limit	0 (unlimited)
Dense cloud building	
Quality	High
Depth filtering	Mild

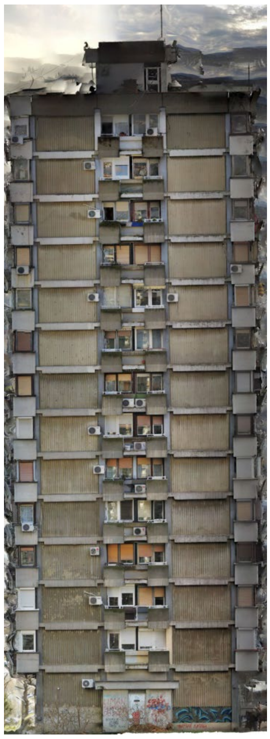
For georeferencing, GCPs obtained with an average accuracy of 1.2 mm (Table 2) were used, and that accuracy is entered into the software during GCPs input. Table 5 shows the residuals for GCPs in processing, their measures of central tendency, dispersions, and RMSE.

The process results in a georeferenced point cloud with 116 million points (Figure 4a). The created point cloud generates the orthomosaic with an average GSD of 2.1 mm (Figure 4b). The achieved average GSD of the generated orthomosaic corresponds to the GSD of the initial images, determined in the flight planning phase. Analysis of orthomosaic shows that most of the details on the facade are realistically presented. Thanks to well-planned data collection, this also applies to the edges of the facade surface, even though fewer images are overlapped in these zones than in the central parts.

Table 4. GCPs residuals

Point	E [mm]	N [mm]	H [mm]	3D [mm]
46	0.1	-1.0	1.4	1.7
47	-0.1	0.1	-0.7	0.7
48	-2.1	-1.0	-1.3	2.6
49	-0.8	1.0	0.7	1.5
50	2.0	0.9	-2.9	3.6
51	0.8	-0.9	1.9	2.2
52	0.0	0.6	1.5	1.6
53	-0.2	0.0	0.0	0.2
54	-1.3	-0.5	-0.4	1.4
55	-0.5	-0.4	0.0	0.7
56	0.5	0.4	0.1	0.7
57	1.2	-0.6	1.0	1.7
58	0.6	1.3	-0.7	1.6
Min.	-2.1	-1.0	-2.9	0.2
Max.	2.0	1.3	1.9	3.6
Average	0.0	0.0	0.0	1.6
Median	0.0	0.0	0.0	1.6
Range	4.0	2.3	4.7	3.4
Standard deviation	1.1	0.8	1.3	1.4
RMSE	1.0	0.8	1.2	1.8

a)



b)

Figure 4. a) point cloud and b) orthomosaic of the facade

3. DISCUSSIONS

During the analysis of the orthomosaic, cracks found on the facade are shown in Figure 5. It can be concluded that the cracks appeared on different parts of the facade. However, the procedure of manual detection of cracks on the orthomosaic is time consuming and laborious. The detection and classification of cracks largely depend on the individual expertise and experience of the surveyor and lead to data redundancy. In addition to the manual analysis of cracks on the facade, there are tools for automatically detecting cracks on the orthomosaic facade, such as the AIM method [23]. After detecting cracks on the georeferenced orthomosaic, it is possible to determine the coordinates of those cracks on the object in the global coordinate system, in this case, EPSG: 3909. Since a geodetic network and GCPs with an accuracy of several mm have been established, it is possible to mark the cracks on the object with very high precision.

a) *b)*

c) *d)*

Figure 5. Cracks on the facade

4. CONCLUSION

This paper presents the procedure for detecting cracks on the facade of a 13-story building. Cracks were detected on an orthomosaic created using a SfM algorithm based on images collected from a UAV. GCPs measured from an established geodetic network were used for georeferencing. The average standard deviation of GCP determination is 1.2 mm, while the average accuracy of georeferencing (GCP residuals) was 1.6 mm. This accuracy makes it possible to detect even the most minor cracks in the facade, and the minimum number of pixels that can detect a target is at least a 2-pixel square (2x2 pixel), even for high-contrast images. In some conditions might need to consider a 4-pixel square [24].

Along with manual detection of cracks on the facade, there is also an automatic one. However, the efficiency, reliability, accuracy, and objectivity of the automated building facade inspection process depend on the ability of the applied model to identify, locate, and quantify damage on images acquired by the UAV. One of the reasons for the appearance of cracks on this building is that residential buildings built with industrial building technology in Novi Sad in the second half of the XX century indicated the unsatisfactory technical condition of facade elements [25].

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55
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COMPARATION OF PHOTOGRAMMETRY AND TERRESTRIAL LASER SCANNING METHODS FOR EROSION MONITORING IN THE AREA OF DEVIL'S TOWN: PROJECT "DEMONITOR"

Abstract

Project "Devils' town Erosion MONITORing - DEMONITOR" involves the monitoring of accessible earth pillars in the area of Devil's town, by using a combination of several non-invasive methods. Terrestrial laser scanning (TLS) and photogrammetric imaging with unmanned aircraft (UAV) as a platform showed as great solutions for 3D modeling of this site and erosion monitoring. In this work it is shown that using manual free flight mode for imaging with UAV gave much better results than the missions performed with predefined flight plans. The desired long-term effect from this research should have a significant part in the overall socioeconomic development of the municipality of Kuršumlija, and the entire Toplica district.

Keywords: earth pillars, 3D model, photogrammetry, laser scanning

ПОРЕЂЕЊЕ МЕТОДА ФОТОГРАМЕТРИЈЕ И ТЕРЕСТРИЧКОГ ЛАСЕРСКОГ СКЕНИРАЊА ЗА ПРАЋЕЊЕ ЕРОЗИЈЕ НА ПОДРУЧЈУ ЂАВОЉЕ ВАРОШИ: ПРОЈЕКАТ „ DEMONITOR"

Сажетак

Пројекат "DEMONITOR" подразумијева праћење приступачних земљаних стубова на подручју Ђавоље вароши комбинацијом неколико неинвазивних метода. Терестричко ласерско скенирање и фотограметријско снимање коришћењем беспилотне летјелице као платформе показала су се као одлична рјешења за 3Д моделирање овог локалитета и праћење ерозије. У овом раду је показано да је коришћење ручног режима мануелног летења за фотограметријско снимање дало много боље резултате од мисије која се обавља са унапријед дефинисаним планом лета. Жељени дугорочни ефекат овог истраживања требало би да има значајан удио у укупном друштвено-економском развоју општине Куршумлија, али и Топличког округа.

Кључне ријечи: земљани стубови, 3Д модел, фотограметрија, ласерско скенирање

1. INTRODUCTION

The DEMONITOR project focuses on monitoring a rare geological marvel at the “Devils’ town” site near Prolom Spa in southern Serbia (Fig.1). This site features approximately 200 tall rock pillars, known colloquially as “the Devils”, formed by the interplay of erosional forces and volcanic rock. These pillars are the result of ages of weathering and erosion.

The project aims to monitor these pillars and surrounding weather conditions using advanced non-invasive methods such as terrestrial laser scanning (TLS), aerial photogrammetry with unmanned aerial vehicles (UAV), satellite radar interferometry (InSAR), and geophysical techniques over a three years period to quantify changes like erosion rate, rockfall occurrence, and ground subsidence.

This project is a follow-up of the pilot project MEĐA, which was realized by a part of DEMONITOR’s research team in a period of 2017-2018 [1]. During that project, two acquisitions of the test site were performed in November 2017 and November 2018 (using TLS and UAV methods). With first acquisition a so-called zero state model was produced as a 3D representation of the initial terrain surface, while each subsequent acquisition produced a new point cloud with the same characteristics in terms of reference system, resolution, and precision. By comparing the new 3D model with the previous, the spatial differences that occurred between two acquisition epochs as consequence of erosion of a pillar can be picked up and measured [2]. Newest acquisition was performed as a part of project DEMONITOR in February 2024.

For the needs of this paper, only results collected with TLS and UAV photogrammetry will be discussed because till now only these methods were used for monitoring mentioned area. Both methods give a point cloud as a result - i.e. three-dimensional model of the surface represented by high resolution points with the corresponding 3D coordinates. Model generation for these methods is different because laser scanning produces a point cloud directly, while optical imaging requires photogrammetric processing to generate a point cloud [3]. Resolution and accuracy of a point cloud is higher in the case of TLS technology [4], which allows the monitoring of the earth pillar erosion at a cm level [5], while photogrammetrically recorded images can be used for 3D modeling of the area of interest, but these results were not reliable for erosion monitoring. Another difference is in the point of view, because TLS is suitable for capturing the details on the pillars’ sides, from the ground in multiple positions, while by using UAV as a platform for photogrammetric imaging, it is possible to perform imaging above the pillars and get better approach to some hidden spots, such as shadowed objects that are inaccessible from the perspective of the scanner. These point clouds can be combined in order to generate a unique surface model, which will benefit from advantages of both source clouds – level of detail obtained with TLS and measured inaccessible areas by using UAV photogrammetry.

It is expected that results of the DEMONITOR project will not only portray the change, but also allow prediction of the change rate and trend, entailing design of appropriate prevention or stabilization measures, ultimately leading to the permanent site’s conservation. All scientific findings will be used to promote and credit the site, especially in UNESCO context, while improving its touristic value, which might further entail benefits for the local economy.

2. STUDY AREA

Devils’ town, a rare geomorphological and geological phenomenon and protected natural heritage site in southern Serbia, features nearly 200 rock pillars, some towering up to 15 m tall and 6 m in diameter, formed over years by erosional forces. The site is part of the Lece volcanic complex, showcasing a unique combination of volcanic genesis and erosion. These pillars, known colloquially as "the Devils" hold geological evidence of past volcanic activity, including violent eruptions that produced pyroclastic flows. The erosion process, influenced by various factors, continues to shape and change (collapsing, sinking and emerging) these remarkable landforms, prompting intrigue into their future amidst climate change.

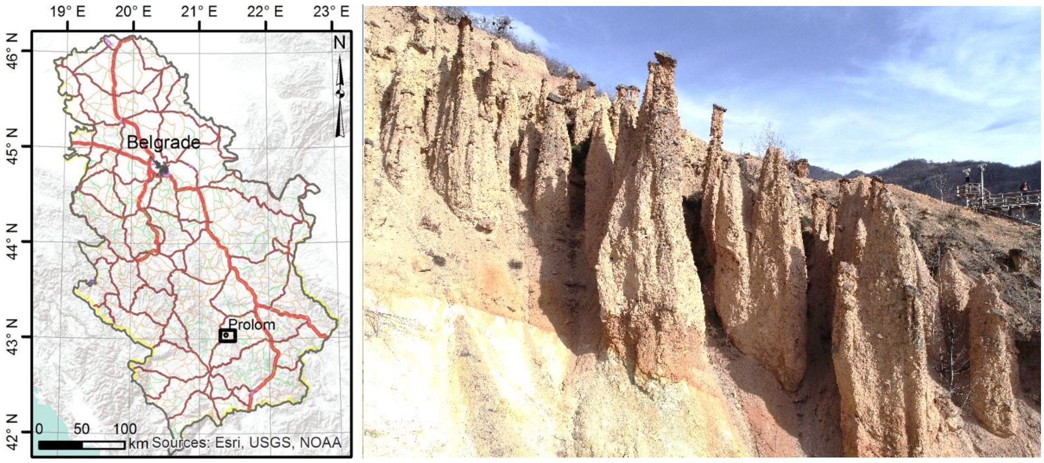

Figure 1. Devils' town location in Serbia (left) and its landforms – earth pillars (right)

3. CONCEPT AND METHODOLOGY

For the needs of this project, TLS and UAV methods will provide high-resolution local surface models, while InSAR will be used to monitor displacements of fixed ground control points (corner reflectors, and possibly strong natural reflectors, such as caprock), ensuring that the global stability of the site is satisfied, i.e., that the changes are relative to the pillars and not the wider terrain deformations, such as regional subsidence for instance. Currently, TLS and UAV approaches are used for collecting data in soil erosion monitoring [6]-[8]. UAV photogrammetry aka structure-from-motion (SfM) method using UAV imagery is a beneficial tool for topographic data collection.

It was planned to have at least two TLS and UAV acquisition sequences, i.e., two site visits, per year. Both visits are scheduled for the non-vegetative part of the year, which coincides with the touristic low season (late autumn/early spring), in order to minimize possible noise introduced by vegetation and visitors. Each sequence of scanning/imaging will produce current surface model (3D point-cloud) of the major landforms. The principal idea is to compare these surface models in appropriate software package such as CloudCompare [9], which will allow interpretation, i.e., detection and quantification of the 3D surface change between consecutive sequences (or any other combination of sequences). In plain words, it would be possible to visualize which parts of the pillars have changed between two visits and for how much.

The TLS and UAV acquisition methods are capable of capturing sub-cm changes and indicate locations that are prone to weathering and collapsing. Therefore, it is expected that pre-failure deformations can be also registered and linked to the subsequent stability models.

The software solution Agisoft Metashape [10] was used to generate point clouds with UAV data. It represents an advanced solution for 3D modeling based on images, which aims to generate high-quality 3D content from images. The images can have any position, but under a condition that the object to be reconstructed is visible in at least two images. Image alignment and 3D model reconstruction are fully automated.

Data collection using photogrammetric methods requires several stages. The first phase is flight preparation, which includes the creation of flight plan and defining the GCP (Ground Control Points) project. The flight plan is defined in such a way as to ensure the minimum overlap between images (transverse 80%, longitudinal 80%), the number of flight lines and number of images within each line. GCP project includes markers that were used for terrestrial laser scanning method, which evenly cover the entire site area. The GCP coordinates were determined by post-processing the data collected with terrestrial laser scanning in the local coordinate system. The scanner registers data in its unique coordinate system.

In MEĐA project, all of the flight missions for UAV photogrammetry were performed in a way to cover whole area of the interest with a sufficient number of overlapping images needed for 3D reconstruction. These images were usually close to nadir and collected from above on a height of 50m or 80m above the ground. The imaging was double routed, using longitudinal and transverse flight direction. In the first acquisition of the DEMONITOR project, imaging was performed manually during free flight mission which offers greater coverage of complex objects such as these landforms. In this way, much more images were collected during this type of flight but a higher level of detail was acquired with smaller number of shadowed objects (Fig. 2).

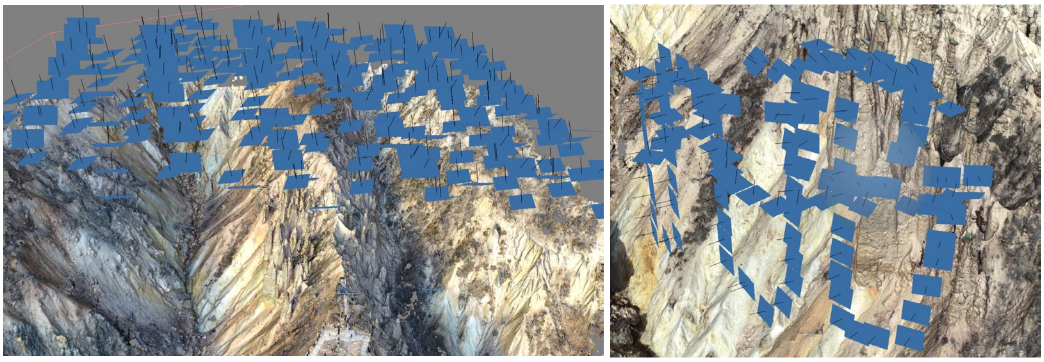

Figure 2. Two ways of mission planning – automated flight mission plan from a height of 50m (left) and free flight manual mission plan from a distance under 20m (right)

From this analysis it is obvious that in order to obtain greater detail using a UAV, a lower flight height should be achieved and the object of interest should be flown over and photographed from all sides, in order to collect as many points as possible and obtain higher detail.

4. RESULTS AND DISCUSSION

The first field work in MEĐA project was conducted in November 2017. The first results of the erosion calculation were obtained after the second acquisition, which was performed in November 2018. Time period between missions was not long enough for the detection of noticeable changes of earth pillars.

First field work in DEMONITOR project was conducted in February 2024. The TLS scanning took about 3.5 hours, while UAV imaging with lasted about one hour and 30 minutes with three batteries used. Terrestrial laser scanner used was Leica ScanStation P20 while available UAV used for photogrammetric mission was DJI Phantom 4 PRO. This aircraft has a 20Mpix camera with mechanical shutter which makes this UAV camera more suitable for photogrammetry needs. Real field conditions caused that certain parts of the area remained inaccessible for scanning and imaging, for example, between the closely positioned pillars, which shadowed one another. Also, there were areas behind these landforms that were not accessible for measuring. A local coordinate system was set up for LiDAR scanning process, while a total of 10 surveying marks were used as tie points for linking successive scans from different stations, and these points were also used as GCP points for georeferencing photogrammetric block of aerial images.

A total of 680 images were recorded from a distance of 20 m from earth pillars resulting in image generation at each 2 m of traveled way that gives sufficient image overlap between consecutive image locations (> 80%). The recording included an area of 0.047 km2. The mean total error of the resulting point cloud was about 2.6 cm. For the creation of a dense point cloud with high qualty option, 48.1 million points were generated. Comparison with UAV missions performed in 2017 and 2018 is presented (Table 1).

Table 1. Results comparison of each UAV mission

Epoch	Number of images	Number of points	GCP total error [cm]	Processing time [h]
2017	254 (80m height)	15,8 million	1.0	16
2018	424 (182 at 50m and 242 at 80m height)	31.3 million	1.1 (50m) 2.9 (50m+80m)	20
2024	680 (20m distance)	48.1 million	2.6	26

Finally, an orthophoto with resolution of 2 cm/pix was obtained while reconstructed digital elevation model's resolution was 4 cm/pix.

As it can be seen from the results, 3D point cloud generated using photogrammetric processing of imagery collected in 2024 showed much greater detail when comparing with 3D point clouds obtained from mission performed in 2018. This is obviously the result of using a new imaging procedure with free flight manual mission plan that also gives higher spatial resolution. Also with this type of analysis, rockfall occurrence is possible to identify (Fig. 3).

Figure 3. Difference between level of detail between 3D model reconstructed with automated mission flight plan (left) and free flight manual mission flight plan (right)

By visual comparison, it was concluded that the point cloud obtained by the UAV system has a lower resolution than the cloud of points obtained by the TLS method. We observed the details of one pillar, called “Barjaktar”. Upon observation of the “Barjaktar” figure, it can be concluded that a significant number of details, such as small pebbles and rocky outcrops, are missing in the point cloud obtained by the UAV system, whereas they are clearly indicated in the TLS method (Fig. 4).

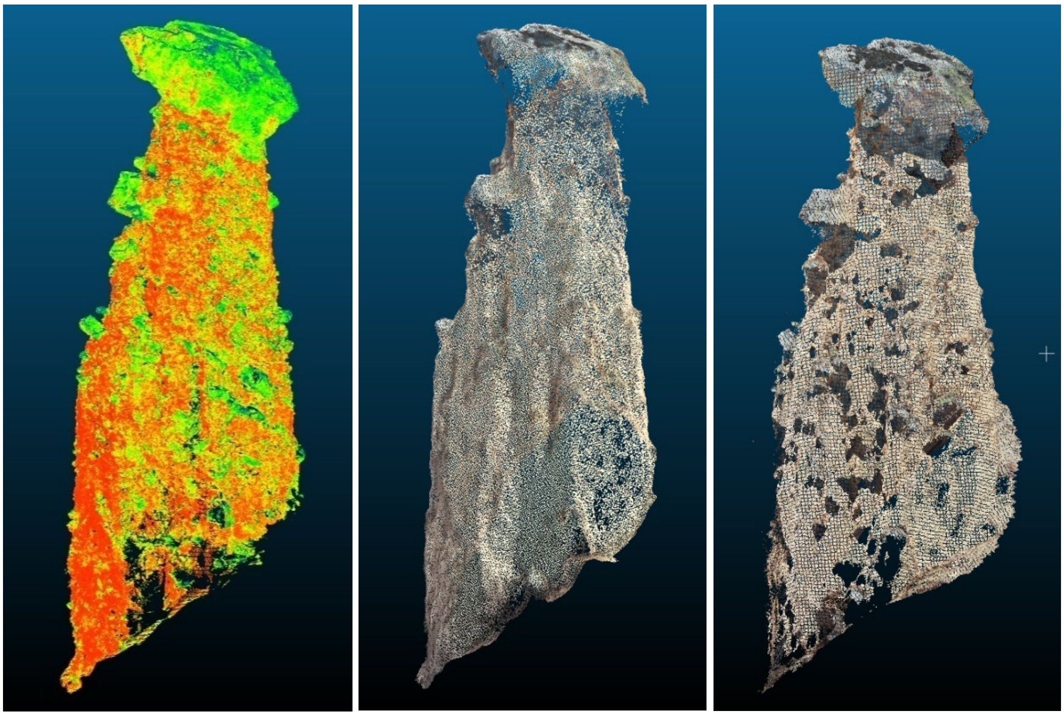

Figure 4. The point cloud of Barjaktar figure obtained by TLS method (left) and the point cloud of Barjaktar obtained by using UAV photogrammetry (middle 2018 and right 2024)

It can be seen that 3D model obtained in 2024 has more detail than the model generated in 2018, but model from 2024 also has lots of shadowed areas. This model was made from a much smaller distance but the UAV didn’t have a good perspective when fluing above the “Barjaktar” figure. For this particular case it would be better that some of the images were made with camera from the ground. Due to the lower level of detail generated in UAV 2018 mission, there was no sense in comparing these results with TLS point cloud. When comparing UAV 2024 mission with TLS point cloud it can be seen that there are still shadowed areas where comparation would not be appropriate. So erosion monitoring should be performed only between TLS missions from different epochs until better area coverage with UAV mission is performed. Model comparison of the "Barjaktar" figure generated from different TLS and UAV acquisition missions is presented (Table 2).

Table 2. Model comparison of earth pillar Barjaktar in TLS and UAV acquisition missions

Mission epoch and type	Number of points	Number of triangles	Spatial density [pnts per sqm]
2017 UAV	117 734	41 471	3 500
2018 UAV	207 820	94 737	6 600
2024 UAV	2 278 708	1 464 082	86 884
2017 TLS	668 907	1 322 612	16 981
2018 TLS	2 412 074	4 483 676	112 294

Point clouds of the "Barjaktar" created from data collected with UAV photogrammetry missions were generated by using Ultra High quality option when making dense point cloud in Agisoft.

Erosion monitoring was performed by using volume calculation function based on a grid in CloudCompare. Before that TLS models from 2017 and 2018 were finely registered cloud to cloud (Fig. 5) and distances between points from point clouds were calculated. It was calculated that the volume of eroded landslide material was 36 dm^3.

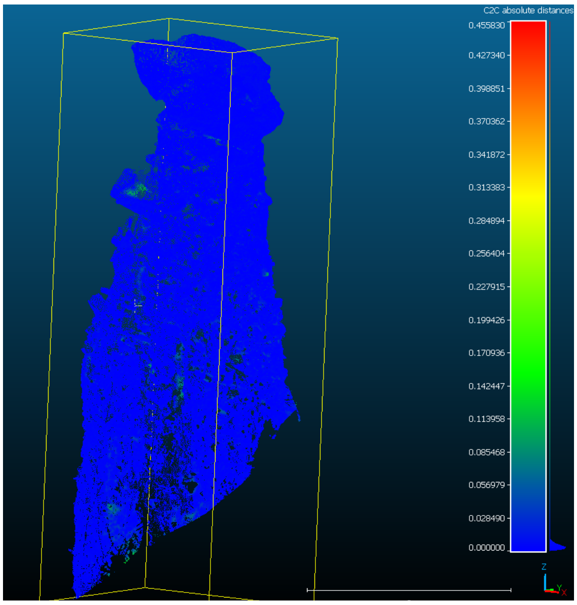

Figure 5. Comparison of TLS models from 2017 and 2018 time epoch by cloud to cloud distance

5. CONCLUSION

Modern laser scanners and UAV systems as measuring platforms are gaining more and more space in geodetic and other engineering activities. Fast, high-resolution data acquisition with optimal project costs brings TLS and UAV photogrammetry into the sphere of interest for the engineering and photogrammetry public.

UAV photogrammetry has the indisputable advantage of collecting data in inaccessible areas, especially when it is not possible to find a stable position to place the instrument, when compared to other methods, and now it is applied in many geodetic and engineering fields. Thus, UAV is extremely useful in recording and tracking objects, in engineering photogrammetry, but also in monitoring the behavior of the terrain in larger areas of interest. In this paper, the acquisition of data by the UAV system is shown, which enables very precise data for further analysis of the mutual comparison of the quality of the TLS and UAV systems.

As part of the research, it was noticed that the data obtained by the TLS method contained more detailed data compared to UAV photogrammetry, especially due to the higher spatial resolution. The application of the TLS method required the selection of stable places for placing the scanner stations, and the whole scanning process required more time, while with the UAV system the whole process takes much less time when performing automated flights. UAV photogrammetry had more advantages in the form of access to the shadowed objects in the area of interest. This was possible because UAV was much more mobile when compared with TLS and had a much bigger number of viewpoints.

By performing free flight UAV imaging with an optimal flight path it is possible to collect data for 3D model generation with much higher spatial resolution due to the shorter distance from earth pillars. In this way also shadowed areas will be avoided as much as possible. This was much better than the missions performed in the past with almost nadir images captured from a bigger distance above the earth pillars.

Rockfall occurrence is possible to detect with UAV photogrammetric missions especially when comparing models during longer period of time. With TLS method it is possible to quantify changes like erosion rate and ground subsidence. If UAV missions are planned in detail and with much better mission coverage it will maybe give even better results than TLS especially due to the limitation of this kind of scanning and producing shadowed areas. Another solution for overcoming these limitations would be laser scanning with high precicion LiDAR sensor mounted on an UAV but with a possibilty to control the angle of scanning sensor and get much better coverage of the area and higher level of detail.

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56
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COMPARATIVE ANALYSIS OF DIFFERENT VARIANTS OF AZIMUTHAL CONFORMAL PROJECTION FOR THE TERRITORY OF THE REPUBLIC OF SERBIA

Abstract

The paper analyzes four variants of conformal azimuthal projections for the territory of the Republic of Serbia. In the procedure, a double conformal mapping was applied. As it is common practice to perform mapping in azimuthal projections from a sphere to a plane, it was initially necessary to perform a conformal mapping from the ellipsoid to the sphere, after which a conformal mapping from the sphere to the plane was executed. The central point of the projection is a point with a value of 44° north latitude and 21° east longitude. The mapping territory is trapezoidal in shape, defined by the values of the geographic latitudes and longitudes of the southernmost (41°53'), northernmost (46°11'), westernmost (18°49'), and easternmost (23°) points in the territory of the Republic of Serbia. The mapping variants are defined based on different values of linear scale at the central point of the projection. Data processing was carried out within the Jupyter Notebook component, part of the Anaconda software package, using the Python programming language. The results are presented numerically, graphically, and visualized using AutoCAD software.

Keywords: Azimuth projection, conformal mapping, linear scale, linear deformations

КОМПАРАТИВНА АНАЛИЗА РАЗЛИЧИТИХ ВАРИЈАНТИ АЗИМУТНЕ КОНФОРМНЕ ПРОЈЕКЦИЈЕ ЗА ТЕРИТОРИЈУ РЕПУБЛИКЕ СРБИЈЕ

Сажетак

У раду су анализиране четири варијанте конформних азимутних пројекција за територију Републике Србије. У поступку рада је примијењено двоструко конформно пресликавање. Како је пракса да се пресликавање код азимутних пројекција врши са сфере на раван, првобитно је било потребно извршити конформно пресликавање елипсоида на сферу, након чега је извршено конформно пресликавање са сфере на раван. Централна тачка пројекције јесте тачка са вриједношћу 44° сјеверне географске ширине и 21° источне географске дужине. Територија пресликавања је трапезастог облика, дефинисана вриједностима географских ширина и дужина најјужније (41°53`), најсјеверније (46°11`), најзападније (18°49`,) и најисточније (23°) тачке на територији Републике Србије. Варијанте пресликавања су дефинисане на основу различитих вриједности линеарног размјера у централној тачки пројекције. Обрада података је вршена у оквиру компоненте *Jupyter Notebook*, софтверског пакета *Anaconda* употребом *Python* програмског језика. Резултати су приказани нумерички, графички и визуализовани су помоћу програмског софтвера *AutoCAD*.

Кључне ријечи: Азимутна пројекција, конформно пресликавање, линеарни размер, линеарне деформације

1. INTRODUCTION

The first cartographic projections (from the group of perspective and azimuthal projections) date back to the ancient period and are attributed to ancient Greek scientists, who proposed them for astronomical and other maps. It should be noted that with the appearance of these maps, a stage in the development of cartography begins in which cartography, along with mathematical cartography, takes on the characteristics of scientifically based disciplines [1].

In azimuthal projections, the plane of projection touches the Earth at a chosen point [2]. Depending on the latitude of the point where the plane of projection touches the sphere, azimuthal projections can be divided into three categories:

- vertical (straight) or polar where $\varphi_{\circ}=90°$;
- oblique where $90°<\varphi_{\circ}<90°$ and
- transverse (equatorial) where $\varphi_{\circ}=0°$.

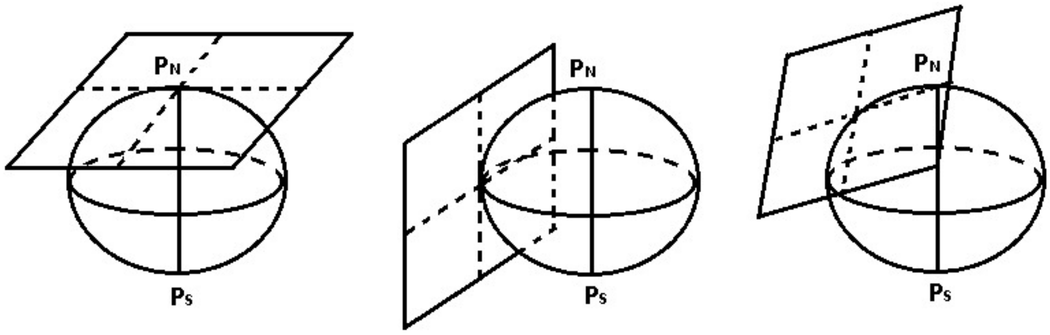


Figure 1. Vertical, transverse, and oblique azimuthal projection

According to the position of the projection point, azimuth projections are divided into (Figure 2) [3]:

- Gnomonic (projection center is in the center of the Earth);
- Stereographic (the projection center is on the opposite pole) i
- Orthographic (center of projection is at infinity)

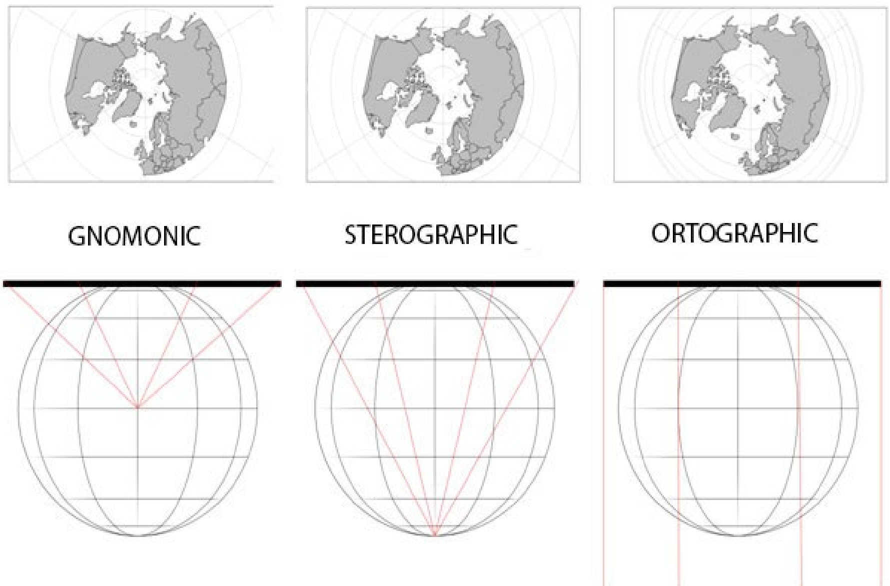


Figure 2. Division of azimuth projections in relation to the point of projection [3]

In the study, an oblique azimuthal stereographic projection was used with a central point at 44° north latitude and 21° east longitude because this point is located at the center of the territory to be mapped. As it is common practice in azimuthal projections to map from a sphere to a plane, it was necessary to first conformally map the ellipsoid onto a sphere [4]. The WGS84 ellipsoid was chosen for this purpose, and conformal mapping was performed from it onto a sphere. After conformally mapping from the ellipsoid to the sphere, a conformal mapping from the sphere to the plane was carried out [5]. This process involved a double mapping [6].

The mapping area includes the entire territory of the Republic of Serbia and is trapezoidal in shape. Since the aim of the study is to analyze linear deformations in various variants of azimuthal conformal projection, what defines the variants and input parameters for data processing is the linear dimension at the central point of the projection. The linear dimension represents the relationship between corresponding linear elements on the projection surface and the original surface.

The variants that will be considered in the study are as follows:

- Variant 1: $\mu = 0.9996$
- Variant 2: $\mu = 0.9997$
- Variant 3: $\mu = 0.9998$
- Variant 4: $\mu = 0.9999$

2. DATA PROCESSING

The first step in data processing is to define the radius of the sphere that is most suitable for mapping from the WGS84 ellipsoid depending on the parallel where the central point of the projection is located and conformally mapping the ellipsoid to the sphere, which is defined by the following formulas [1]:

$$R = a * (1 - \frac{e^2 * sin^2(44°)}{2}) \tag{1}$$

$$\varphi' = \varphi - \frac{1}{2} e^2 sin^2 \varphi \tag{2}$$

$$\lambda' = \lambda \tag{3}$$

Then it was necessary to determine the integration constant that appears in the formula for calculating the linear dimension, as well as the deformation as a function of latitude. The integration constant (c) is calculated on the basis of the following formula in which the unit z figures as the value of the degree distance from the central point of the projection:

$$\mu = \frac{C}{2*R} sec^2 \frac{z}{2} \tag{4}$$

When using this formula, the value of the linear scale varied depending on the variant under consideration. The value of the integration constant for the first variant in the code was determined as follows:

```
ckonst=(0.9996*2*R)
```

Figure 3. The line of code for calculating value of integration constant

After the equation for the linear scale is equal to one, the distances from the central parallel are obtained where the values of the linear deformations d are equal to zero (d = |1-μ|), where cen represents the value of the geodetic latitude of the central point of the projection. This is written in the code for the first variant as follows [7]:

```
rast=2*acos(sqrt(ckonst/(2*R)))

rast1=rad2DMS(cen-rast)

rast2=rad2DMS(rast+cen)
```

Figure 4. The lines of code for calculating distances from the central parallel where the values of linear deformations are equal to zero

In the code, two lists are defined with values of geographic latitudes and longitudes, and they have the following values:

- Geographic latitudes: 41°53`, 42°, 42°30`, 43°, 43°30`, 44°, 44°30`, 45°, 45°30`, 46°, 46°11`
- Geographic longitudes: 18°49`, 19°, 19°30`, 20°, 20°30`, 21°, 21°30`, 22°, 22°30`, 23°

The defined values of geographic latitudes and longitudes on the ellipsoid are input data for calculating spherical geographic coordinates[8]. After obtaining these values, mapping from the ellipsoid to the sphere was performed, enabling further processing of conformal mapping from the sphere to the plane and obtaining rectangular coordinates, linear scale values, and linear deformation values. The formulas used in the process of calculating these values are as follows (variant 1) [9]:

$$\mu = \frac{C}{2*R} sec^2 \frac{z}{2} \tag{5}$$

$$x = 2*R*0.9996*\frac{sin\phi cos\phi_\circ - cos\phi sin\phi_\circ cos\lambda}{1+(sin\phi sin\phi_\circ + cos\phi cos\phi_\circ cos\lambda)} \tag{6}$$

$$y = 2*R*0.9996*\frac{cos\phi sin\lambda}{1+(sin\phi sin\phi_\circ + cos\phi cos\phi_\circ cos\lambda)} \tag{7}$$

$$d = \left|1-\mu\right| \tag{8}$$

Since we are dealing with variants of conformal azimuthal projection, the values of angular deformation are equal to zero, considering that the condition of conformity is defined during the derivation of the formulas used in the study.

3. ANALYSIS OF RESULTS

The following tables show the values of linear scales and deformations depending on the geographic latitude in four variants:

Table 1. Values of linear scale and deformation depending on the geodetic latitude- Variant 1

Geodetic Latitude	Linear Scale	Deformation Value
41°53`	0.9999389	0.0000611
42°00`	0.9999025	0.0000975
42°30`	0.9997702	0.0002298
43°00`	0.9996756	0.0003244
43°30`	0.9996189	0.0003811
44°	0.9996	0.0004
44°30`	0.9996189	0.0003811
45°00`	0.9996756	0.0003244
45°30`	0.9997702	0.0002298
46°00`	0.9999025	0.0000975
46°11`	0.9999605	0.0000395

Table 2. Values of linear scale and deformation depending on the geodetic latitude- Variant 2

Geodetic Latitude	Linear Scale	Deformation Value
41°53`	1.0000389	0.0000389
42°00`	1.0000026	0.0000026
42°30`	0.9998702	0.0001298
43°00`	0.9997756	0.0002244
43°30`	0.9997189	0.0002811
44°	0.9997	0.0003
44°30`	0.9997189	0.0002811
45°00`	0.9997756	0.0002244
45°30`	0.9998702	0.0001298
46°00`	1.0000026	0.0000026
46°11`	1.0000606	0.0000606

Table 3. Values of linear scale and deformation depending on the geodetic latitude- Variant 3

Geodetic Latitude	Linear Scale	Deformation Value
41°53`	1.0001389	0.0001389
42°00`	1.0001026	0.0001026
42°30`	0.9999702	0.0000298
43°00`	0.9998756	0.0001244
43°30`	0.9998189	0.0001811
44°	0.9998	0.0002
44°30`	0.9998189	0.0001811
45°00`	0.9998756	0.0001244
45°30`	0.9999702	0.0000298
46°00`	1.0001026	0.0001026
46°11`	1.0001606	0.0001606

Table 4. Values of linear scale and deformation depending on the geodetic latitude- Variant 4

Geodetic Latitude	Linear Scale	Deformation Value
41°53`	1.000239	0.000239
42°00`	1.0002026	0.0002026
42°30`	1.0000702	0.0000702
43°00`	0.9999756	0.0000244
43°30`	0.9999189	0.0000811
44°	0.9999	0.0001
44°30`	0.9999189	0.0000811
45°00`	0.9999756	0.0000244
45°30`	1.0000702	0.0000702
46°00`	1.0002026	0.0002026
46°11`	1.0002606	0.0002606

In the following tables, values of geodetic latitudes where the deformation value is equal to zero are presented for each variant (Values are calculated based on formula (4), where the unit μ is equal to one):

Table 5. Values of geodetic latitudes without deformation - Variant 1

d=0	°	‘	‘‘
Latitude 1	41	42	28.85761
Latitude 2	46	17	31.14238

Table 6. Values of geodetic latitudes without deformation - Variant 2

d=0	°	‘	‘‘
Latitude 1	42	0	54.42020
Latitude 2	45	59	5.579794

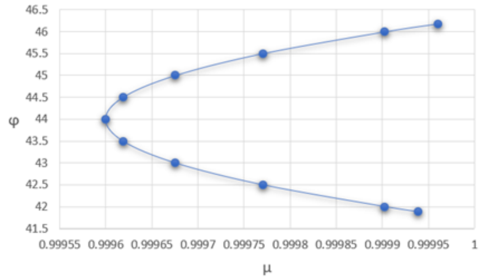
Table 7. Values of geodetic latitudes without deformation - Variant 3

d=0	°	‘	‘‘
Latitude 1	42	22	45.75578
Latitude 2	45	37	14.24421

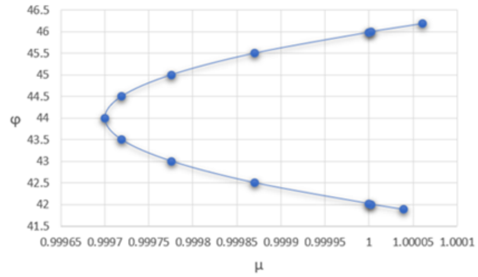
Table 8. Values of geodetic latitudes without deformation - Variant 4

d=0	°	‘	‘‘
Latitude 1	42	51	14.63511
Latitude 2	45	8	45.36488

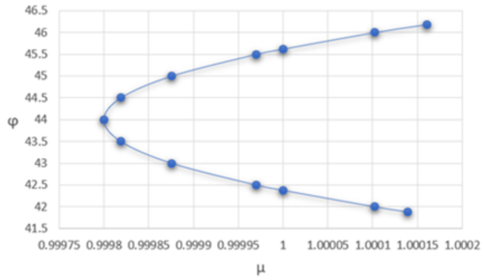
The following graphs represent the relationship between linear scale and the value of geodetic latitude for all four variants:



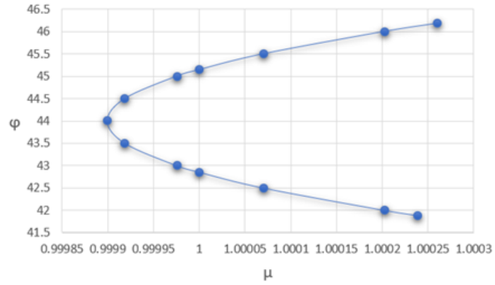
Graph 1: Dependence of linear scale value on geodetic latitude - Variant 1



Graph 2: Dependence of linear scale value on geodetic latitude - Variant 2



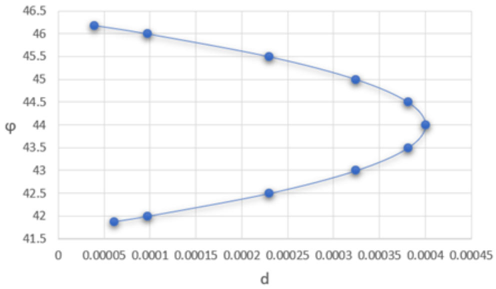
Graph 3: Dependence of linear scale value on geodetic latitude - Variant 3



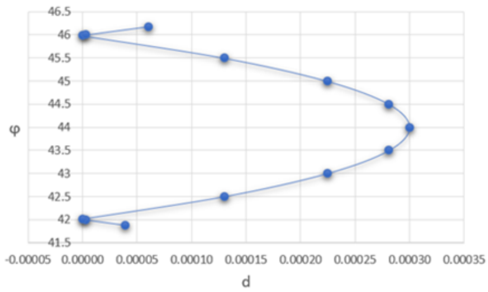
Graph 4: Dependence of linear scale value on geodetic latitude - Variant 4

Figure 5. Dependence of linear scale value on geodetic latitude

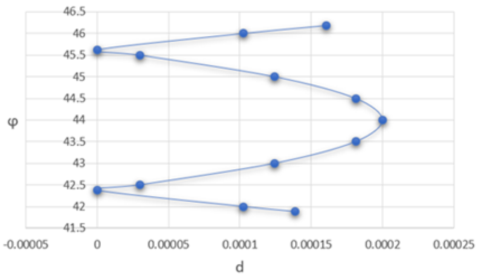
The following graphs show the values of deformations depending on geodetic latitudes:



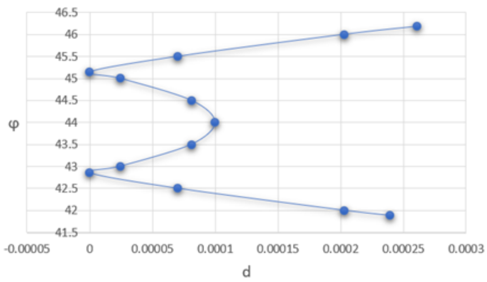
Graph 5: Dependence of deformation values on geodetic latitude - Variant 1



Graph 6: Dependence of deformation values on geodetic latitude - Variant 2



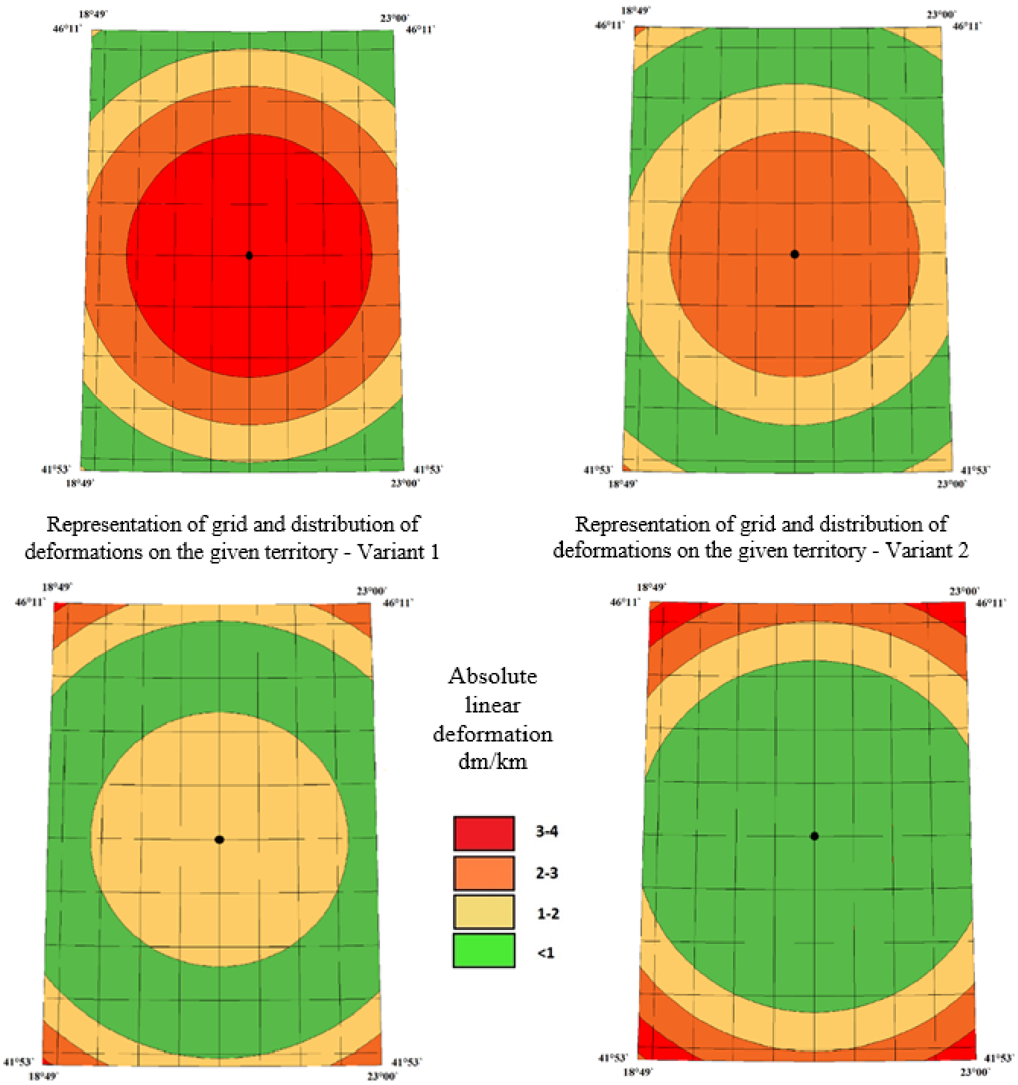
Graph 7: Dependence of deformation values on geodetic latitude - Variant 3



Graph 5: Dependence of deformation values on geodetic latitude - Variant 4

Figure 6. Dependence of deformation values on geodetic latitude

The following images show the generated coordinate grid in the *AutoCAD* environment with a visual representation of deformations for the given territory in all four variants under consideration. Red areas represent regions where the deformation value is between 3 dm/km and 4 dm/km, orange areas represent regions with deformations between 2 dm/km and 3 dm/km, lighter orange areas represent regions with deformations between 1 dm/km and 2 dm/km, while green areas represent regions where the deformation value is less than 1 dm/km.



Representation of grid and distribution of deformations on the given territory - Variant 1

Representation of grid and distribution of deformations on the given territory - Variant 2

Representation of grid and distribution of deformations on the given territory - Variant 3

Representation of grid and distribution of deformations on the given territory - Variant 4

Figure 7. Absolute linear deformation dm/km

4. CONCLUSION

After examining the results presented numerically, in tables, in the form of diagrams, and graphically, certain conclusions can be drawn. When considering the values of linear deformations in all four variants, it can be observed that in the first variant, a larger part of the territory is affected by linear deformations whose value exceeds 2 dm/km, with a large percentage of areas where deformations are even greater than 3 dm/km. In the second variant, deformations between 2 dm/km and 3 dm/km are prevalent in the central part of the territory, with no areas having deformations exceeding 3 dm/km. The values of deformations in the third variant are mostly in the range between 0 dm/km and 2 dm/km, except for border areas where they become larger. In the fourth variant, it is noticeable that the central part of the territory is affected by deformations up to 1 dm/km, while deformations significantly increase towards the border of the territory, reaching values up to 4 dm/km. Depending on the desired accuracy and the allowed maximum value of linear deformations, as well as defining areas of interest within the mapping territory, it is necessary to choose optimal variant of azimuthal projection [10], [11]. Considering the need to ensure conformal mapping where the boundary of linear deformations is defined not to exceed the value of 3 dm/km, with equal importance of the central part of the mapping territory as well as the boundary parts, then the second variant is optimal. Additionally, the second variant is optimal if there is a requirement for linear deformations at the boundary parts of the mapping territory to be minimal, while their maximum value in the central part of the territory does not exceed 3 dm/km. If it is required that linear deformation on the largest part of the mapping territory be less than 1 dm/km, then the fourth variant is optimal, despite significant deformations occurring as one moves away from the central projection point. If the allowed boundary of linear deformations is increased from 1 dm/km to 2 dm/km, so that the largest part of the territory is covered by deformations up to this boundary value, then the third variant is optimal.

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5. APPENDIX 1 - CODE IN JUPYTER NOTEBOOK

```
#loading the necessary modules
from math import *
from konverzijaUglova import *
import numpy as np
#WGS84 ellipsoid parameters
a=6378137
b=6356752.314
e=sqrt((a**2-b**2)/a**2)
cen=DMS2rad([44,0,0])
#calculation of the most suitable value of R
R=a*(1-1/2*e**2*pow(sin(cen),2))
ckonst=0.9997*2*R
#lists with the geodetic latitude and longitude values
fi=[DMS2rad([41,53,0]),DMS2rad([42,0,0]),DMS2rad([42,30,0]),DMS2rad([43,0,0]),DMS2rad([43,30,0]),D
MS2rad([44,0,0]),DMS2rad([44,30,0]),DMS2rad([45,0,0]),DMS2rad([45,30,0]),DMS2rad([46,0,0]),DMS2ra
d([46,11,0])]
fii=[[41,53,0],[42,0,0],[42,30,0],[43,0,0],[43,30,0],[44,0,0],[44,30,0],[45,0,0],[45,30,0],[46,0,0],[46,11,0]]
la=[DMS2rad([18,49,0]),DMS2rad([19,0,0]),DMS2rad([19,30,0]),DMS2rad([20,0,0]),DMS2rad([20,30,0]),D
MS2rad([21,0,0]),DMS2rad([21,30,0]),DMS2rad([22,0,0]),DMS2rad([22,30,0]),DMS2rad([23,0,0])]
laa=[[18,49,0],[19,0,0],[19,30,0],[20,0,0],[20,30,0],[21,0,0],[21,30,0],[22,0,0],[22,30,0],[23,0,0]]
fi_R=[]
fi_R1=[]
#loop for calculating spherical geographic latitudes
for i in range(11):
    fi_l=fi[i]-(1/2)*e**2*pow(sin(fi[i]),2)
    fi_R.append(fi_l)
    fi_R1.append(rad2DMS(fi_l))
lan=la[5]
fin=fi_R[5]
fin1=fi_R[0]
#distances where deformations are equal to zero
rast=2*acos(sqrt(ckonst/(2*R)))
rast1=rad2DMS(cen-rast)
rast2=rad2DMS(rast+cen)
x=[]
y=[]
n=[]
d=[]
fiix=[]
laax=[]
fiip1=[]
#double loop for calculating coordinates of intersection points, linear scale and deformations
for i in range(11):
    fix=fi_R[i]
    fip=fi[i]
    fip1=rad2deg(fip)
    for j in range(10):
        lax=la[j]
        xix=(2*R*0.9997*(sin(fix)*cos(fin1)-cos(fix)*sin(fin1)*cos(lax-
lan)))/(1+sin(fix)*sin(fin1)+cos(fix)*cos(fin1)*cos(lax-lan))
        yix=(2*R*0.9997*cos(fix)*sin(lax-lan))/(1+sin(fix)*sin(fin1)+cos(fix)*cos(fin1)*cos(lax-lan))
        nix=0.9997/(pow(cos((((fin-fix)))/2),2))
        dix=abs(1-nix)
        x.append(xix)
        y.append(yix)
        n.append(nix)
        d.append(dix)
        fiip1.append(fip1)
        fiix.append(rad2deg(fix))
        laax.append(rad2deg(lax))
tabela1 = np.column_stack(( fiix,laax,n,d))
np.savetxt('rezultati.csv', tabela1, delimiter=',', fmt='%.7f')

#code in the imported module konverzijaUglova
```

```
import math
def DMS2deg(ugaoDMS):
    ugaoDeg = ugaoDMS[0]+(ugaoDMS[1]/60)+(ugaoDMS[2]/3600)
    return (ugaoDeg)
def DMS2rad(ugaoDMS):
    ugaoRad = math.radians(ugaoDMS[0]+(ugaoDMS[1]/60)+(ugaoDMS[2]/3600))
    return (ugaoRad)
def deg2DMS(ugaoDeg):
    negative = ugaoDeg < 0
    dd = abs(ugaoDeg)
    minutes,seconds = divmod(dd*3600,60)
    degrees,minutes = divmod(minutes,60)
    if negative:
        if degrees > 0:
            degrees = -degrees
        elif minutes > 0:
            minutes = -minutes
        else:
            seconds = -seconds
    return [int(degrees), int(minutes), seconds]
def rad2deg(ugaoRad):
    return math.degrees(ugaoRad)
def rad2DMS(ugaoRad):
    ugaoDMS = deg2DMS(rad2deg(ugaoRad))
    return (ugaoDMS)
```

57
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DETECTION OF DISTRICT HEATING PIPELINE USING UAV-MOUNTED THERMAL CAMERA AND GPR SCANNING

Abstract

In this paper the benefits of integration of UAV-mounted (Unmanned Aerial Vehicle) thermal camera and GPR (Ground Penetrating Radar) are analysed. As an example we analized a district heating pipeline in a part of university campus in Novi Sad. Thermal camera mounted on UAV enables fast mapping of routes. These data are then used to detect critical zones where leaking or some other problem occurs and to validate utility cadastral data. Detailed inspection of zones is done using GPR scanning. This provides data such as geometry, precise location of damage, etc. In the last section of the paper advantages of non-invasive detection of district heat line combining active and passive sensors with UAV are explained.

Keywords: GPR, thermal camera, UAV, district heating pipeline, mapping

ДЕТЕКЦИЈА ТРАСЕ ТОПЛОВОДА КОРИШЋЕЊЕМ ТЕРМАЛНЕ КАМЕРЕ НА БЕСПИЛОТНОЈ ЛЕТЈЕЛИЦИ И СКЕНИРАЊЕМ ГЕОРАДАРОМ

Сажетак

У овом раду анализиране су предности интеграције снимања термалном камером постављеном на беспилотну летјелицу и технологије скенирања георадаром. Као примјер за анализу узет је дио трасе топловода у кампусу Универзитета у Новом Саду. Термална камера на беспилотној летјелици омогућава брзо мапирање трасе. Ти подаци се потом користе за одређивање критичних зона или за провјеру валидности катастарских података. Детаљна претрага зона се изводи скенирањем георадаром. На тај начин се долази до информација о геоетрији, тачној локацији оштећења итд. У посљедњем дијелу рада објашњене су предности детекције коришћењем беспилотних летјелица са активним и пасивним сензорима.

Кључне ријечи: георадар, термална камера, беспилотна летјелица, топловод, мапирање

1. INTRODUCTION

District heating networks function by circulating heat through underground pipes containing hot water or steam from a central power plant. Common issues include heat loss due to damaged insulation or media leakage from cracks, exacerbated by the aging of pipes, some of which have been in use for decades in certain cities. The loss of media or energy is not only costly but also environmentally detrimental [1, 2]. Modern remote sensing technologies are more and more applied for fast and efficient detection of underground infrastructure. Their main advantage is that, unlike usual detection methods, they cannot cause damage to underground objects. Also, they have an important role in creating, updating and maintaining of the utility cadastre. Due to its wide area of applications, Ground Penetrating Radar (GPR) is the leading Non-Destructive technology (NDT) for underground utility detection [3-5]. Contemporary methods for non-intrusive examination and evaluation (NDT) of district heating pipelines fall into two main categories: technologies aimed at detecting and analyzing the geometric features of the pipelines, such as Ground Penetrating Radar (GPR), thermal cameras, and electromagnetic locators (EML); and technologies focused on analyzing the condition of the pipelines, including thermal cameras, ultrasound methods, leakage detection systems, and monitoring systems for pipeline flow and pressure [6-8].

In this paper we are analyzing the advantages of integrated system for district heating line detection. Data obtained with GPR and UAV-mounted thermal camera are combined. Thermal camera provides fast localization of heating lines and identification of zones with possible damage. This method involves generating a georeferenced image where pixel colors denote temperature. Establishing the position model of the district heating pipeline network entails identifying pixels along the route with higher temperatures compared to those outside the route, while considering all relevant constraints [6]. In the papers [9] and [10] authors have explored ground thermography using handheld cameras. In comparison to aerial thermography, this method has several drawbacks, such as limited access to many areas of interest and reduced scalability. Aerial thermography for locating heating pipelines involves generating a georeferenced image where pixel colors denote temperature. Establishing the position model of the district heating pipeline network entails identifying pixels along the route with higher temperatures compared to those outside the route, while considering all relevant constraints. On the other hand, GPR is used to check the localization and to obtain additional data on heating lines, such as depth, radius or dimensions of concrete channel or earthen trench [11]. Main advantages of integrated system are:

- Fast and efficient acquisition, with relatively low costs
- Easier identification of district heating infrastructure
- Prevention and detection of damages
- Automated data extraction

2. TEST AREA

Zone within the University campus in Novi Sad, in front of the building of Scientific-Technology Park is chosen to be the test area (Fig. 1). Part of district heating line route lies in this area, in Veljka Petrovica and dr Ilije Djuricica streets. This part of the network involves heating pipelines of different diameters, with many turns and pipe joinings, and this complexity makes it a good example for procedure examination.

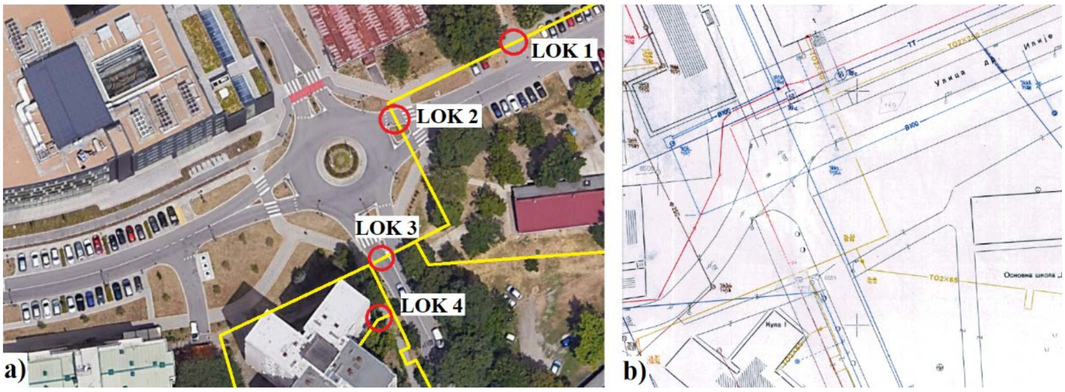

Figure 1. Test area with marked locations of GPR scanning

Test locations are shown in Fig. 1 and numerated with 1 to 4. They are selected with the aim of having all important elements of district heating network, such as deviations, junctions, heat compensators. Convenience for GPR scanning is important as well. Along with locations, approximate routes of heating lines are represented in Fig. 1. These routes are drawn based on existing records in cadastral maps. In this paper utility cadastral data are important since they are used as the initial information on the heating network in the survey zone and as a data that results can be compared to.

3. SENSORS

GPR scanning and UAV-mounted thermal camera are used for data acquisition (Fig. 2).

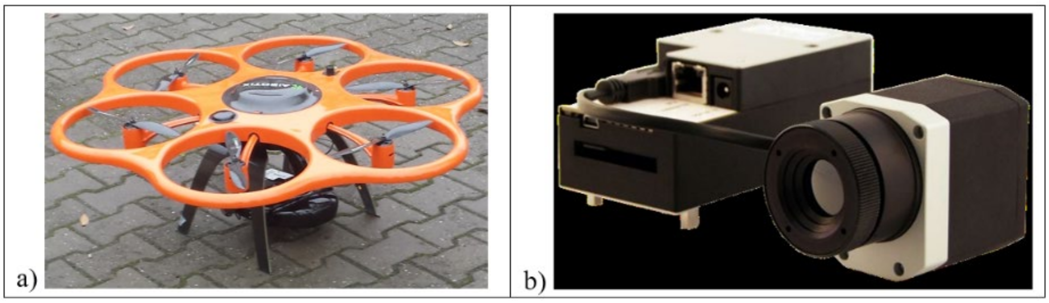

Figure 2. Unmanned Aerial Vehicle (a) and thermal camera (b)

Specification of Aibot X6 UAV and PI400LW are given in following table.

Table 1. UAV „Aibot X6“ and thermal camera „PI400LW“ specification

UAV - Aibot X6 [12, 13]		Thermal camera - PI 400 LW	
Length/Width	1.05m	Detector	UFPA, 382x288 pixels
Weight	3.4kg	Spectral range	7.5...13μm
Max. payload	2kg	Temperature ranges	-20...100°C, 0...250°C, 120...900°C
Max. speed	up to 50km/h	System accuracy	- ±2°C do ±2%
Climbing speed	8m/s		
Max. height	1000m		
Flight duration	30min		
Operating temperature	-20°C do 40°C		

Since maximum payload of UAV is 2kg various sensors can be mounted, such as digital camera, thermal or multispectral camera, which widens the area of application.

Information on the depth of heating pipes or the cover of concrete channel cannot be obtained using thermal camera and therefore GPR scanning is used. In this survey we used GSSI SIR3000 control unit and antenna with 200MHz central frequency (Fig. 3).

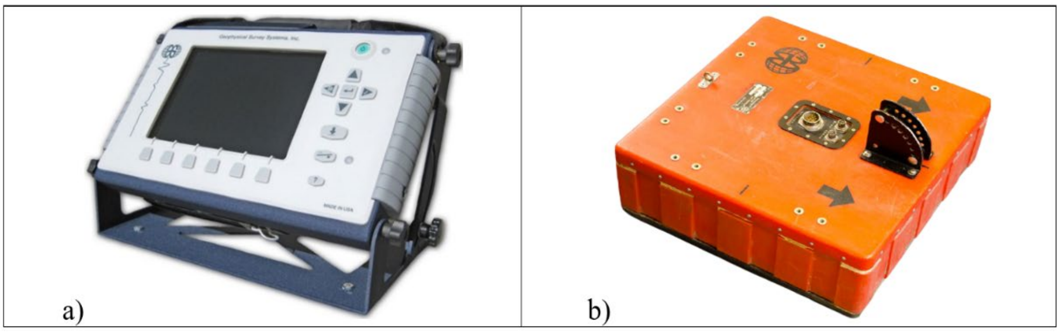

Figure 3. GPR control unit GSSI SIR3000 (a) and GPR antenna of central frequency 200MHz (b)

4. METHODOLOGY

In the first phase a fast localization of existing district heating pipeline is done using thermal camera records. Data acquisition was done during winter time when small differences in temeprature of surface above the heating line and surrounding soil could be recorded. Also, these data are used to detect potential damage zones, differences between actual route and the one in cadastral maps and to recognize the parts with and without concrete channel.

Second phase of survey involved GPR scanning to acquire additional data such as depth and dimensions of concrete channel or earthen trench. Scanning is done on locations suitable for GPR. Acquired data are then analysed using different strategies for automated processing [14-19]. Application of these methods is possible since district heating pipes are installed in specific way (two pipes in concrete channel or earthen trench) which have a signature reflection in a radargram. In case of earthen trench there are two intersecting hyperbolic reflections with constant mutual distance along the entire route. There are algorithms that use these reflections to automatically assess pipe's radius [14, 20, 21]. In case of concrete channel reflections from the cover and sidewalls can be seen in the radargram and then standard dimensions of the channel are used to estimate pipes' diameters [11].

5. RESULTS

Results of integrated application of mentioned NDT technologies show that in only 10 minutes of flight over 50000m2 area it is possible to detect and georeference the route of district heating pipeline. To examine each location using GPR 5 minutes on average is sufficient. Data from thermal camera are then used to generate raster maps of test area with the colour of each pixel corresponded to relative temperature. The difference between temperatures above the heating pipeline and surrounding soil is up to 4˚C. Besides, preinsulated heating pipes placed in concrete channel are successfully detected. GPR scanning provided additional information:

- Heating pipes are placed in concrete channel on entire route of the pipeline
- Depth of the concrete cover is between 20 and 30cm
- Two different widths of concrete cover are detected, 130-140cm (1) and 75-80cm (2).

Survey results are shown in following figures (Fig. 4 – Fig.7). Four representative images from thermal camera are selected (on left-hand side of the figure) as well as four radargrams collected using GPR (right-hand side of the figure). Black arrows indicate location and direction of GPR scanning.

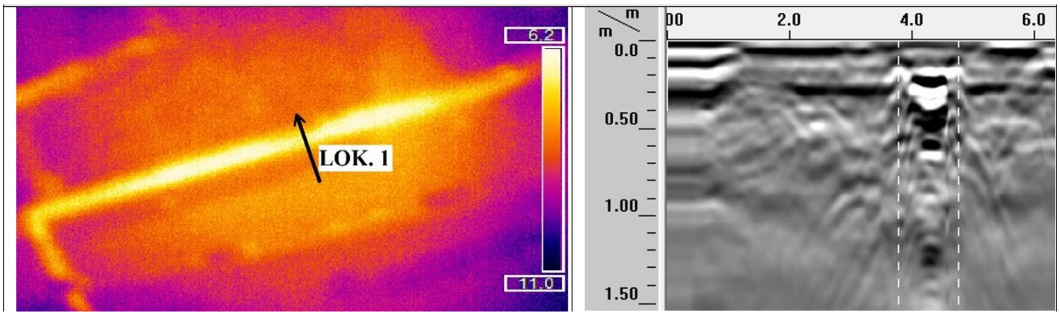

Figure 4. Thermal image and radargram obtained on test location 1

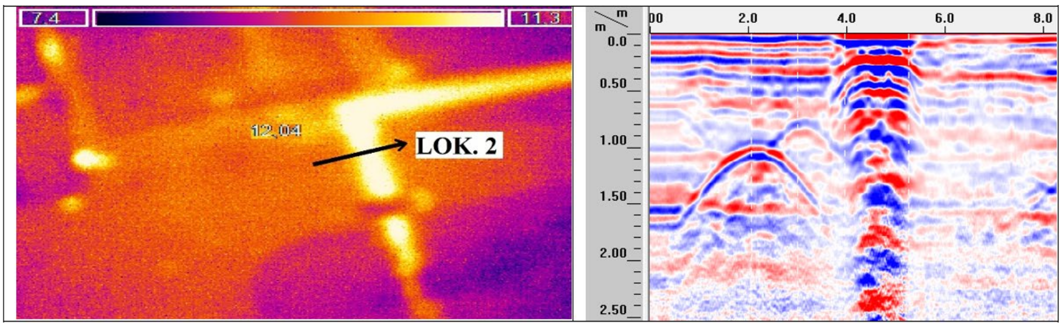

Figure 5. Thermal image and radargram obtained on test location 2

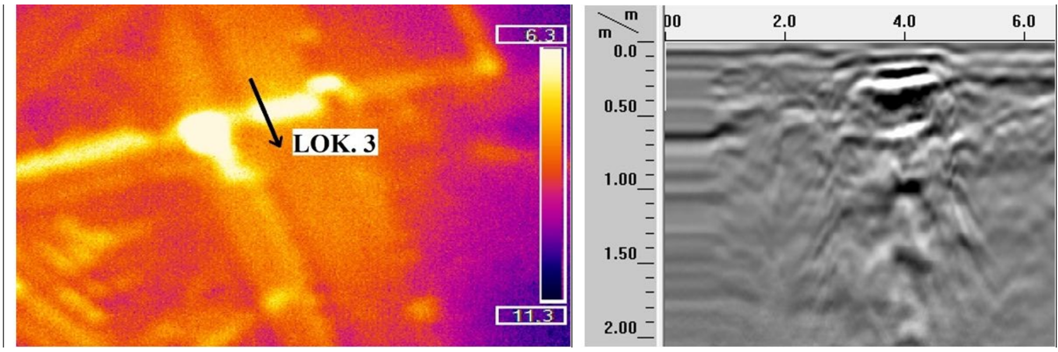

Figure 6. Thermal image and radargram obtained on test location 3

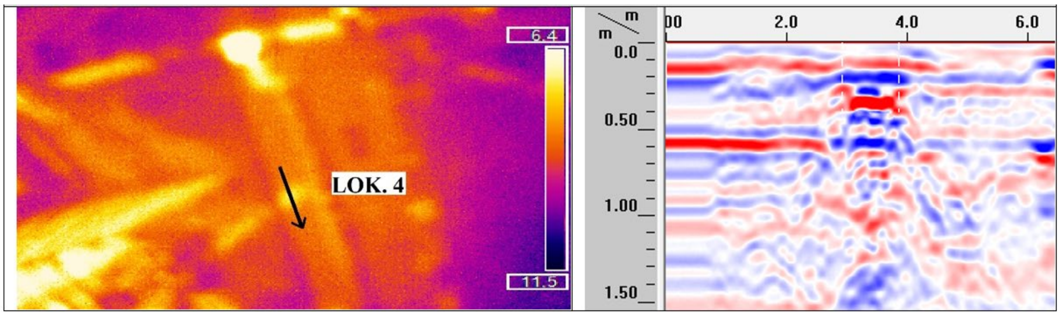

Figure 7. Thermal image and radargram obtained on test location 4

First test location is on straight part of heating pipeline route. The pipes are beneath the sidewalk and GPR scanning can be performed with no obstacles. Data from thermal camera show that there are no significant temperature variations on examined part of the route. Heating district heating route can be clearly distinguished from surrounding soil and corresponds to cadastral data. In radargram obtained by GPR scanning a concrete channel cover can be seen. It is approximately 130-140cm wide and at 20cm depth. Based on these information it is concluded that the pipes have standard diameter of 250mm.

Second location is in line with the first one at the point where the route changes direction. Data from thermal camera show that the direction chance corresponds to cadastral data. Big change in temperature is a consequence of a car parked just above the heating pipe. GPR scanning is done on paved sidewalk. In radargram at distances of 2.1m and 3.1m and at depths of 1 and 0.80m two hyperbolic reflections can be seen. Since they are not in pair, i.e. they are at different depths, they do not indicate a heating pipeline. At di distance of approximately 4-5.4m there is a reflection at 20cm depth, originated from concrete channel containing heating pipes. Estimated width of the cover is 1.3m-1.4m which indicates that pipes' diameter is 250mm.

Data from location 3 show higher values of temperature on the route which corresponds to cadastral data. Highest value is on the part of the route in the vicinity of a manhole on a sidewalk. In this manhole route splits into two directions. Part that continues along the Veljka Petrovića street shows lower temperature which indicates that pipes' diameter may be smaller. Along the second direction the temperature retains almost same value, which indicates that diameter is the same as before the split. These findings are confirmed in GPR data, since in radargram from this location a reflection at 30cm depth (distance 3.1-4.4m) can be clearly seen. According to data pipes on location 3 are 250mm in diameter and placed in the concrete channel.

Fourth location is on the part of the route with smaller diameter pipes, after the aforementioned split. Here the temperature has lower value and detected route does not correspond to cadastral data. Lower values of temperature indicate that the pipes' diameter is smaller. Confirmation for this can be found in GPR data. At depth of 30cm, a reflection of the concrete channel approximately 90cm wide can be seen. Based on these data it is estimated that the pipes' diameter is 60mm or 80mm.

6. CONCLUSION

Research results presented in this paper show that using both UAV-mounted thermal camera and GPR it is possible to perform fast, reliable and high-quality inspection of district heating pipeline.

Thermal images provided detection of heating pipeline route in time-efficient manner. These data enabled the comparison with cadastral data (to detect the mismatch between the actual route and the route mapped in cadastre), as well as detection of locations where the heat is dissipated. This also reduced the zone of GPR scanning. Additional data such as pipeline depth are provided by GPR. In case of pipes in earthen trench, radius estimation is done based on the shape of hyperbolic reflection. If heating pipes are placed in concrete channel diameter is estimated based on the width of the channel and standardized pipes' dimensions for given channel with. At each test location the width of the channel is done successfully.

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58
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GEOMATIC DATA FOR TREATMENT OF HISTORIC BRIDGES. THE CASE STUDY OF THE RIBNICA BRIDGE IN PODGORICA, MONTENEGRO

Abstract

Stone bridges, all around Europe stand as enduring testaments to engineering mastery, cultural heritage, and historical continuity. They served as crucial infrastructural lifelines, connecting communities and fostering trade routes. Their enduring presence symbolizes the craftsmanship and innovation of their eras, reflecting diverse regional styles and technological advancements. Geometric documentation of a stone bridge provides critical insights into its structural integrity, aiding in preservation efforts. Accurate data obtained through geomatic techniques ensures informed conservation decisions, safeguarding the bridge's historical significance for future generations. This paper focuses on the geometric documentation of the Ribnica Bridge in Podgorica, Montenegro.

Keywords: cultural heritage, stone bridges, geo-spatial methods, technical documentation, terrestrial laser scanner, structural integrity

ГЕОДЕТСКИ ПОДАЦИ ЗА ТРЕТМАН ИСТОРИЈСКИХ МОСТОВА. СТУДИЈА СЛУЧАЈА МОСТА НА РИЈЕЦИ РИБНИЦА У ПОДГОРИЦИ, ЦРНА ГОРА

Сажетак

Камени мостови широм Европе представљају трајни доказ инжењерског мајсторства, културног насљеђа и историјског континуитета. Они су служили као кључне инфраструктурне линије спаса, повезујући заједнице и подстичући трговачке путеве. Њихово трајно присуство симболизује занатско умјеће и иновације њихових епоха, одражавајући различите регионалне стилове и технолошки напредак. Геометријска документација таквог каменог моста пружа критичан увид у његов структурални интегритет, помажући у напорима за очување. Тачни подаци добијени геодетским техникама осигуравају информисане одлуке о очувању, чувајући историјски значај моста за будуће генерације. Овај рад се фокусира на геометријску документацију моста на ријеци Рибници у Подгорици, Црна Гора.

Кључне ријечи: градитељско насљеђе, гео-просторне методе, техничка документација, интегритет конструкције

1. INTRODUCTION

In pre-industrial Balkans, the main building material was stone, and one of the most significant issues that concerned the residents, especially in the mainland and less so in the island areas, was the safe passage of pedestrians and transportation means over rivers, streams, and torrents.

Until the 20th century, the only feasible and functional engineering work that the skilled craftsmen of that era could construct to address the transportation problem that affected not only themselves but all their fellow citizens was a stone bridge, either single-arched like the one in Konitsa (fig. 1a) or multi-arched like the one in Arta (fig. 1b).

Figure 1. a) The single-arched stone bridge of Konitsa (https://www.allovergreece.com) b) The multi-arched stone bridge of Arta (https://discoverarta.gr/)

The construction work was so significant that it led to the creation of related songs, traditions, and legends that even referred to human sacrifices to solidify the coveted bridge. However, the construction of such bridges has ceased since 1940, and this complex art has already faded into oblivion, so today there is not a single "bridge builder" or "kioproulis," as the popular and almost always illiterate bridge builder was typically called. Stone arched constructions have been characterized by specialized scientists as one of the greatest discoveries in architecture for pre-industrial humanity and as the first major milestone in the evolutionary path of global bridge construction.

Stone bridges across Europe encapsulate a rich tapestry of history, engineering excellence, and cultural significance. These structures, often centuries-old, crafted with meticulous precision and enduring craftsmanship, serving as vital links connecting communities, trade routes and civilizations.

The importance of stone bridges in Europe is multifaceted, encompassing their pivotal role in transportation, their architectural splendor, and their symbolic resonance within the collective consciousness of diverse societies. Historically, these bridges acted as lifelines, fostering economic growth by facilitating the movement of goods, people, and ideas across regions. Their strategic placements over rivers and valleys were fundamental in expanding trade networks, enhancing commerce, and consolidating cultural exchange throughout the continent.

Beyond their utilitarian function, stone bridges embody architectural excellence and engineering ingenuity. They stand as enduring testaments to the mastery of ancient builders, showcasing diverse styles, techniques, and artistic flourishes reflective of their respective epochs. The construction of these bridges required immense skill, utilizing local materials and specialized knowledge passed down through generations. Their enduring presence serves as a testament to human innovation, withstanding the test of time and natural elements.

Moreover, stone bridges hold profound cultural and symbolic significance. They serve as landmarks, anchoring cities and towns, and often becoming iconic symbols of regional identity. Many of these bridges are steeped in folklore, legends, and historical events, enriching the collective heritage of the communities they serve. Their arches, spandrels and intricate designs narrate stories of societal evolution, technological advancements, and the resilience of human creativity.

Through the years stone bridges have suffered physical phenomena and disasters, like earthquakes, strong winds, snow and last but not least, the continuous flow of the water.

While all of them are a particular kind of cultural heritage and tourist attractions, some of them are still used as a way of crossing the river on which they are built. So, their geometric documentation is necessary not only for preservation and restoration reasons but also to ensure the stability of the construction and the safety of the people who use it.

In this paper, the procedure for documenting the Ribnica Bridge in Podgorica, Montenegro is presented. It’s a typical Balkan stone bridge with a history of centuries and historical and architectural value, which is fully operated till today.

The paper focuses on the geometric documentation of the of the bridge, carried out with geodetic methods, while it also attempts the overall recognition of the monument, based on the perspective of revealing, saving, and exploiting this unique historical monument of Podgorica.

Going a bit further a 3d structural model of the bridge is created and tested for its integrity to various types of loads.

The rest of the paper is organized as follows; Section 2 explains the importance of geometric documentation of stone bridges, records the various methods and techniques for documenting a stone bridge and numbers some characteristic examples of similar documentations. Section 3 the methodology of the specific case study is described. The data field operations, the equipment and the process of the data for the development of the 3d model and the integrity tests are explained thoroughly. Finally, Section 4 discusses practical application of produced results, and provides the concluding remarks.

2. BACKGROUND

Preservation and documentation of these stone bridges are imperative to safeguard their historical, architectural, and cultural value. Geometric documentation plays a pivotal role in this endeavor. Reliable planning for the conservation and prevention of damage to historic stone bridge structures requires theoretical and experimental research that includes the problems of the historic stone structure in terms of mineralogical and petrographic aspects, the problems of chemical and biochemical degradation processes and the effect of these processes on the properties of the building materials and the life of the historic structure as a whole [1]. Accurate measurement and detailed mapping through geomatic techniques enable comprehensive understanding of these structures. Laser scanning, photogrammetry and other advanced methods provide precise geometric data, aiding in assessing their condition, identifying potential vulnerabilities, and formulating conservation strategies [2].

Furthermore, geometric documentation ensures that the intricate architectural details and structural complexities of these bridges are preserved digitally, allowing for meticulous reconstruction or restoration in case of damage or decay. This documentation not only serves as a blueprint for maintenance but also facilitates scholarly research, educational outreach, and public appreciation, fostering a deeper understanding of these historical treasures, like the two stone bridges in Plaka, Greece and Stari Most of Mostar, Bosnia & Herzegovina [3].

Stone bridges are exposed to conditions, like the river flow, strong winds and natural disasters. The evaluation of their integrity can show weaknesses, prevent their collapse and implement possible repairs or reinforcements.

Their structural vulnerability assessment is a pivotal part of a risk mitigation strategy for preserving them. The development of digital twins has gained much attention lately to provide an accurate digital model for performing finite element (FE) analyses [4].

After their modeling, finite elements analysis, is a method that has been used on several occasions, not only in Balkans, like the stone bridges of Ivanjica, Serbia [5] and Pasha bridge, Greece [6], but all around the world [7, 8]. Going a bit further, apart from finite element method, there have been proposed and compared more methods for the structural analysis of a stone bridge. Some of them are described in a case study of the stone bridge of Cernadela, Spain [9].

Moreover, some of them are still in use not only by people but also by cars, like the famous Roman bridge of Alcantara, Spain [10]. So, their frequent assessment of structural integrity is vital for ensuring public safety too.

3. CASE STUDY – RIBNICA BRIDGE

3.1. HISTORICAL AND GEOGRAPHICAL DATA

Ribnica Bridge or Adži-paša Bridge is in Podgorica, Montenegro. Podgorica, the capital and the largest city of Montenegro is located at the south part of the country. The city is just north of Lake Skadar and close to coastal destinations on the Adriatic Sea. Historically, it was Podgorica's position at the confluence of the Ribnica and Morača rivers and at the meeting-point of the fertile Zeta Plain and Bjelopavlići Valley that encouraged settlement. The surrounding landscape is predominantly mountainous terrain.

In the area around the confluence of Ribnica and Morač, during the reign of the Romans in this area, there was the city of Birziminium. It was the trade center of the province of Prevalis, through which the caravan route passed.

The oldest bridge in Podgorica is considered to be the stone bridge on Ribnica, on today's Skaline, which is believed to date back to the Roman period.

This bridge is one of the rare remnants of the former Roman city, which was apparently almost completely destroyed in the catastrophic earthquake that struck this area in 618 AD.

The people of Podgorica call this bridge “Most na Sastavci”, because the area around the delta of Ribnica in Morač was called Sastavci.

The bridge was rebuilt sometime in the first half of the 18th century by Adži Pasha Osmanagić, so this bridge is also known as Adži Pasha's Bridge [11].

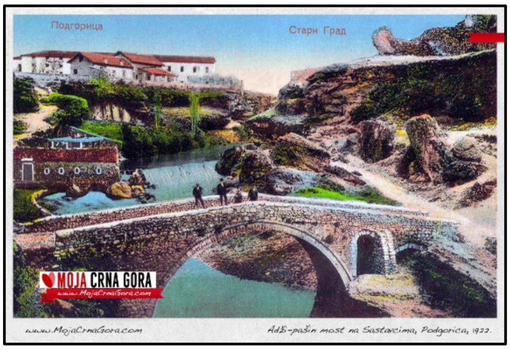
In figures 1a – 1d and 2, one can see the bridge in 100 years’ time span (1922-2022).

The locals call it "the stone bridge of Ribnica" and the area surrounding it is a notable townscape for them, who also refer to it as Skaline or Skalimost since about the 1950s, meaning "staircase", because of the steps built from the bridge to the fort next to it.

It belongs to the category of arched stone bridges and has a single arch and two relief arches.

Architectural heritage is one of the most important contents of the cultural heritage of Montenegro. Old stone bridges are a recognizable segment of that heritage. They bear witness to the historical duration of the community [12].

Podgorica is a city of rivers, so it is undoubtedly also a city of bridges. Numerous bridges connect the banks of the Morača, Ribnica, Mareza, Cijevna and Zeta rivers. However, one stands out. It is in the heart of Podgorica and has preserved traces of history for centuries. It is the bridge on Sastavci, popularly known as Hadji Pasha's bridge [13].





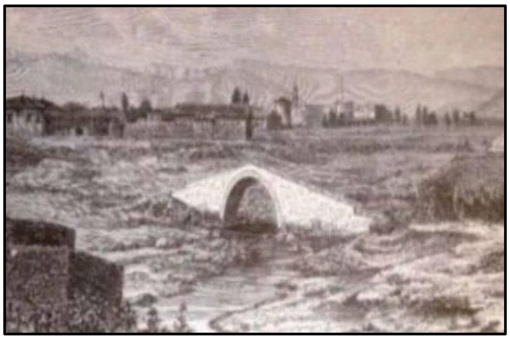


Figure 2. a) View of the bridge from 1922 (http://www.mojacrnagora.com/) b) View of the bridge [12] c) View of the bridge [12] d) View of the bridge [16]

Figure 3. View of the bridge (authors, 2022)

The bridge at Sastavci - over the river Ribnica, just before its confluence with the Morača - is the oldest bridge in Podgorica. The layout of the bridge, i.e. its vertical projection and width, indicate that it is an asymmetric bridge structure that spans the Ribnica river, and is dominated by the main opening of 10.8 m. Two smaller openings are located towards the right abutment of the bridge. Dimensionally, the opening with a width of 1.18 mm, which is located next to the arch of the bridge, is more conspicuous [14]. Facilitating openings served for greater water flow, when the high waters of Ribnica and Morača (autumn-spring) would rise due to heavy rainfall, often turning the Sastavci zone into a real lake (fig. 4a, 4b). The total length of the bridge is approx. 25m.

Figure 4. a) Passing Ribnica bridge in a boat b) Ribnica bridge flooded on 27/2/2023 (authors)

Historical sources and literary data primarily indicate that the bridge is a creation of bridge construction of the Middle Ages [15]. It was restored in the first half of the 17th century by Hafiz Pasha Osmanagić, who also built the Clock Tower in Podgorica. [16]. However, there are indications that the bridge was built on the foundations of earlier structures, especially from the Roman period. It is assumed that the bridge is one of the rare remnants of the former Roman city that was situated in this location. The bridge is built of stone and paved with river pebbles.

The bridge was rebuilt and restored after World War II. Today, the people of Podgorica especially love the bridge, it is a distinguishable place that is integrated into the modern urban settings of the city and the arrangement of the Morača and Ribnica riverbeds.

The capital city of Podgorica (1441 km2) is in the southeast of Montenegro and belongs to the largest part of the Podgorica-Skadar basin. The altitude is in the range of 4.6 masl (minimum level of Lake Skadar) and 2487 masl (Kučki Kom). The very center of the Podgorica city center is about 52 meters above sea level. Podgorica is the central settlement of the Zeta plain, and since 1946 it has been the capital of Montenegro. It is characterized by a diverse climate - from sub- Mediterranean to high mountain. The geospatial base of Podgorica is located between two seas (the Adriatic Sea and the Black Sea) and three large river basins (the Morača, Tara and Lim watercourses). It is well connected by traffic with all urban settlements in Montenegro and the immediate surroundings [17].

The terrains of the Capital City of Podgorica mostly belong to the regional geotectonic unit of Visoko karst, and to a very small extent, to the geotectonic unit of Durmitor thrust fault.

The geological structure and geomorphological characteristics have determined the hydrogeological characteristics of the terrain, which in time alternate and overlap in intensity with geomorphological phenomena. The terrains in question are made up of rock masses characterized by effective supercapillary intergranular porosity. These are terrains that are also built up by quaternary granular fluvioglacial, alluvial, glacial and deluvial sediments. Subterranear waters are present in them in the form of compacted outcrops [17].

The bridge on Sastavci - over the river Ribnica, which springs from Vrela Ribnička below Kakaricka Gora (Vojna 199 masl, Bojčin 235 masl), runs its entire length through Ćemovsko polje, to the mouth of Morača, flows almost through the very center of the city, its bed is located in the zone of fluvioglacial sediments of the so-called II terrace. Terrace sections in the Ribnica bed can be clearly seen. Its course is about 10 km long. Its water level is directly dependent on the variable yield of the spring and Ribnica almost dries up in the summer months. [17, 18].

Subterranear waters from the terrain of the Capital City are drained towards the main erosion bases. The main erosion base is Lake Skadar with its tributaries, i.e. the main tributary which is the Morača River. The speeds and directions of subterranear waters movement in the area of the Capital City of Podgorica are highly variable and depend on the hydrogeological and geomorphological characteristics of the terrain and the climatic characteristics of the region. All the waters of the Capital City flow into the erosion bases of Lake Skadar with the Zeta plain and watercourses that flow over the terrain of those basesBased on the determination of underground connections in the karst terrain of the Capital City, it was found out that these velocities are very variable and range from 1 to 11 cm/s. In summary, the intergranular rock masses of the Zeta Plain have a filtration coefficient Kf=1x10-1 do 1x10-3 cm/s [19].

Everything mentioned above about the composition, structure and features of the terrain is of influence - it conditions the engineering-geological features of the terrain. Terrains built from unbound sediments on flat or slopes below 5o if they are further away from the action of water are stable. The bearing capacity of such terrains depends on the granulometric and mineralogical petrographic composition, the degree of sorting and settlement of the sediments, the presence of occasional or permanent water, etc. For these reasons, it is necessary to define each location or stretch in terms of bearing capacity, as it is generally significantly low (below the bearing capacity of the terrain built from well-bound petrified rocks) and rarely exceeds2-3 kg/cm2. Large bearing capacity can be terraces of glaciofluvial sediments, with a deeper level of subterranear waters and further from watercourses, such as larger parts of the Zeta plain above 15 masl [19]. Historical and instrumental records show that the area of the Zeta-Skadar depression was shaken by harmful and destructive earthquakes from its own hotspots and from neighboring hotspots, and so the terrain of the Capital City Podgorica is shaken as well The most recent document that investigated the seismicity of these areas is the „Proučavanje seizmičnosti balkanskog regiona“ ("Study of the seismicity of the Balkan region") as part of an international project UNDP/UNESCO. According to the aforementioned research, it was shown that the maximum intensities of earthquakes in the Zeta depression were from VIII units of the MCS scale. This is confirmed by earlier research and studies after the Skopje earthquake (1963), and especially after the Montenegrin earthquake (1979). In addition to all this, it is known that the old Roman city of Duklja was destroyed in the 6th century by an earthquake which, based on circumstantial evidence (the degree of destruction of buildings), is estimated to have an intensity of 90 MCS [20].

3.2. MEASUREMENTS AND DATA PROCESSING

Geometric documentation of stone bridges presents several challenges owing to the intricate nature of these structures. The irregular surfaces, intricate details, and varying textures of aged stone pose difficulties during the measurement process. Moreover, a big part of the documentation concerns the lower part of the bridge which stands on the shore of the river. In Ribnica river, the water has continuous flow (Fig. 4), which made the procedure even more difficult. In this work, the terrestrial laser scanner of Leica Geosystems BLK360-G1 was implemented.

Leica BLK360-G1 is a terrestrial laser scanner with integrated spherical imaging system and thermography panorama sensor system. It is easy to use (one-button operation) with an accuracy of 6mm at 10m range of scan. It scans up to 360,000 points per second in a range of 60m, having a field of view of 360^{o} horizontal and 300^{o} vertical. The points can be downloaded to a pc through type-C port or Wi-Fi [21].

Figure 5. Ribnica bridge during scanning process (authors)

All scans were performed with a 4 mm step and the distance between the object and the scanner was always less than 20m. The percentage of the scan overlap ranged from 40% to 70%. (fig. 5)

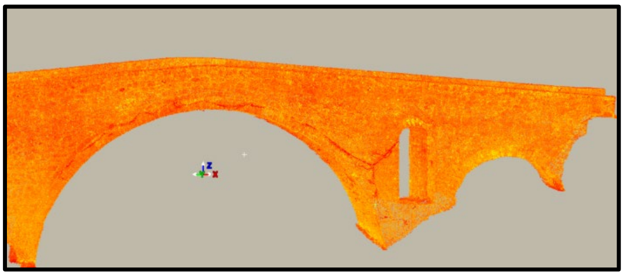


Figure 6. Snapshot of the scanning process (left) and example of a pointcloud output (right).

In total 13 setups were made, so that the whole bridge would be covered with the aforementioned overlap (fig. 7a, 7b). Moreover, 18 black and white targets were used as tie points.

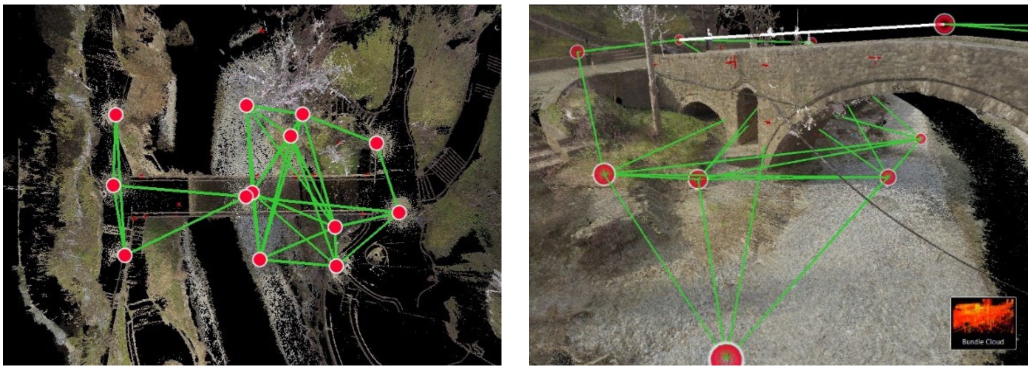


Figure 7. a) Setup distribution (plan view) b) Setup distribution perspective view

The process of the point clouds conducted in the Leica Cyclone Register 360 and Leica Geosystems Cyclone environment [19]. The alignment of the individual scans was performed using tie points in an independent reference system. From the 13 setups, 29 links were created using common points from adjacent setups. As a whole the point cloud was aligned with a mean square error (RMS) of 7mm, an average overlap of 53% and strength of the total model of 77%, consisting of more than 427 million points (fig. 8)

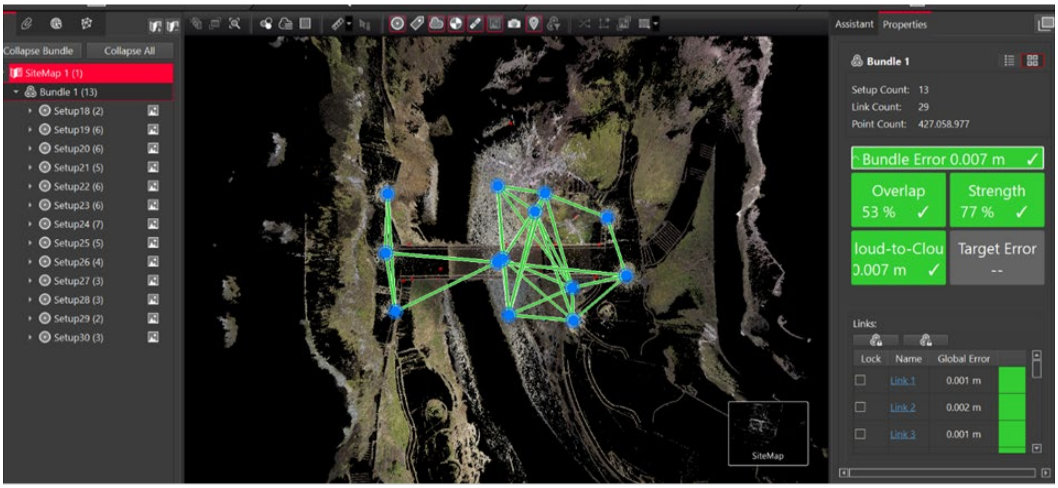


Figure 8. The links between the setups and the final results from the point cloud alignment

The point cloud was cleaned from noise (e.g. vegetation, obstacles etc.) and inserted in the Leica 3DR software for further processing and modeling. The cleaning of the point cloud is an essential procedure for all similar application. Keeping only the information that concerns the construction itself, reduces the final size of the file and makes the modelling more precise. The final 3D model is given RGB colors derived from the pictures than were taken from the laser scanner during the scanning process (fig. 9a, 9b, 9c)

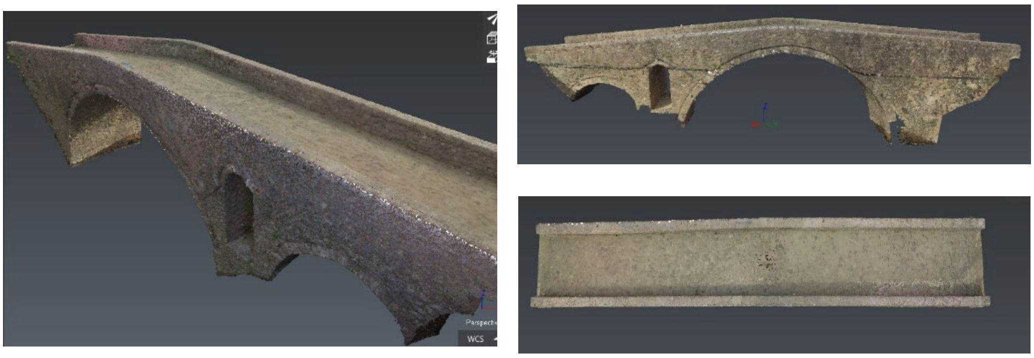


Figure 9. a) Perspective view of the model b) c). Facade and plan view

3.2.2. CREATION OF DRAWINGS AND ORTHOPHOTOS

One basic aspect of the current study was the creation of drawings and orthophotos so that they can be used in the future for projects of restoration, preservation or reinforcement of the bridge. Moreover, these drawings can also be used for the touristic or cultural promotion of the monument. The proper projections and coordinate systems in CAD environment and the corresponding orthophotos were created (fig. 10, 11). The orthophotos were digitized so that the floor plan of the deck, the 2 façade and 4 cross-sections of the bridge were prepared (fig. 12)

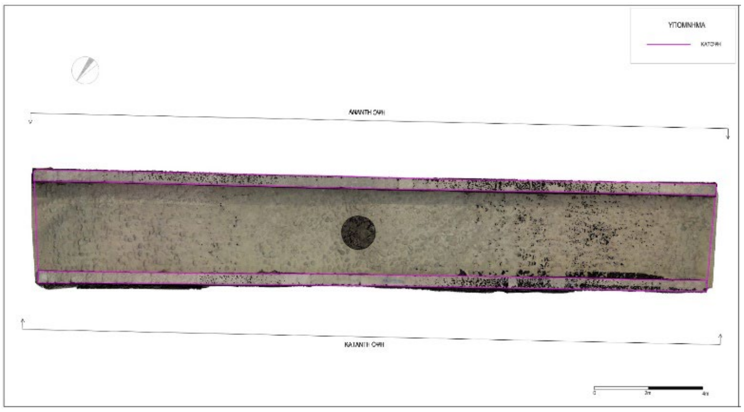


Figure 10. Orthophoto / floor plan of the deck.

Figure 11. Orthophoto of the downstream façade

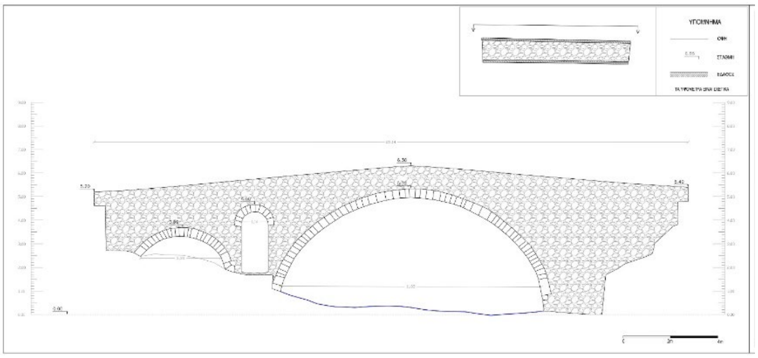


Figure 12. Drawing of the upstream façade

3.2.3. MODELING OF THE POINT CLOUD

On the merged point cloud, the region-grow algorithm was applied, and surfaces of planes and cylinders were modeled on the three arches of the bridge (Figures 13 and 14). The fit quality was with a standard deviation of 6 mm. From this modeling the initial geometric elements of the bridge were extracted.

Moreover, the mesh of the bridge was created by implementing triangle edges of 20 cm (fig. 15). This model was used for the integrity checks of the bridge that are described in the next paragraph.

Figure 13. Snapshot of the point cloud of the first relief arch (left) and the modeled surfaces output (right).

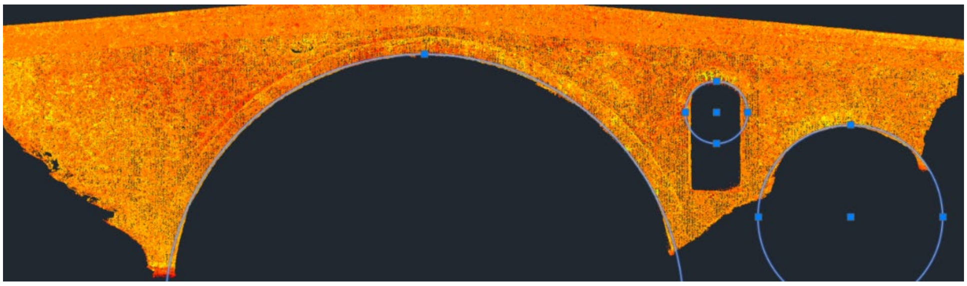


Figure 14. Adjustment of circles to the three arches of the bridge.

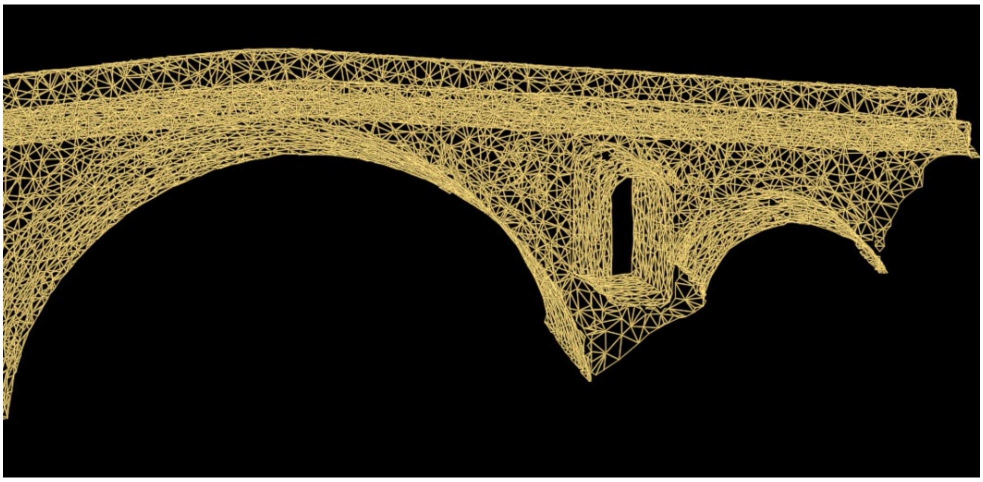


Figure 15. Mesh of the bridge

3.2.4. INSPECTION AND ASSESSMENT OF THE BRIDGE

To check bridge integrity, the 3D structural model was created in Radimpex Tower 8 (Figure 11). The model was created based on geomatic data using shell elements of adequate thickness and dimension. The bridge was modeled with empirically estimated material characteristics, because no measurements at site were made. The Young's modulus of elasticity is adopted in the amount of 1 GPa, and compressive stresses are limited to 1.5 MPa in static and 2.0 MPa in seismic design situation (bridges made of sandstones and limestones) [14].

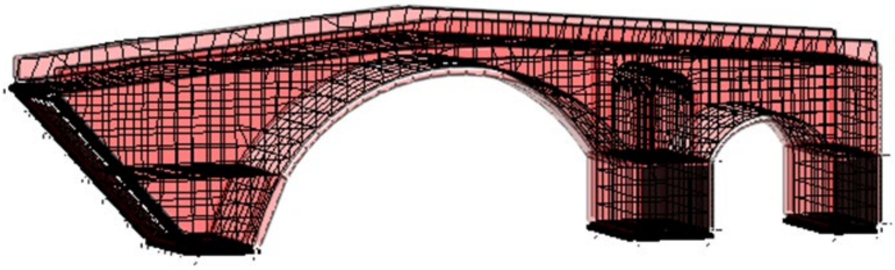


Figure 16. 3D view of the bridge structural model

The main objective was to determine whether the arches, as a main structural part of the stone bridge, have adequate load capacity and if doesn't to propose rehabilitation and strengthening measures. The static and seismic design situation were carried out. In static load situation self-weight and pedestrian load of 5 KN/m^2 were considered. For the seismic analysis the lateral force method according to Eurocode 8 was used. The first vibration period of the structure in the longitudinal direction is Tx=0.213s, and in the transverse direction is Ty=0.325s (Figure 12). For the relevant load combinations (static and seismic), internal forces are calculated (Figure 13), and stresses and deflections are controlled in all cross-sections of the span structure.

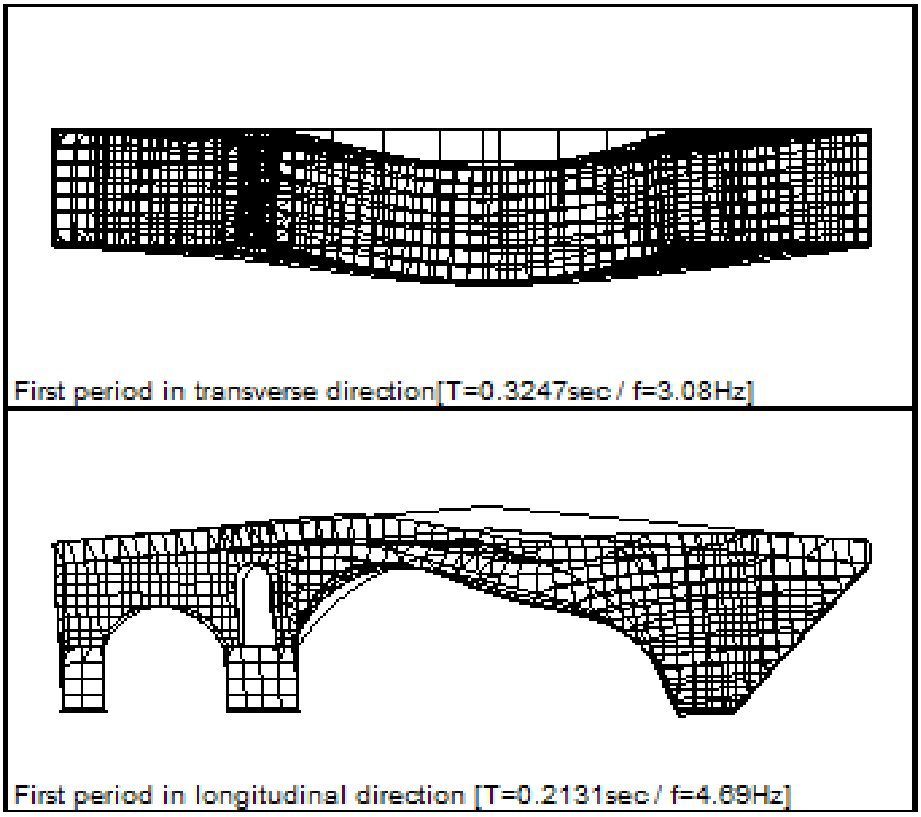


Figure 17. First two vibration periods of the bridge

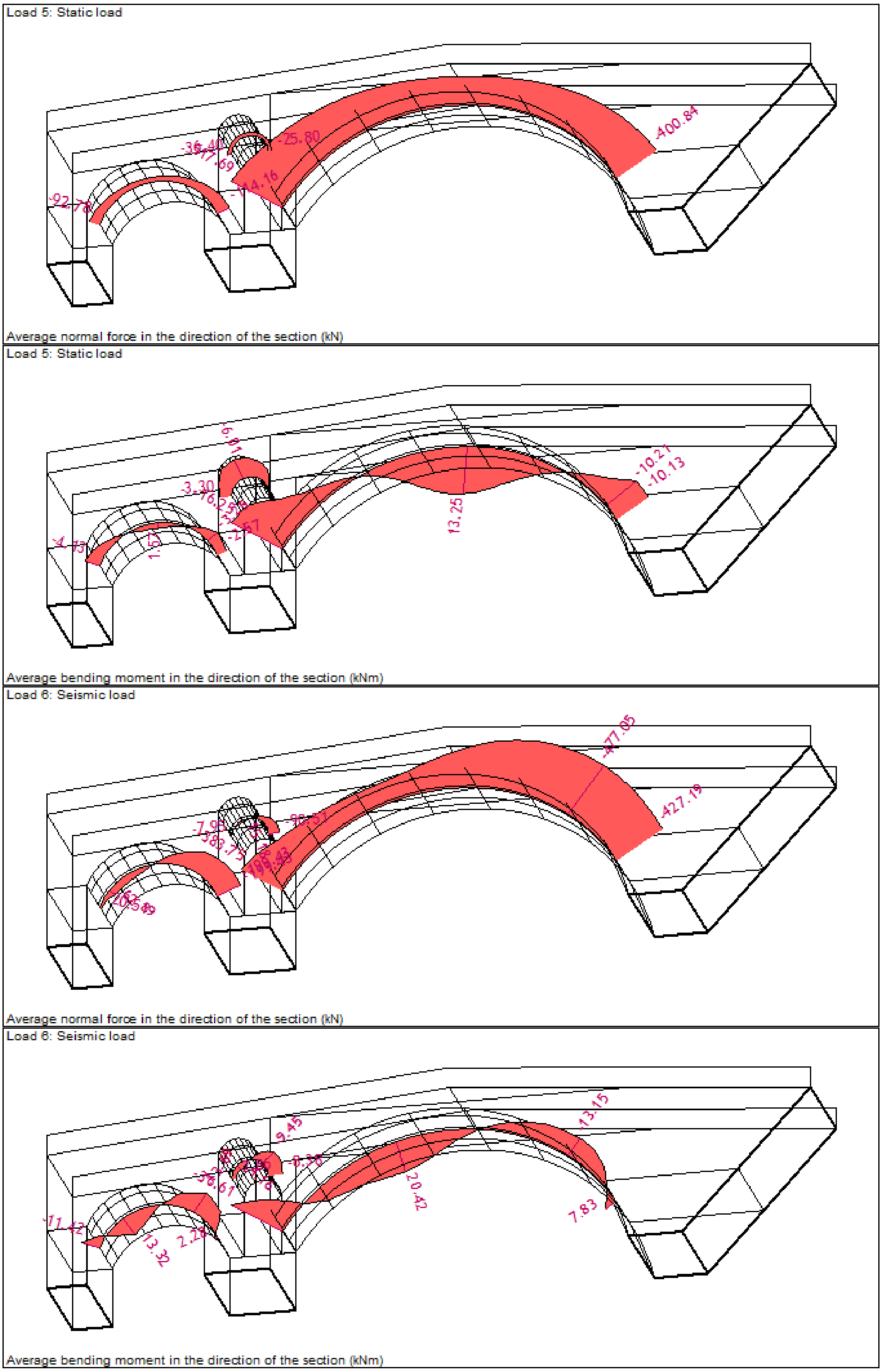


Figure 18. Mean value of internal forces at the arches

In all controlled design situation, the tensile stresses do not occur (or can be neglected), and the compressive stresses are within the permitted limits, while deflections are around L/800, as can be seen at the Figure 14 and Figure 15.

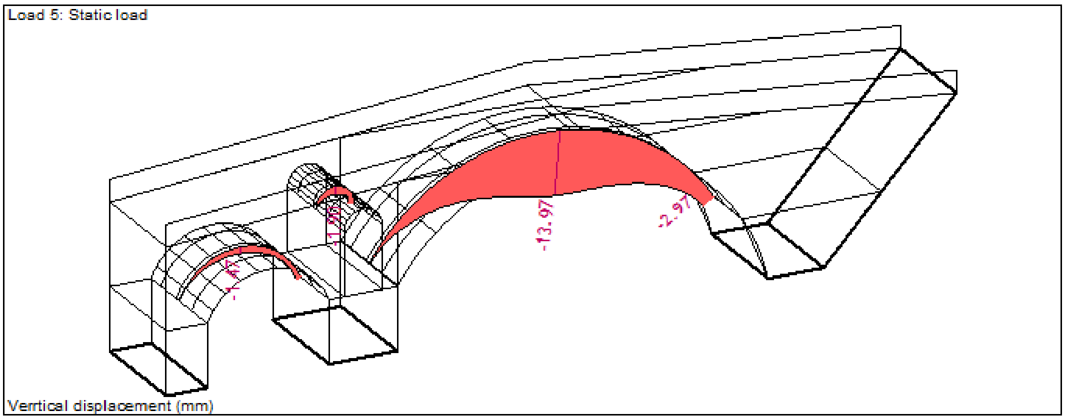


Figure 19. Deflections in the arches due to static load

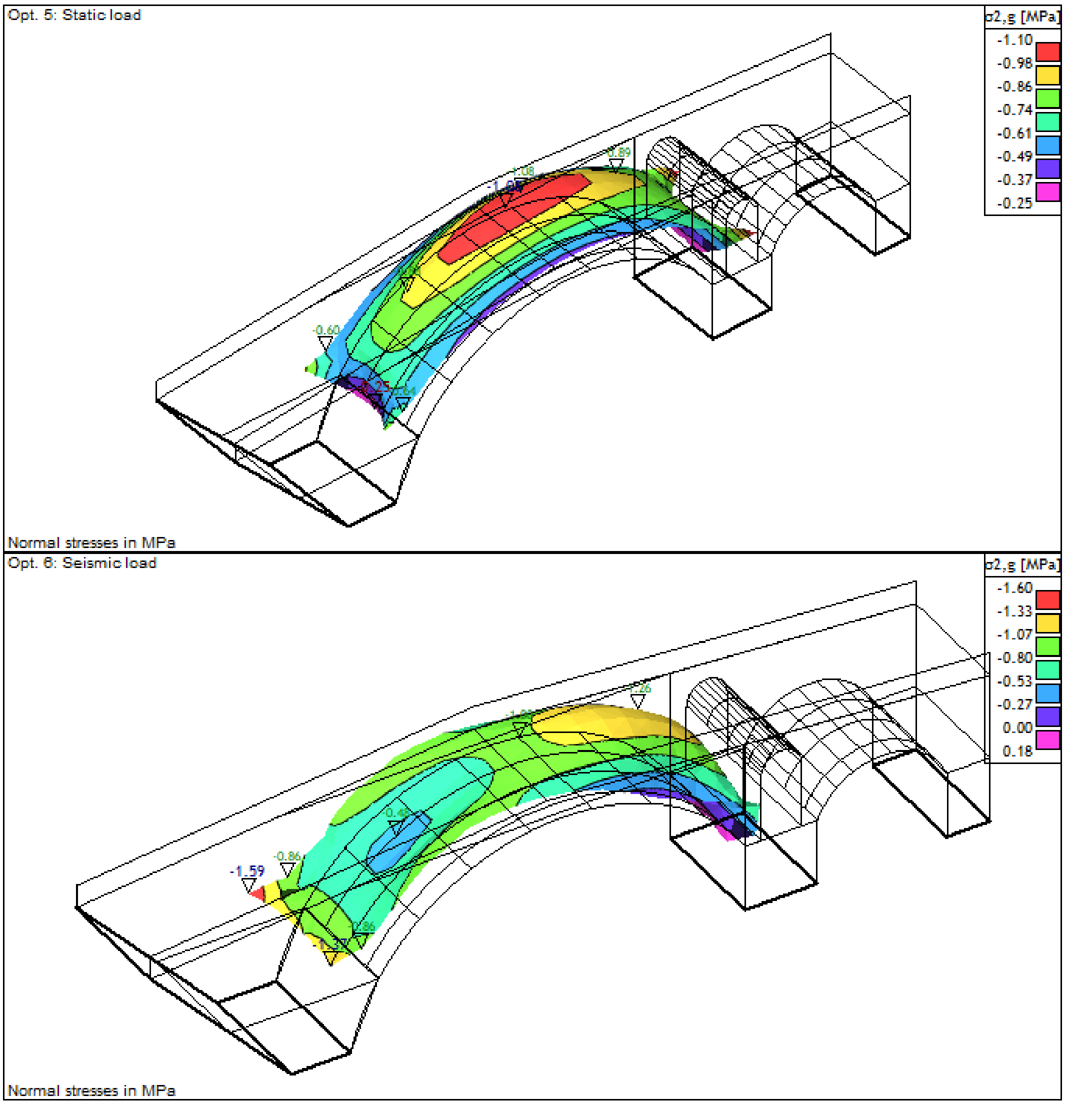


Figure 20. Normal stresses in the main arc due to static and seismic loads

4. DISCUSSION AND CONCLUSIONS

The evolution of technology has given many equipment and methods to reach the desired precision and minimize the measurements' time in the geometric documentation of complex structures, such as a stone bridge.

This paper explained the use of laser scanner technology for treatment of historic bridges. The focus was on electronic regeneration to facilitate the preservation and possible renovation of the bridge. Therefore, the data of Adji-Pasa stone bridge recorded by laser scanner and the integration of this data into various systems were investigated.

Nevertheless, a substantial understanding a stone bridge and a fundamental condition for any intervention, should include not only geometric documentation but also the recognition of the structure (i.e. the synthetic and functional composition) and its form (i.e. its construction characteristics). The specific bridge exhibits a high degree of integrity and resistance to static and seismic loads. The choice of the ratio of arch arrow and span contributed significantly to the good load conditions of the bridge, which confirms the experience and knowledge of the old one's craftsmen.

Particular attention must be paid to the effects of moisture on the stress and deformation of the stone bridge structure and its interaction with the bridge filler. Future work in this context could be the classification of point cloud data, where individual points are categorized into different classes based on their characteristics. These classes could represent wet or dry areas of the bridge. Supervised learning is a basic approach (data-driven method) that relies on labeled data to train algorithms for pattern recognition in the point cloud. Machine learning improves this process by automating classification based on learned patterns on the bridge surface.

In conclusion, stone bridges in Europe stand as more than mere infrastructure; they are enduring symbols of human ingenuity, cultural identity, and historical continuity. Their preservation through geometric documentation ensures that these iconic structures continue to inspire awe and admiration while serving as invaluable heritage assets for generations to come.

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59

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GEOSPATIAL TOOLS FOR THE STUDY AND DOCUMENTATION OF THE COMMUNAL CULTURAL HERITAGE IN MOUNTAINOUS AND ISOLATED AREAS. THE CASE STUDY OF DOLO POGONIOU

Abstract:
This paper outlines a method for researching and recording heritage in remote mountainous regions, using the Municipality of Pogoni, Community of Dolo, Greece, as a case study. It details the documentation of various monuments with high accuracy and precise 3D rendered models. Emphasizing the importance of preserving cultural heritage in remote areas, geospatial technologies are integrated to understand artifacts and traditions. The "GeoDolo Portal" provides access to educational and historical content on architectural structures. The findings underscore the importance of geospatial tools in enhancing the documentation process and fostering community engagement for sustainable heritage conservation initiatives.

Keywords: GeoSpatial data, 3D laser scanning, cultural heritage, communal cultural practices, Municipality of Pogoni, pentatonic routes

ГЕОПРОСТОРНИ АЛАТИ ЗА ИСТРАЖИВАЊЕ И ДОКУМЕНТОВАЊЕ КУЛТУРНЕ БАШТИНЕ ЗАЈЕДНИЦА У ПЛАНИНСКИМ И ИЗОЛОВАНИМ ПОДРУЧЈИМА. СТУДИЈА СЛУЧАЈА ДОЛО ПОГОНИОУ

Сажетак
Овај рад представља метод истраживања и документовања баштине у удаљеним планинским регионима, користећи општину Погони, заједницу Доло у Грчкој, као студију случаја. Детаљно се описује документовање различитих споменика са високом прецизношћу и прецизним 3Д моделима. Наглашава се важност очувања културне баштине у удаљеним подручјима, уз интеграцију геопросторних технологија ради разумијевања артефаката и традиција. "ГеоДоло Портал" пружа приступ едукативном и историјском садржају о архитектонским објектима. Резултати истраживања истичу важност геопросторних алата у побољшању процеса документовања и подстицању ангажовања заједнице за иницијативе одрживог очувања културне баштине.

Кључне ријечи: геопросторни подаци, 3Д ласерско скенирање, културна баштина, културне праксе заједница, општина Погони, пентатонске руте

1. INTRODUCTION

A country's cultural heritage is an integral part of its history, and its promotion contributes to the preservation of its national identity. Today, advanced societies have as their main concern the protection of cultural assets with a spatial dimension, i.e. immovable monuments and sites, their preservation and promotion. The management, protection, conservation and restoration of cultural heritage is achieved through its documentation, which creates the primary basis for its preservation.

Recent developments in 3D documentation and technologies in general, have contributed significantly to the digital preservation and dissemination of cultural heritage. 3D models of cultural heritage are now a critical component in heritage conservation. They include the geometric documentation of archaeological sites in their entirety (earth surface and fixed objects), in order to record, evaluate and represent spatial information.

Many questions are raised for the multiple ways and methodologies concerning cultural heritage preservation, especially having to do with the relations developed with tourism. It is here proposed, that the main focus of the previous mentioned task, should have the concept of the community at its core.

In the age of digital-communication globalization, cultural activities serve as vital means for safeguarding, preserving, and advancing cultural heritage, alongside fostering contemporary cultural expressions. These activities encompass the production of cultural artifacts, materials, and intangible experiences accessible to the wider public. Geospatial technology as a crucial player in the realm of arts and culture, particularly in the preservation of cultural heritage [1]. Geospatial tools have revolutionized the preservation, exploration, and understanding of cultural heritage across the globe. Through the integration of Geographic Information Systems (GIS), remote sensing technologies, and advanced mapping techniques, researchers and cultural heritage experts can meticulously document, analyze, and interpret historical sites, artifacts, and landscapes [2], [3]. Geospatial tools offer a multidimensional approach to cultural heritage management, enabling the creation of detailed maps, 3D models, and virtual reconstructions of heritage sites, thereby providing invaluable insights into their spatial context and historical significance [4]. These tools facilitate not only the conservation of tangible heritage but also the documentation of intangible cultural practices, languages, and traditions, enriching our understanding of diverse cultural landscapes and promoting intercultural dialogue and appreciation. A notable application is evident in UNESCO World Heritage Sites, where geospatial tools offer significant advantages. Leveraging high-resolution satellite imaging and advanced 3D scanning techniques, researchers can construct intricate virtual models of these sites, facilitating comprehensive documentation and analysis. In times of natural calamities or human-induced damage, these digital replicas serve as invaluable resources for restoration endeavors. Presently, culture flourishes dynamically across two interconnected yet distinct landscapes: the physical realm and the digital domain. This dual growth fosters the evolution of culture in both spheres, creating conducive environments for the establishment of local, regional, and global cultural policy networks [5], [6], [7]. Furthermore, geospatial technologies play a crucial role in mitigating risks and addressing challenges faced by cultural heritage sites, including natural disasters, environmental degradation, and human-induced threats. High-resolution satellite imagery and LiDAR scanning enable the identification of potential risks to heritage sites and assist in developing strategies for their protection and conservation [8]. Geospatial analysis helps monitor changes in land use, detect illegal activities, and assess the impact of climate change on cultural heritage sites, thus empowering decision-makers and heritage managers to implement informed conservation policies and sustainable management practices. In essence, geospatial tools serve as indispensable assets in safeguarding our shared cultural heritage for future generations and fostering a deeper appreciation of our diverse cultural identities and legacies [9].

Architectural heritage refers to the built environment, structures, and artifacts that provide a tangible link to history and reflect the evolution that took place in a specific place and period of time. Studying of the architectural heritage is fundamental to understanding the achievements and lifestyle of previous civilizations as well as gaining knowledge of the structural techniques, social dynamics, and technological achievements of a particular era [10]. To begin with, the way a small village or a bigger urban environment is planned takes into account social, economic, environmental, cultural, political, moral, and aesthetic aspects of space organization. It is common practice for the urban environment to be organized around some central buildings that house community functions, such as a town hall, a school, or even the central square where people can gather together. Local people’s residences are usually placed around the above. Some buildings house specific occupations, craftsmanship, and workshops where local craftsmen develop their art and constructions such as bridges, aqueducts, watermills, etc. that indicate human intervention in nature to facilitate its own daily needs and movement. Moreover, the existence of churches and chapels in the area indicates the religious conviction, cultural and traditional practices of the inhabitants. Finally, the morphological features of each building reveal not only the form but also the local materials used based on the environment we study, the means and methods of the construction process, and the financial surface of the locals.

While in past historical periods, the community, in those rural mountainous areas we study - and its cultural imprint - was geographically located and limited to one place, in contemporary reality, it is disconnected from the narrow geographical boundaries of a place or area and is progressively denationalized [11]. In the inquiry for criteria for the definition of modern communities, cultural practices are used as an identification tool of the fluid spatial imprint of community relations, including social, customary, and symbolic processes in a certain field of culture. Through the example of Dolo, the role played by polyphonic music as a capacitor of the community-place relationship will be explored. The previous line of thought aims to document the importance of place and landscape in the context of contemporary rural communities and research the transformations they and their collective memory have undergone. This methodology contributes to the study and reinvention of place - and the landscape as its organic part - in today's society.

Three-dimensional (3D) spatial data is a three-dimensional mathematical representation of natural and human real-world objects on a map, an image, and a scene with height values (zvalues), stored with geometric information [12]. 3D spatial data modeling are series of processes that use the spatial interactions of spatial characteristics to imitate real world circumstances within a GIS [13]. Digital documentation with different technologies as a means of the preservation and safeguarding of a cultural heritage site is based on retaining the image of its status so that probable future deterioration may be reversed on the basis of the visual and three-dimensional digital data already gathered [14].

2. DOLO POGONIOU

2.1. GEOGRAPHY AND HERITAGE

Pogoni is a border region separated by the Greek-Albanian border, with a part of the wider area belonging to the prefecture of Ioannina, Greece, and the rest to Albania (Figure 1). Pogoni is located at the northwestern edge of Ioannina prefecture, between Zagori, Konitsa, Deropolis, Kurenton and Thesprotia. The area belonging to the Greek side is gradually being abandoned with most villages being sparsely populated or abandoned (Figure 2).

The entire territory of the area of Pogoni is made up of mountain clusters, narrow valleys and gorges, as well as small areas of grassland and pasture. The repetition of these geomorphological formations gives the area the geographical form of a homogeneous area, which also has clear natural boundaries. The area of Pogoni is bounded by Drinos and Gormos rivers and by Nemertska, Tsamantas, Kasidiaris and Makrykampos mountains (Figure 3).

Dolo is located on the border of Greece with Albania, 39° 59΄30΄΄ North, 20° 26΄ 29΄΄ East and 800m height, in an area of special natural beauty. It is 70 km NW. from Ioannina and 38 km NW. from Kalpaki (seat of the Municipality).

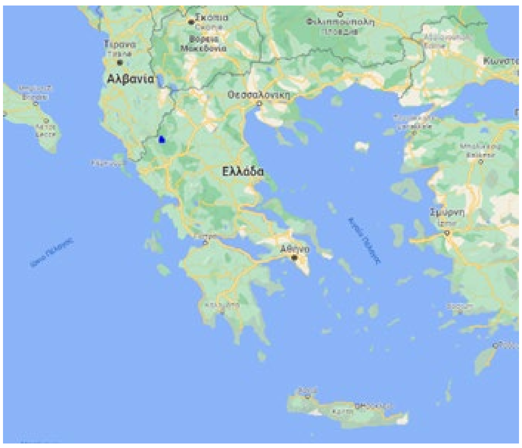


Figure 1. Location of Dolo Pogoni [15]

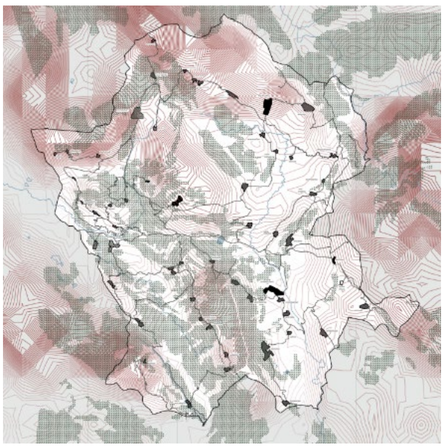


Figure 2. Map of the region of Pogoni [21]

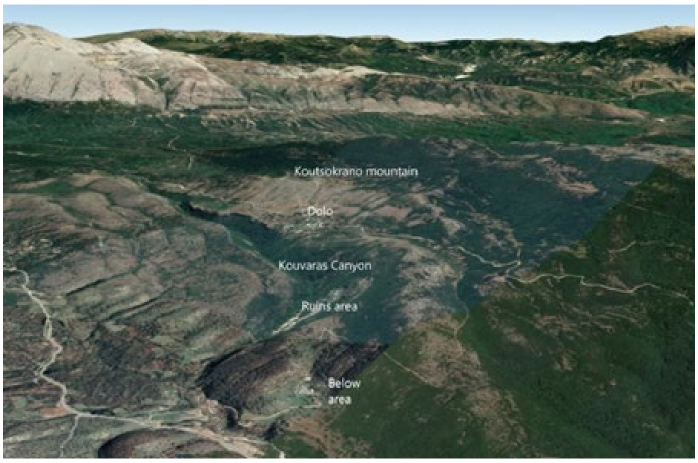


Figure 3. 3D Representation of the wider Dolo area [16]

Dolo - its first name is considered from the oral tradition to be д о л (in Slavic) which means something low and low compared to its high mountain range - is located on the sidewalks of the mountain complex called Koutsokrano and below the hill of Agios Christoforos. The old settlement may have been in the place that is now known as *"χαλάσματα"* (ruins) and which before it subsided would be level with the slope *"παρακάτωνα"* (below). In 1030 mentioned "country of Dolo" in the list of donors of the Monastery of Panagia Molyvdoskepasti [17].

The main occupations of the residents were livestock farming, agriculture, and logging, as the village is located in a wooded and secluded area, far from thoroughfares and influences. In the early 20th century, the population of the village was estimated to exceed 300 inhabitants. The village had a school in the central square (Figure 4), which still exists, initially built in 1824 and relocated to the upper part in 1950. Additionally, the central church of the village was located there, built in 1812, and it is still preserved today with some minor modifications.

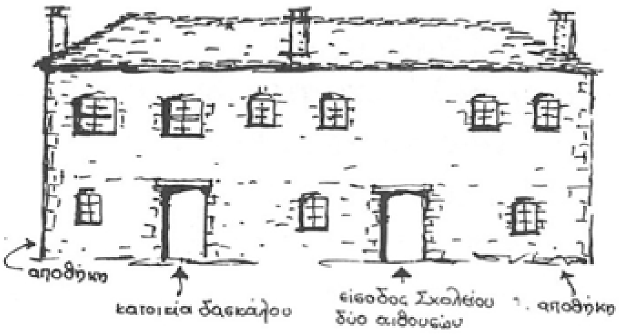


Figure 4. Plan of the first school where, in addition to the two classrooms (είσοδος σχολείου δύο αιθουσών), the teacher's residence (κατοικία δασκάλου) with storage (αποθήκη) can be seen [18].

Each household had its animals, herds next to the house, and fields in various areas around the central settlement. Each family was to some extent self-sufficient in basic products. This characteristic was reflected in the layout of the settlement. Despite the number of inhabitants, the settlement was sparsely populated and geographically spread out. Most houses had a courtyard, which, as an extension of the house, was surrounded by a stone fence and a gate (Figure 5). This means that each house was at a considerable distance from the others, as beyond the residence, at the boundaries of the property, there were auxiliary spaces such as a barn, one or more stables for animals (goats, cattle, horses, etc.), and cultivated plots for basic vegetables [19].

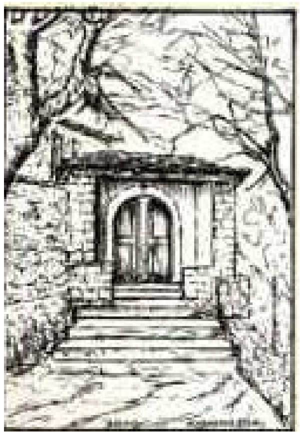


Figure 5. Typical house entrance with a wooden door [18]

The main building, usually a two-story structure made of stone and wood, had a supporting structure of stonework hewn with lime plaster, and the floors were wooden on wooden beams. The roofs of the houses consisted of wooden shingles with a final covering of stone slabs. The internal walls were usually made of "tsatma" (wooden planks), while others were made of "bagdati" (woven wood). Externally, the houses appeared simple and unadorned with clean rectangular volumes, but internally, according to residents' testimonies, they were particularly luxurious with wooden stairs and elaborately carved wooden furniture and other woodwork, depending on the taste of each owner.

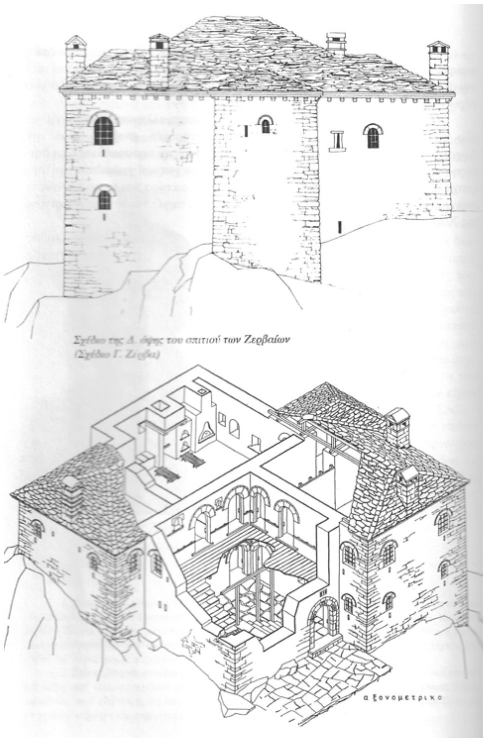


Figure 6. West front view and axonometric plan of the Zervas' house [18]

The layout of the spaces in the two-story buildings usually had auxiliary spaces on the ground floor (storage spaces, kitchen, etc.) and bedrooms on the upper floor, which were sometimes arranged as reception areas. For heating, either fireplaces were constructed, or wood stoves were used (Figure 6).

There is a dependent relationship between community and landscape, in the sense that in earlier years, productive activities were directly linked to it. The family home was both a residence and the center of the productive unit that the family itself constituted. All the families had some sheep and chickens, usually, in their house backyard, while many of them were breeders, by profession, keeping flocks. Other than that, the rocky and largely barren land of Pogoni made life, extremely, difficult and the standard of living, significantly, low.

There were close community ties, who were reflected in the solidarity and mutual aid between the villagers. In Dolo of Pogoni (as perhaps in other places) the village maintained a 'communal' flock: the shepherd rotated for each day of the week and the flock was the sum of the few domestic animals (sheep and goats) of each family in the village. Religious ceremonies and rituals also played a key role in the formation of the community. The festivals and celebrations in the various villages of Pogoni were -and remain nowadays in a different form- the customary practices of great importance for the reproduction, constitution and cohesion of each community (Figure 7).

It was an expression of the continuity of the past with the present and the future, in the sense of repetition from year to year. The interdependence of place-landscape-community is also reflected in the chronological sequence of the festivals with the completion of some agricultural work, such as harvesting, sowing, etc.

But apart from the annual religious festivals and special occasions, which constituted the "sacred time of the community", a coherent role and common cultural practice for the villages of Pogoni was the polyphonic singing, which was fully interwoven with life itself, and constituted the "daily time of the community".

Figure 7. Map of the region of Dolo [21]

For the construction of the 3D models of the buildings and churches that are included in the platform, a series of technical procedures for data collection need to take place. Initially, the fieldwork implements geodetic and surveying techniques to set up the geodetic infrastructure for the georeference of the digital models and all the products in the platform. The laser scanning of the monuments then follows that will produce the necessary point cloud data and the resulting digital models.

Initially, for the geodetic control of the project, a geodetic network comprising 18 benchmark points around each village were established in the area (ex-municipality of Pogoniani, 6 on Pogoniani, 4 on Stavroskiadi, 3 on Drimades and 4 on Dolo). These points are used to support the field measurements and the georeferencing of all data and form a geodetic infrastructure that will facilitate additional work in the future.

The 3D data collection involved the use of terrestrial laser scanning for the geometric documentation of the external and internal parts of the heritage spots (Figure 8). The scanning was performed using the Leica Geosystems BLK360 image laser scanner (https://leica-geosystems.com). All scans were performed with a 4 mm step and the distance between the object and the scanner was always less than 10m. The percentage of the scan overlap ranged from 30% to 40%. The collected point clouds were processed in proprietary software (Leica Geosystems Cyclone). The alignment of individual scans was performed using tie points in an independent reference system. Regarding the accuracy of the merged point cloud, the mean square error (RMS) ranged from 1 to 1.3 cm. From the merged point cloud, a number of products were created including the meshed model and the ortho-photo models with texture (e.g. RGB, gray scale etc) as seen in Figure. 16 . When all 3D models were created, they were imported into the platform with suitable software offering interactive measuring tools. In this work, the proprietary Leica Geosystems TruView Enterprise software was used where the online user can browse inside and outside the churches, choose to browse through different layers (such as RGB, IR, HDR, Intensity Grayscale and Intensity Hue Layer) and take distance, angle and temperature readings.

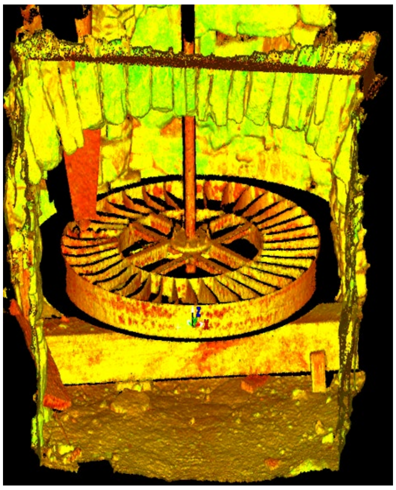


Figure 8. Snapshot of the scanning process (left) and example of a point cloud output (right).[Authors]

The heritage of Dolo:

- **Polyphonia:** Epirotic music is based on the pentatonic scale and is divided into instrumental and vocal music, i.e. music played with instruments and simply sung music. Polyphony (Greek word stands for a style of musical composition employing two or more simultaneous but relatively independent melodic lines), whose roots are lost in time, is a strong element of the intangible cultural heritage of Epirus and Pogoni, within and outside the borders (Figure 9). The polyphonic song was an element inscribed in inhabitants' life and their daily activities, being at the same time a collective/participatory process. Polyphonics are sung by groups of people, each of whom has their musical role, precisely defined. 'Partis' is the main singer, 'Giristis' (twirler) follows and sings a melody different from the main singer, 'Richtis' participates in certain parts of each piece and the equalizers, who are usually at least three people, hold the equal, i.e. a standard note. Each voice is developed in unison with the others, while all of them "compete" musically to contribute to the consonance [20]. Polyphonic singing was a way of expression and, at the same time, a way of communication, socialization and interaction between people, the constitutive element of which is the fact that it is a group expression. Nowadays, correspondingly with the dissertation of Pogoni, the footprint of cultural heritage has been descending.
- **Watermill and bridge of Nonoulo**: Just before the settlement of Dolo there is a watermill (Figure 10; 13) and a traditional stone bridge, called the Bridge of Nonoulo (Figure 11).

They are located at the entrance of Kouvaras canyon. The canyon is crossed by the Gormos river which used to supply water to the watermill for its operation. The bridge was built at the expense of an active Pogonian woman named Nonoulo, from whom it bears its name and connects Dolo with Pogoniani through a path. The bridge is a stone single-arched bridge and was built in the early 20th century (1908). It is 6 meters high, while its opening arch is estimated to be 7m. The length and width of the bridge deck are 9.40 and 2.70 (1.80 internal) meters respectively (Figure 12). A low parapet has been built on the sides of the deck, which further ensures a comfortable and safe passage. The bridge is an ornament of folk architecture for the area, which records on the one hand the local folk architecture and the pre-industrial era.

Figure 9. map of the density of the remaining cultural practices remaining in the Pogoni region (dark blue) in comparison with the early 20th century (light blue) [21].

Figure 10. View of the water mill and the stone bridge of Nonoulo in the background [Authors]

Figure 11. The stone bridge of Nonoulo [Authors]

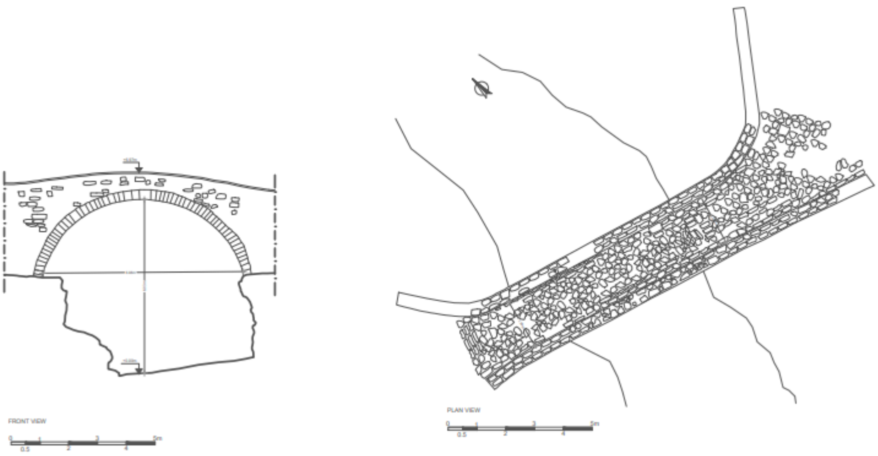


Figure 12. Drawings of Nonoulo bridge [Authors].

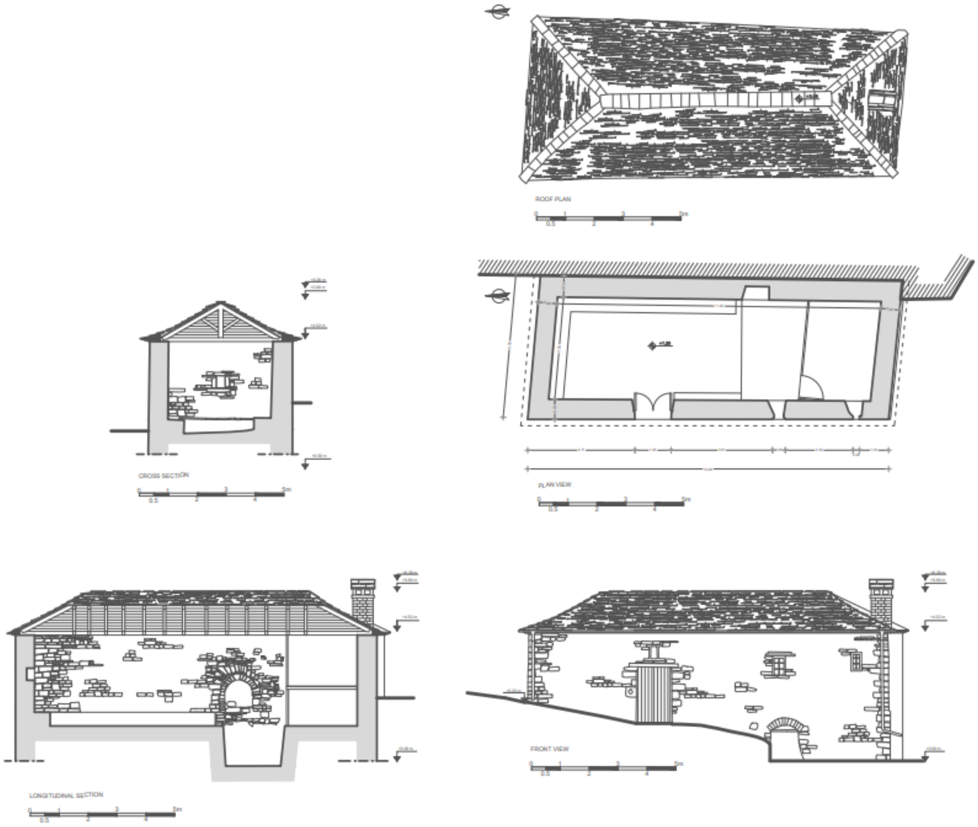
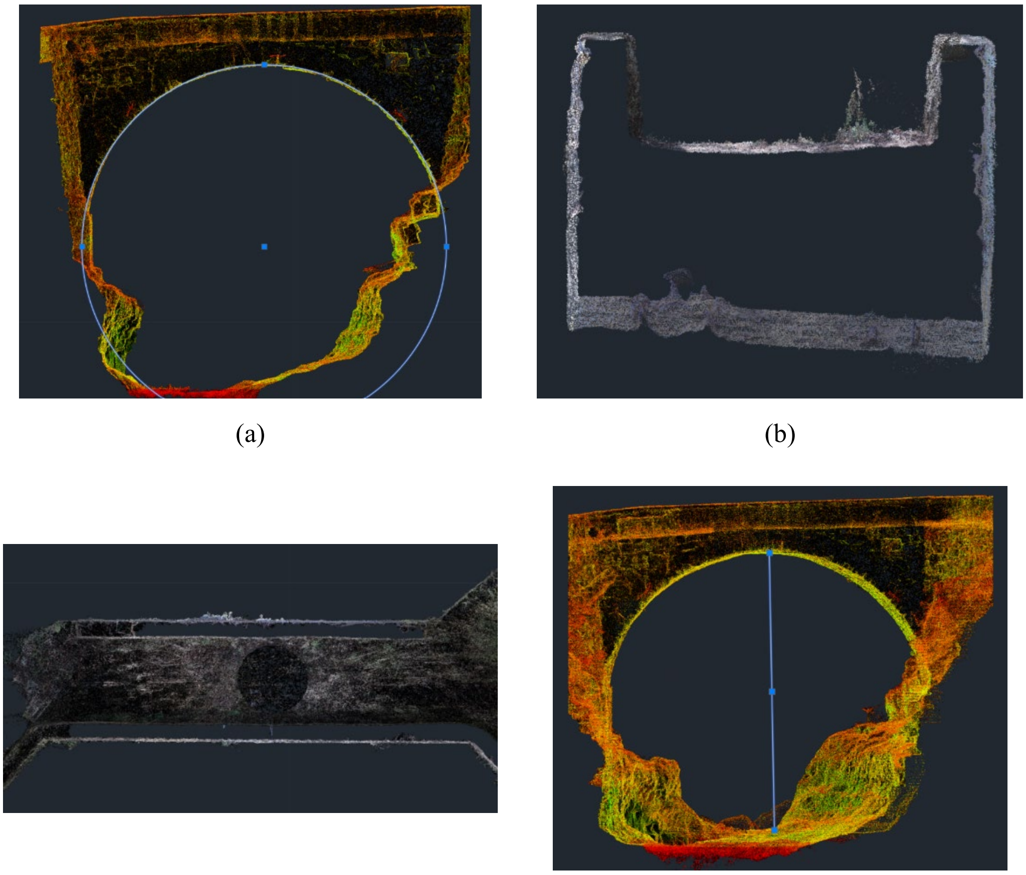


Figure 13. Drawings of watermill [Authors].

- **Kouvaras bridge**: This is a stone single-arch bridge that spans the Kouvara stream (Figure 14). The bridge was built in 1926 and is located northwest of the settlement at the point where the path from Dolo passes through the gorge, under the icon in Tchoubari, towards Pogoniani at an altitude of 780 meters. It was built at public expense by the master builder Paschalis Zounis (1898-1988) from Pyrsogianni (Konitsa). The arch has a span of 7 meters and a height of 6.5 meters. The total length of the bridge is 7.80 meters (Figure 15). The original stone pavement is preserved, and the protective parapets have been repaired.

Figure 14. Photos of Kouvaras bridge



(a) (b)

(c) (d)

Figure 15. Construction components for Kouvaras bridge (a) adjusted circle, (b) Section of the pavement, (c) top view and (d) arc height [Authors].

- **The churches of Dolo**: In Dolo there are 7 chapels (Agios Christoforos, Agios Dimitrios, Agia Triada, Agios Giannis -Cemetery, Agios Georgios, Agios Nikolaos, and Ai Lias) and the central church of Agios Nikolaos.

Central church of Agios Nikolaos. The church is located in the central square of Dolo, right next to the café and is one of the most beautiful churches in Epirus (Figure 16). The holy church was built in 1812 and is of the three-aisled basilica type. It has a large, integrated two-zone bell tower on its south side. The building is made of stone, is spacious and has small windows. The windows had the same dimensions until 1870 when they were rearranged. The roof of the windows was also altered and changed from an aligned to a Gothic roof. The elegant outdoor areas (loggia) were built at the beginning of the 20th century. To this end, a theatrical performance was held in the village in 1910, the proceeds of which were used to build the choir stalls. However, several interventions were also made to the exterior of the temple in later years, which nevertheless appear harmonious (Figure 18).

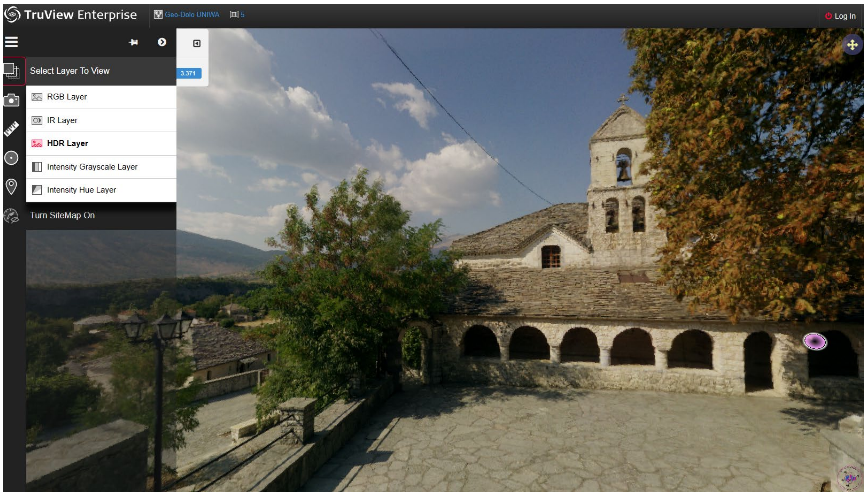


Figure 16. South view of the church of Saint Nicholas [Authors].

Inside, the main church had the following form: the sacred step, which was separated from the iconostasis (templo) (Figure 17) by the andronite, the main church (andronite) and the gyneconite, which was separated from the main church by a stone wall. It should be noted that the wood-carved iconostasis of the church was designed by the painter Haris Mexis (who comes from Dolo) and occupies the width of three naves. The general design generally follows the form - architecture, technique, and aesthetics of the elaborate post-Byzantine iconography. The oldest frescoes in the church are the work of the painter Kouros also comes from Dolo).

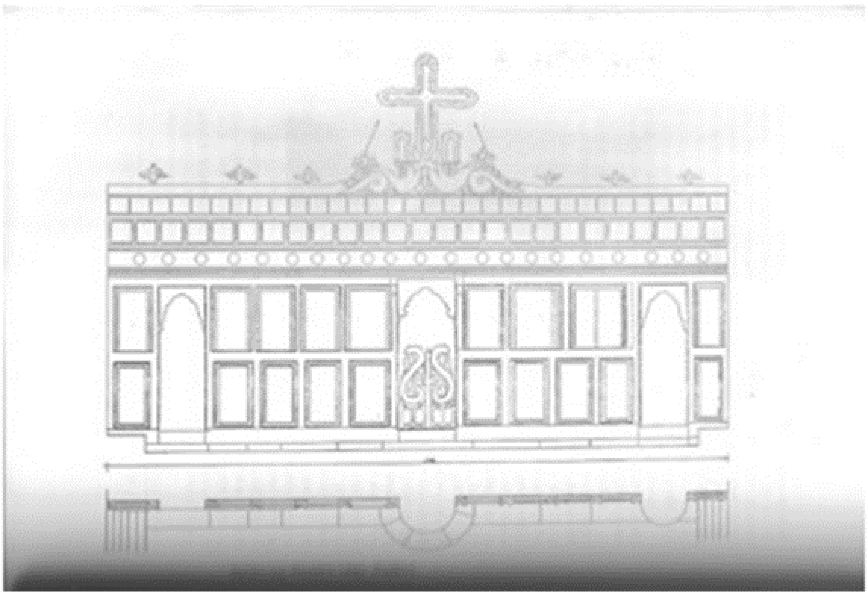


Figure 17. Drawing of the iconostasis [18]

The double bell tower of the church, built of stone, was erected a few years later, in 1830 to be precise, by Paschalis Zounis, an archmason from the neighboring village of Pogoniani. The dimensions of the bell tower are 10.40x2.60 meters.

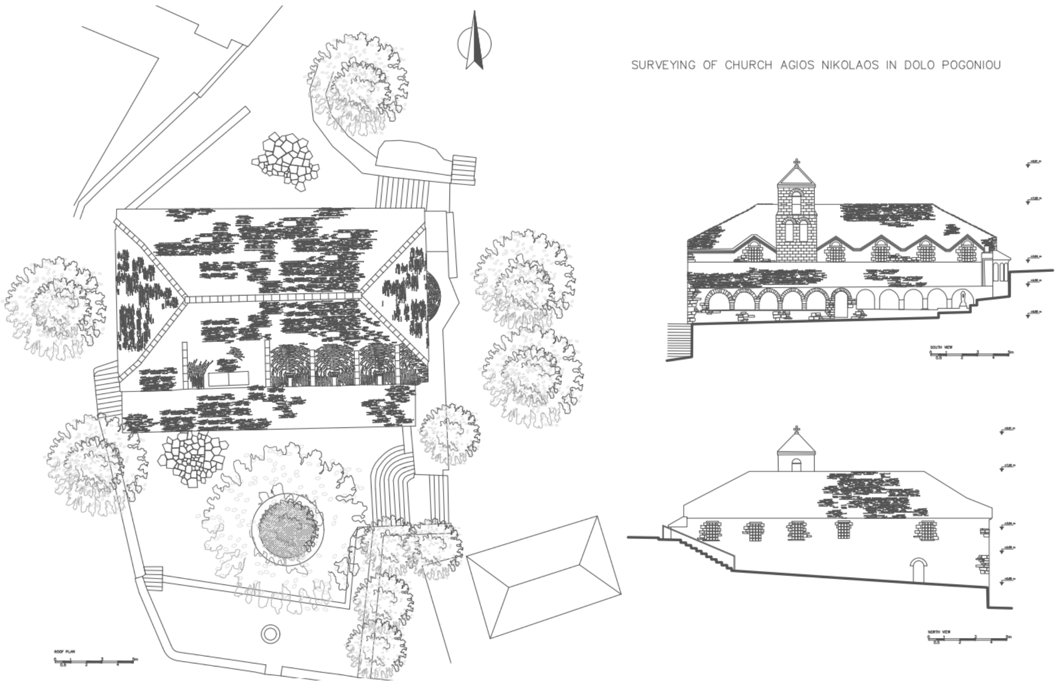


Figure 18. Surveying of church Agios Nikolaos in Dolo Pogoniou [Authors].

2.2. PENTATONIC ROUTES AS A COMMUNITY SPATIAL IMPRINT AROUND THE CHURCHES OF DOLO

In almost every village, there are some annual celebrations related to religious ceremonies and local traditions. These celebrations are also cultural practices bonding the community, thus, while they are practiced, produce a spatial imprint. The most characteristic example is the celebration of Aghios Christophoros, a saint "protector" of Dolo, whose chapel named after him is placed on the top of Koutsokrano mountain, above the village (Figure 19). Every year, on the 9th of May, all villagers in Dolo, wake up early and have the one-hour walk towards the chapel, where a church service takes place. It is a custom also for the elders of the village to follow that route, to attend the service. Afterwards, they return downhill to their final destination the village's square. In the "entrance" of the village a traditional music group (kombania) waits to accompany the community to the square. There is a whole part of musical tradition concerning the songs that are sung while walking (*δρομικά τραγούδια*, in greek) and the case of Aghios Christoforos is only one example of that. Up until the 80's the above-mentioned party (musicians and villagers) used to make a halt to every house that a Christopher lived in, celebrating each member of the community in their houseyard with music, dance, tsipouro (traditional drink), and food (kerasma). When that part of the celebration was over, the party ended up in the village square with the customary panighiri, where they drank, danced and celebrated.

That analyzed root can easily be called a cultural practice, that is part of the sacred time of the community and interweaves the cultural heritage (pentatonic music) with the place itself. The root seems to have a spatial imprint, as there is a specific song that matches with a specific landmark of the path. The music plays an important role during the house-celebrations as well, giving a chance to each villager to express his individuality through communal practice.

Figure 19. Root form St. Cristophoros church to Dolo Village [21]

3. DEVELOPMENT OF GEODOLO PORTAL

The GeoDolo Portal is a geographical information map that was developed to promote the cultural heritage and traditional polyphonic music of Dolo region and it is freely accessible (http://195.130.106.60/GeoDolo/). It was developed using exclusively Free and Open Source Software (FOSS). The applications that were used are given in Table 1 with their respective releases and licenses.

Data stored in the database are available through a server that supports the Web Map Services (WMS) standard for versions 1.1.1 and 1.3.0. The WMS is accessible at http://195.130.106.60/geoserver/dolo/wms where all available information can be retrieved. The GET SDI Portal v4.0 mapping platform (https://github.com/GeospatialEnablingTechnologies/GET-SDI-Portal) was used to disseminate all available data to citizens and **the** scientific community. This mapping platform, developed by Geospatial Enabling Technologies (http://www.getmap.gr), was based on **open-source** projects and is available under the terms of the GNU=GPL v3 license.

The mapping layers were grouped into seven basic teams. The following five groups relate to the basic background:

- Administrative borders for Pogoni Region,
- terrain features,
- environment - protection,
- anthropogenic environment,
- heritages,
- churches,
- routes,
- musical tradition.

The portal is constantly being updated when new data are available to the database. A schematic of the design structure of the web portal is given in Figure 20.

Table 1. Free and Open Source Software used to develop the "GeoDolo portal".

Software Package	Version	License
QGIS (http://qgis.com)	3.6.0	GNU-GPLv2
PostgreSQL (http://www.postgresql.org)	10.5	PostqreSQL
PostGIS (http://postgis.net)	2.4	GNU-GPLv2
Geoserver (http:/geoserver.org)	2.15	GNU-GPLv2
GeoWebCache (http://geowebcache.org)	1.14.2	GNU-LGPL
GET SDI Portal (http://www.getmap.gr)	4.0	GNU-GPLv3

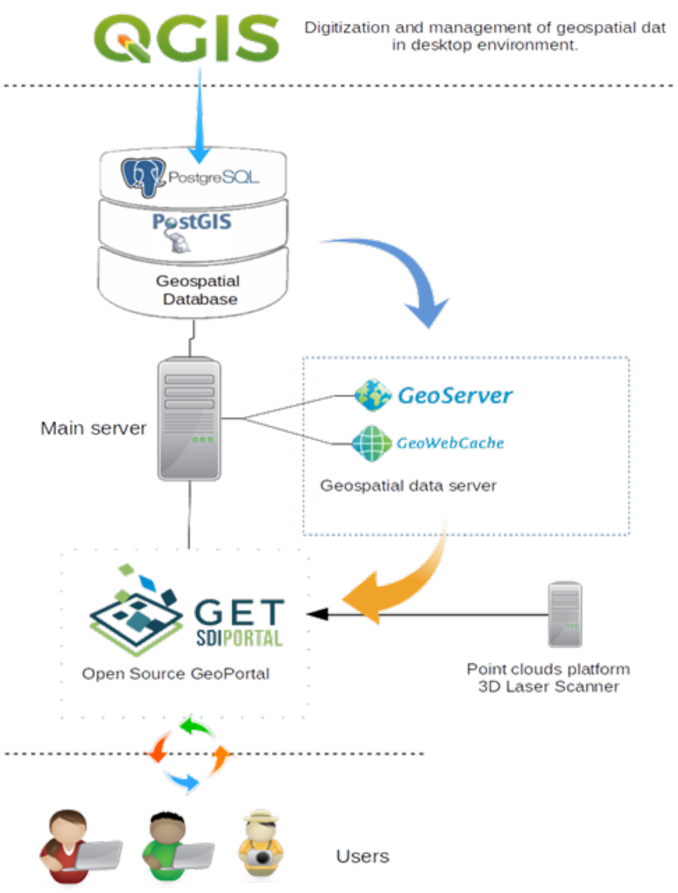


Figure 20. Workflow implementation portal [Authors].

The database that supports the GeoDolo Portal was developed in a PostgreSQL environment to store, share, and easily retrieve the metadata of each thematic layer. The Post GIS extension was used to access the geospatial information of each level. The database was installed on a central server of the Department of Surveying and Geoinformatics at the University of West Attica.

Cultural content in museum collections, libraries, and other content repositories is usually described using metadata schemas (also called annotation schemas or annotation ontologies). These templates specify a set of obligatory and optional elements, i.e. properties, by which the metadata for content items should be described.

The structure of the database includes tables related only to geospatial information such as the digitized contours for the production of the terrain model, relief information, rivers, Natura regions, etc. At a second level, it includes the entities for all the necessary police information that is available through the platform with the corresponding metadata that each user can access. These concern the sites of interest where the geometric documentation of cultural monuments has been carried out as well as the necessary information for the routes that are created and which each visitor can browse digitally

In its current form, GeoDolo Portal follows traditional portals where the search is usually based on free text search (e.g., Google), database queries, and/or a stable classification hierarchy (e.g., Yahoo!). However, it aims to use semantic content which makes it possible to provide the end-user with more “intelligent” facilities based on ontological concepts and structures, such as semantic search, semantic autocompletion, and (multi-)faceted semantic search (e.g Junnila et al., 2006). In addition, semantic content facilitates semantic browsing and the semantic associations between search objects can be exposed to the end-user as recommendation links, possibly with explicit explanations. Also, other kinds of intelligent services can be created based on machine interpretable content, such as knowledge and association discovery, personalization, and semantic visualizations based on e.g. historical and contemporary maps and timelines.

4. DISCUSSION (INCLUDING LIMITATIONS)

Cultural heritage provides a rich application domain in which useful collection contents are available, and where relevant organizations are eager to make their content easily and publicly accessible. In this work, a portal named GeoDolo Portal has been developed to provide collection content about the monuments of the Pogoni region. Leveraging a geographic platform to highlight cultural heritage can actively and meaningfully involve community members. The use of such a platform offers ways and methodologies for deepening, revealing, recording, examining, analyzing, interpreting, presenting and disseminating information about people, communities, societies, places and material objects and customs related with these. The online platform presented in this paper aspires to be functional, simple to use and scientifically accurate in terms of the data included. The role of the internet in highlighting and promoting monuments and cultural routes is important, especially when geospatial data is used online for smart mobile devices, serving search capabilities to people who love nature and have specific cultural interests. The aim is to use customized solutions to promote cultural heritage as a public good.

Experiences, collective memory and cultural practices are imprinted on space and transform it into a place that is emotionally, empirically and historically charged. This mapping also forms a narrative or many parallel narratives and stories about a place. Community ties, stories, songs, rituals, tales and myths form a collage of experiences and spatial reference points in a virtual map of the place. Modern regeneration and landscape redesign proposals do not seem to always take these criteria seriously into account but, instead, the intention is mainly aimed at fulfilling an economic objective or rather a development objective (decentralized development is development). These economic objectives are accompanied and substantiated by the aforementioned logic of romanticizing non-urban landscapes, transforming rural places in solely a touristic-purposed scenery. In the opposite direction to this logic -of prioritizing tourism needs- the inclusion of the community perspective, i.e. collective experiences, memory, and narratives, is advocated. This can be done in many different ways. The criteria for approaching that design logic surely relates to the reflection a community has in a place and its landscape and vice versa.

Local narratives and their contemporary intakes could be matched with a situational perception of the narrativity of each place. To achieve this, there would be applied art applications using location-aware-technology (which has already started since the early 1990s) making the creation of a digital geoplatform feasible and accessible to the general population. It will collect, using open-source software, data that will capture memory and experience. It will look like a map, on which all the points, where a story or a song from the local folk narrative is mentioned, will be marked with pinpoints. It will include all the places that were -and still are- community reference points, such as a village square, or places that were -and no longer are-, thus inviting wanderers to reappropriate them through their reuse and re-inhabitation.

In its current form, the GeoDolo portal is not semantic. The portal content has been created in a centralized fashion by using a content management system (CMS). However, it is within the future directions of this work to enhance the portal with semantic properties that will help create and maintain links up-to-date automatically based on the metadata and ontologies and allow the portal content to be reused in different applications and cross-portal systems.

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60
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POSSIBILITIES OF TRANSFORMING RECTANGULAR 3D GEODETIC INTO ELLIPSOIDAL COORDINATES USING NEURONAL NETWORKS

Abstract

The transition from ellipsoidal geodetic coordinates to rectangular 3D coordinates is quite simple, while the reverse procedure is somehow more complex due to the mathematical relationship between the ellipsoidal width and 3D coordinates. Until now, several methods for solving this problem have been defined and described in geodetic literature. In this paper, the possibility of applying a backpropagation algorithm based on a multilayer perceptron (Multilayer Perceptron – MLP) neural network for the transformation of rectangular 3D geodetic into ellipsoidal coordinates is analyzed. The applied MLP model is based on Bayesian regularization (BR). The adequacy of the model was verified by a robustness test and a cross-validation test. Based on the obtained results, it was concluded that the MLP neural network can be used for the transformation from rectangular 3D to ellipsoidal coordinates. Future research should analyze the possibility of applying this procedure to solve the problem of data transformation.

Keywords: Coordinate Transformation, Multilayer Perceptron (MLP) Neural Network, Bayesian Regularization.

МОГУЋНОСТИ ТРАНСФОРМАЦИЈЕ ПРАВОУГЛИХ 3Д ГЕОДЕТСКИХ КООРДИНАТА У ЕЛИПСОИДНЕ КООРДИНАТЕ ПРИМЈЕНОМ НЕУРОНСКИХ МРЕЖА

Сажетак

Прелазак из елипсоидних геодетских координата у правоугле 3Д координате је прилично једноставан, док је обрнути поступак нешто сложенији због математичке везе између елипсоидне ширине и 3Д координата. До сада је у геодетској литератури дефинисано и описано неколико метода за рјешавање овог проблема. У овом раду анализирана је могућност примјене алгоритма повратног ширења заснованог на вишеслојној перцептронској (Multilayer Perceptron – MLP) неуронској мрежи за трансформацију правоуглих 3Д геодетских у елипсоидне координате. Примијењени MLP модел заснован је на Бајесовој регуларизацији (Bayesian regularization - BR). Адекватност модела провјерена је тестом робусности и тестом унакрсне валидације. На основу добијених резултата, закључено је да се MLP неуронска мрежа може користити за трансформацију из правоуглих 3Д у елипсоидне координате. Будућим истраживањима треба анализирати могућност примјене овог поступка за рјешавање проблема датумске трансформације..

Кључне ријечи: трансформација координата, вишеслојна перцептронска (MLP) неуронска мрежа, Бајесова регуларизација.

1. INTRODUCTION

To achieve modern geodetic standards and create a basis for the application of new measurement technologies, networks of permanently operational reference GNSS (Global Navigation Satellite Systems) stations are used in many countries. These networks most often represent the realization of a new spatial reference system. The systems are rectangular, rectilinear, three-dimensional and geocentric. In principle, the positions of points, in these new systems are expressed by rectangular three-dimensional coordinates (X, Y, Z), while the ellipsoid GRS80 (Global Reference System 1980) is used for ellipsoidal coordinates (B, L, h). In light of the modern definition of geodetic reference systems, to describe the position of points in the horizontal plane, it is suggested to use the UTM (Universal Transverse Mercator) projection of the corresponding zone and the associated coordinate system.

The transition from spatial rectangles to curvilinear ellipsoidal coordinates is not carried out directly, due to the characteristics of their mathematical connection. There are several approaches to carry out this calculation, which is often called coordinate conversion or inverse transformation, and the iterative and closed-form methods are the most commonly used.

Machine learning, as a branch of artificial intelligence, deals with the development of algorithms and models, which enable computers to "learn and draw conclusions" from data. Machine learning techniques are a key part of this discipline. They enable computers to discover dependencies and connections in data, draw conclusions based on these findings, and then apply them to unknown data. The two basic categories of machine learning techniques are supervised learning and unsupervised learning. In supervised learning, a model is trained on a dataset containing input attributes and corresponding target values. The ultimate goal is to teach the network how to associate input data with appropriate target values. On the other hand, in unsupervised learning, the model is trained on a data set without target values, i.e. internal stratification and grouping of data is performed.

One of the classifiers for supervised learning is algorithms based on artificial neural networks (ANN). These networks, learning from data relationships, can define models, apply linear and non-linear functions, and apply them to unknown situations. Typically, neural networks are adapted, or trained, so that a particular input leads to a particular target output. Several ANN models can be formed with different architectures, depending on:

- number of additional layers and neurons,
- training algorithms and activation functions and
- neuron connection geometries.

Artificial neural networks are applied in various fields of geodesy and geoinformatics [1]–[4], including coordinate transformation. Barci [5] performed a 3D coordinate transformation using ANN, Zaletnyik [6] performed a coordinate transformation between geographic and plane coordinates, and Lin and Wang [7] transformed projection plane coordinates between two different coordinate systems. Tierra et al. [8] performed a comparison of the results of the transformation of ellipsoidal coordinates using artificial neural networks and standard parameters of data transformation, where it was concluded that ANN can be used as a technique for this type of transformation. Kutoglu [9] introduced ANN to the transformation problem as one of the alternative methods to improve the consistency of transformation between geocentric and non-geocentric (local) coordinate systems.

MLP is a powerful modelling tool, which applies a supervised learning procedure using data with known results [10]. The procedure involves the generation of a non-linear functional model that enables the prediction of the output from the given input data. MLP neural networks consist of units arranged in layers. Each layer consists of nodes and in fully connected networks each node is connected to each node in subsequent layers. Each MLP consists of at least three layers consisting of an input layer, one or more hidden layers and an output layer (Figure 1). The input layer distributes the input data to the following layers. The input nodes have a linear activation function and have no thresholds. Each hidden unit node and each output node have an associated threshold in addition to the weight. The nodes of the hidden units have a nonlinear activation function, and the outputs have a linear activation function.

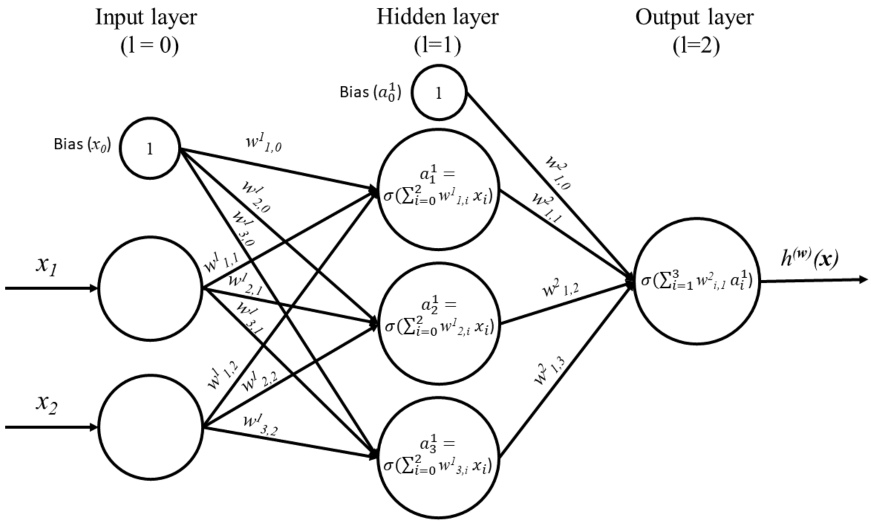

Figure 1. Schematic representation of a three-layer perceptron network [11].

In this paper, the possibility of transforming rectangular 3D into ellipsoidal coordinates was investigated using the MLP neural network. The model was used over a set of points with X, Y, and Z coordinates and their B, L and h coordinates were obtained based on a known mathematical procedure for the transition from one form to another. The results of this research, based on such a set of data, aim at a general verification of the possibility of coordinate transformation using ANN. Also, the results and conclusions of this research can be used as a starting point for researching the possibility of implementing a date transformation from a new to an existing coordinate system, and vice versa, in the research area.

2. MATERIALS AND METHODS

2.1. THE STUDY AREA

The old national reference system of the Republic of Srpska, which has been in use for more than 80 years, is based on the non-geocentric Bessel ellipsoid and the Gauss-Kriger projection of the meridian zones. The system was practically implemented with trigonometric points of various orders within the entire former SFRY. Their coordinates were determined over a long period, and with the use of different measuring technology and methodology. To achieve modern geodetic standards and create a basis for the application of new measurement technologies, since 2011, a network of permanently operational reference GNSS stations of the Republic of Srpska (SRPOS) has been used in the RS. This network represents the implementation of a new spatial reference system, ETRS89 (European Terrestrial Reference System 1989). The system is a rectangular, rectilinear, three-dimensional geocentric system tightly bound to the European lithospheric plate. In principle, the positions of points in this system are expressed by rectangular three-dimensional coordinates (X, Y, Z), while the GRS80 ellipsoid is used for ellipsoidal coordinates (B, L, h). The UTM projection of the corresponding zone is used to reduce the data to the projection plane.

2.2. INPUT DATA

To enable the application of GNSS positioning in various areas, including the state survey and real estate cadastre, the optimal coordinate transformation model between ETRS89 and the existing state reference system of the Republic of Srpska and the residual distribution method was investigated [12]. In this way, the connection between the two reference systems was established on the entire territory of the Republic of Srpska. The data from this research were used in this paper, to investigate the possibility of applying neural networks for the implementation of data transformation between these two systems in the future.

The basic data set for determining the transformation parameters and residuals' grid consisted of 1,758 points with coordinates in both systems (Figure 2). These are trigonometric points of all orders. Their ETRS89 coordinates were determined using the SRPOS grid. Considering the procedure and technology of point coordinates in the ETRS89 system, the accuracy of the horizontal position of the points ranges from 1 cm to 2 cm. Given that the coordinates were determined for each point individually, it can be considered that they are mutually uncorrelated. It can be seen that the basic set of points relatively homogeneously covers the entire territory of Republika Srpska, so it could be used to evaluate the transformation parameters.

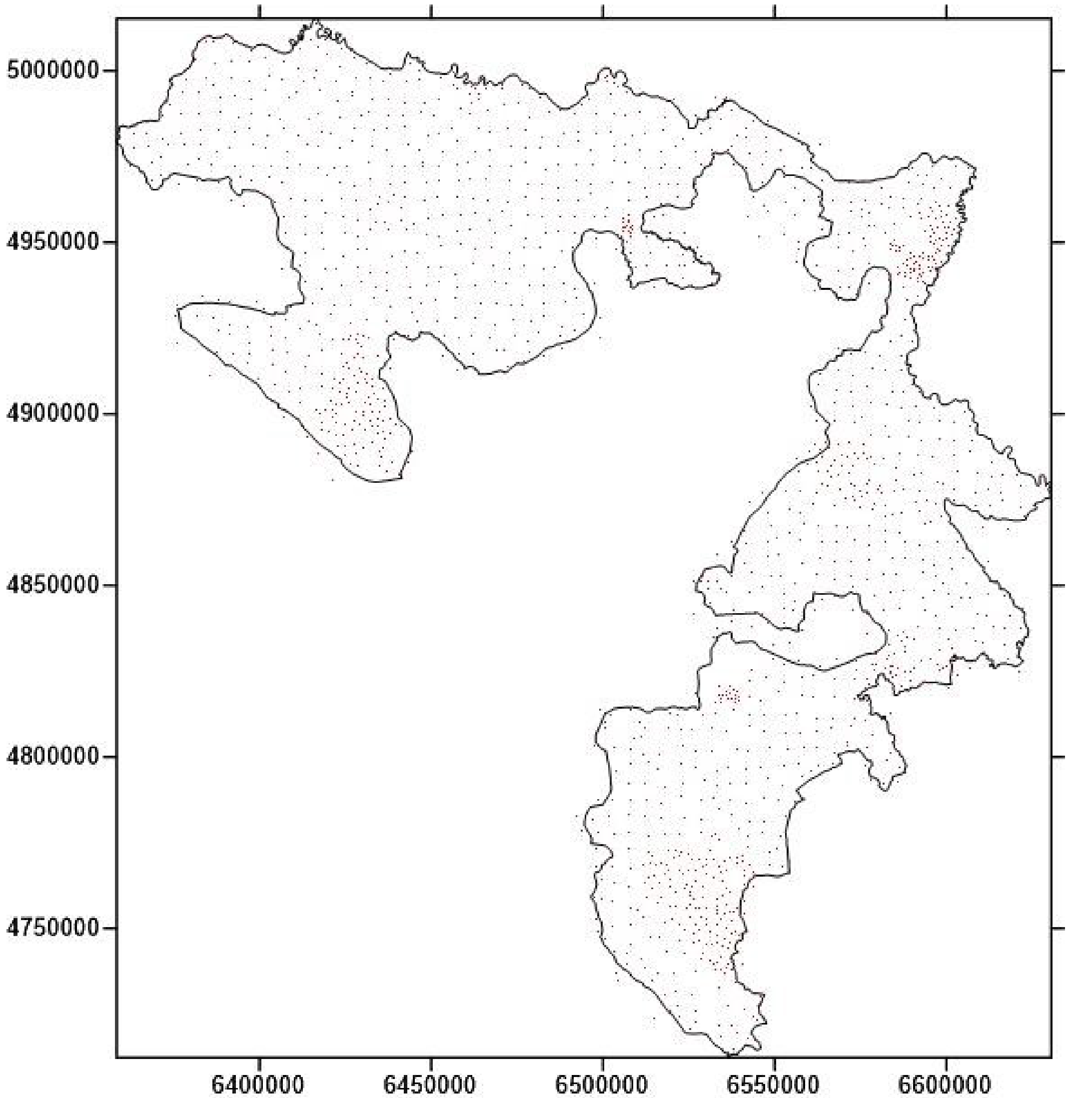

Figure 2. Points used to determine date transformation parameters in the territory of the Republic of Srpska [12]

2.3. CLASSIC TRANSFORMATION OF RECTANGULAR 3D GEODETIC INTO ELLIPSOIDAL COORDINATES

The transformation from rectangular 3D geodetic to ellipsoidal coordinates is not direct, and there are two basic approaches for its implementation: the iterative method and the closed-form method [13], [14]. Both of these approaches use the distance p from the shorter axis of the ellipsoid which is calculated for each point as:

$$p = (N + h)\cos B\,, \tag{1}$$

where N is the radius of curvature:

$$N_i = \frac{a^2}{\sqrt{a^2 \cos^2 B_i + a^2 \sin^2 B_i}}\,. \tag{2}$$

It is also necessary to give the connection between the geodetic latitude B and the rectangular 3D coordinates obtained when calculating the length of the meridian arc, which reads:

$$\tan B_i = \left(\frac{a}{b}\right)^2 \frac{z_i}{p_i}. \tag{3}$$

It can be written as:

$$z = \left(N + h - e^2 N\right)\sin B, \tag{4}$$

where e is the eccentricity of the ellipse:

$$e^2 = \frac{a^2 + b^2}{a^2}, \tag{5}$$

and where a is the semi-major axis, b is the semi-minor axis. In the end, we get:

$$\frac{z}{p} = \tan B\left(1 - \frac{e^2 N}{N + h}\right), \tag{6}$$

which is the basis for both approaches.
The closed-form method starts from the formula:

$$p \cdot \tan B - z = e^2 \cdot N \cdot \sin B. \tag{7}$$

The only unknown in this equation is B since N is also a function of B. By replacing N, dividing the numerator and denominator of the right side by cos B and squaring the entire equation, we get:

$$p^2 \tan^4 B - 2pz\tan^3 B + \left(Z^2 + \frac{p^2 - a^2 e^4}{1 - e^2}\right)\tan^2 B - \frac{2pz}{1 - e^2}\tan B + \frac{z^2}{1 - e^2} = 0. \tag{8}$$

This is a biquadratic equation by tan B in which all the coefficients are known. When B is obtained from this equation, N, h and L are further calculated. This solution is about 25% faster than the iteration method.

Apart from the described closed-form method, there are several other approaches for this transformation, such as the non-iterative method [15], the iterative method [16] and the vector method [17].

2.4. TRANSFORMATION OF RECTANGULAR 3D GEODETIC INTO ELLIPSOIDAL COORDINATES USING MLP NEURONAL NETWORKS

The author of the paper [18] states that the best results for converting rectangular 3D coordinates into ellipsoidal coordinates were given by models based on MLP, where

X, Y, and Z coordinates are used to obtain one output parameter: B, L or h. A neural network structure with two hidden layers was used, and Bayesian regularization was used for training.

The Bayesian method was first explained in detail by a geophysicist from Cambridge, Sir Harold Jeffreys [19]. The logical basis of this method, based on the use of probabilities as a measure of credibility, was subsequently established by Cox [20], who proved that consistent inference in a closed hypothesis space can be mapped onto probabilities.

BR artificial neural networks (Bayesian regularized artificial neural network - BRANN) are more robust than standard feedback regularization networks and can reduce or eliminate the need for long-term cross-validation. BR is a mathematical process that turns nonlinear regression into a "well-posed" statistical problem. These networks provide solutions to numerous problems such as model selection, model robustness, validation set selection, and network architecture optimization [21]. It is difficult to overload them, because BRANN calculates and trains several network parameters or weights, effectively excluding those that are not relevant. This effective number is usually much smaller than the number of weight coefficients in a standard, fully connected, back-propagation neural network.

Considering that the practical research in the work of Konakoglu [18] was performed in the commercial software environment Matlab, the mentioned neural network, for this research, was reconstructed in a free environment. To solve this task, the Google Colab platform was used, that is, the Python programming language with the sklearn, keras, and tensorflow libraries.

The architecture of the applied model is MLP type (Figure 2). It consists of three input neurons (corresponding to the number of input attributes) and two hidden layers with 15 neurons in each layer. Given that there is no rule for selecting the activation function, it was chosen following the context of the research, that is, according to the task being performed. The Tanh activation function [22] was used, because it has gradients that are not constrained to vary in a certain direction. The output layer contains one neuron, which represents the prediction for B, L and h. A separate prediction was made for each element.

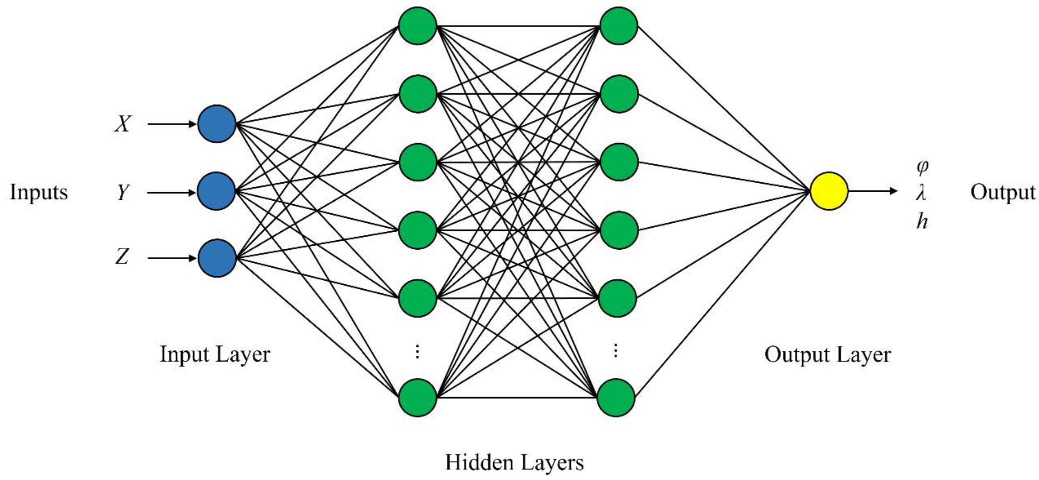

Figure 3. Structure of MLP neural network with one output parameter [18]

Model training was performed on a set of 1,500 points (Figure 2), while the rest was used for validation. The model was trained over 500 epochs, with a batch size of 10, which is an update of the weights every 10 samples.

2.5. STATISTICAL INDICATORS OF ADEQUACY OF TRANSFORMATION USING MLP NEURAL NETWORKS

The quality of the transformation of rectangular 3D geodetics into ellipsoidal coordinates using MLP neural networks was checked by calculating standard statistical measures of quality: root-mean-squared error (RMSE), mean bias error (MBE), mean absolute error (MAE) and Nash-Sutcliffe efficiency coefficient (NSE).

RMSE is the square root of the average of the squared deviations between observed and predicted coordinates. The mean squared error is a type of dimensioned statistical estimate that is always positive and includes the concept of bias and standard deviation. It is used to quantify the degree of dispersion of model predictions on observed data. Ideally, optimal models should have RMSE values of zero. However, in practice, the RMSE could vary from zero to infinity and is calculated as:

$$RMSE = \left(\frac{1}{n} \sum_{i=1}^{n} (O_i - P_i)^2 \right)^{1/2}, \tag{9}$$

where O_i represents the observed coordinates, P_i the predicted coordinates, and n the number of observations.

MBE is an indicator of the average deviation of the predicted values from the corresponding observed data. A positive MBE value indicates that the predicted values of the coordinates are less than their observed values, and vice versa:

$$MBE = \frac{1}{n} \sum_{i=1}^{n} (O_i - P_i). \tag{10}$$

MAE is the average of absolute differences between observed and predicted coordinates and is calculated as:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|O_i - P_i\right|. \tag{11}$$

NSE is used to evaluate the predictability of the model. An efficiency of “1”, i.e. NSE = 1, corresponds to a perfect match between the observed and predicted coordinates and is calculated as [23]:

$$NSE = 1 - \left(\sum_{i=1}^{n}\left(O_i - P_i\right)^2 \Big/ \sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2 \right), \tag{12}$$

where $\bar{O}$ represents the mean value of the observed coordinate.

3. RESULTS AND DISCUSSION

In previous research, which considered the possibility of using ANN for coordinate transformation, it was pointed out that the form of a neural network with one hidden layer is not sufficient for precise predictions. Therefore, a neural network with two hidden layers was applied to the data used in this research, which is the approach that was also used in the research described in the work of Konakoglu [18]. Also, based on the conclusion highlighted in the mentioned paper, the MLP neural network model with one output was chosen and applied in this research.

After the transformation of the coordinates using the mentioned model, the minimum deviation in B and L coordinates is 0.000001", while the maximum deviations in B are 0.00009", and in L 0.00005". The minimum height deviation is 0.00002 m, and the maximum deviation is 0.00003 m.

Statistical indicators of the quality of the neural network model, obtained by training on a set of training points, were evaluated on a set of validation points and are shown in Table 1. Based on the RMSE value, it can be said that MLP neural networks gave good results and showed the potential of these networks for transforming rectangular 3D into ellipsoidal geodetic coordinates. MBE and MAE were also used to evaluate the quality of the neural network (Table 1). The low values of MAE and MBE additionally indicate the possibility of applying the generated neural network for predicting the values of unknown quantities. Finally, an NSE value greater than 0.99 confirms the general performance quality of the network obtained by training on the input data set.

Table 1. Results obtained from testing

	RMSE	MBE	MAE	NSE
X, Y, Z →B	0.0000356 ["]	0.0000037 ["]	0.0000237 ["]	0.99998
X, Y, Z →L	0.0000359 ["]	0.0000020 ["]	0.0000246 ["]	0.99998
X, Y, Z →h	0.0000232 [m]	0.0000014 [m]	0.0000201 [m]	0.99999

4. CONCLUSION

In this research, the possibility of applying MLP neural networks trained using the BR algorithm for the transformation of rectangular 3D (X, Y, Z) into ellipsoidal geodetic coordinates (B, L, h) was examined. Compared to previous researches, this model was applied to data belonging to the territory of an irregular shape. The results showed that MLP neural networks, based on Bayesian regularization with one output, can be used to predict the values of unknown ellipsoidal coordinates. The coordinates are estimated with certain error values, which are not statistically significantly higher than the error values of the coordinates of the points on which the network was "trained". Generally speaking, it can be concluded that the estimated values of the ellipsoidal coordinates maintained a good general agreement and relative relationship, defined by the corresponding values of the rectangular 3D coordinates. Also, previous practical research was performed in the commercial software environment MatLAB, while the mentioned neural network, for the purposes of this research, was reconstructed in a free environment, using the Google Colab platform, that is, the Python programming language.

Research has shown that ANN neural networks, based on BR algorithms, can transform rectangular 3D coordinates into ellipsoidal geodetic coordinates. Future research, which will be based on the results of this research, should analyze the possibility of applying neural networks for data transformation between the mentioned geodetic reference systems that are used and coexist in the research area.

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61
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STEPGRAD
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VALIDATION OF THE NEQUICK AND IRI MODELS BASED ON DATA FROM IONOSONDES

Abstract

This study compares the NeQuick and IRI ionospheric models using data from ionosondes as reference. Validation based on data obtained by direct measurement using ionosondes helps to refine empirical models and improves their reliability. In this way, it is possible to identify the differences and limitations of the model and contribute to its improvement. As the NeQuick and IRI models provide tools for the study of ionospheric variability and forecasts of the ionospheric TEC coefficient, their versions are constantly being improved and need to be validated accordingly. Therefore, this research is based on the comparison of the TEC coefficient for the validation of two different ionosphere models based on data from three different regions of Europe.

Keywords: TEC, IRI, NeQuick, ionosphere, validation, ionosond

ОЦЈЕЊИВАЊЕ МОДЕЛА NEQUICK И IRI НА ОСНОВУ ПОДАТАКА ИЗ ЈОНОСОНДИ

Сажетак

Ово истраживање упоређује NeQuick и IRI моделе јоносфере користећи као референтне податке мјерења добијених примјеном јоносонди. Валидација на основу података добијених директним мјерењем путем јоносонди помаже у усавршавању емпиријских модела и побољшава њихову поузданост. На тај начин омогућава се идентификовање разлика и ограничења модела и доприноси његовом побољшању. Како NeQuick и IRI модели пружају алате за проучавање варијабилности јоносфере и прогнозе TEC коефицијента у јоносфери, њихове верзије се стално унапређују и потребно их је сходно томе валидирати. Због тога ово истраживање је базирано на упоређењу TEC кеофицијента за валидацију два различита модела јоносфере на основу података са три различита региона Европе.

Кључне ријечи: TEC, IRI, NeQuick, јоносфера, валидација, јоносонда

1. INRODUCTION

The validation of ionospheric models is crucial for ensuring the accuracy and reliability of predictions used in various applications, such as satellite communication, navigation systems, and space weather monitoring. Among the widely used ionospheric models, NeQuick and IRI (International Reference Ionosphere) stand out for their extensive utilization and application across diverse fields. Comparing model outputs with data from ionosondes provides valuable insights into their performance under different conditions. This validation process helps researchers identify any discrepancies or limitations in the models and refine them accordingly. By analyzing data from ionosondes, researchers can assess the models' ability to predict ionospheric behavior accurately. Improving the accuracy of ionospheric models is crucial for enhancing various applications, including satellite communication and GPS navigation. Furthermore, validated models contribute to better space weather forecasting, which is vital for safeguarding sensitive technological systems. The validation of NeQuick and IRI models based on data from ionosondes aids in advancing our understanding of ionospheric physics. It also facilitates the development of more reliable tools for studying and monitoring ionospheric variability. The practical implications of this research extend to a wide range of industries and sectors that rely on accurate ionospheric models for operational purposes. Ultimately, the validation of NeQuick and IRI models represents a significant step forward in improving the reliability and effectiveness of ionospheric modeling for various applications.

The ionosphere, a region in Earth's atmosphere, exhibits remarkable dynamism, with electron density undergoing significant spatial and temporal variations. These fluctuations are influenced by various factors, including altitude, geomagnetic location, time of observation, seasonal variations, solar cycle, and geomagnetic field activity. Given the complexity of ionospheric dynamics, accurate modeling of ionospheric parameters is crucial for a wide range of applications, including communication, navigation, and space weather forecasting.

In this context, the goal of the research is to assess the accuracy of two prominent ionospheric models, namely the International Reference Ionosphere (IRI) and NeQuick, by comparing their predictions with ionosonde measurements. Ionosondes provide direct measurements of electron density profiles in the ionosphere, serving as ground-truth data for validating ionospheric models.

By conducting this comparison, the study aims to evaluate the performance of the IRI and NeQuick models across different geographical locations, geomagnetic conditions, and temporal scales. Understanding the strengths and limitations of these models is essential for improving ionospheric modeling capabilities and enhancing the reliability of ionospheric parameter predictions. Ultimately, the research seeks to contribute to advancements in space weather forecasting and the development of more accurate models for ionospheric characterization.

2. IONOSPHERE AND GNSS SIGNALS

The ionosphere, a dynamic region of Earth's atmosphere, plays a crucial role in the propagation of GNSS signals. Its composition of charged particles interacts with radio waves emitted by GNSS satellites, causing delays and distortions in signal transmission. Understanding ionospheric behavior is essential for accurately interpreting GNSS measurements and mitigating navigation errors caused by ionospheric disturbances.[10]

The layers at altitudes ranging from approximately 60 km to 2000 km contain a relatively large number of electrically charged atoms and molecules, constituting the ionospheric region. Depending on the level of ionization, the ionosphere is divided (Figure 1.) into four primary layers: D (60-90 km), E (90-140 km), F1 (140-210 km), and F2 (above 210 km).

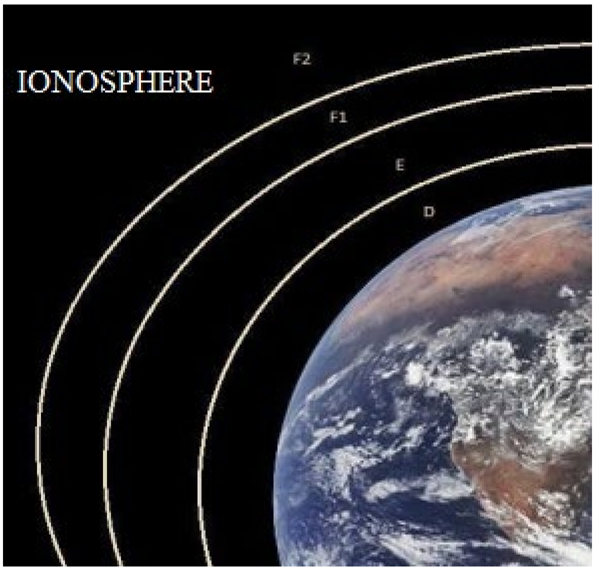

Figure 1. Dividing of ionosphere

2.2. ATMOSPHERE

The Earth's atmosphere is composed of various gases, with oxygen making up only 21%, alongside nitrogen, argon, and trace amounts of other gases like carbon dioxide and methane. It's divided into four main layers: troposphere, stratosphere, mesosphere, and thermosphere, each with distinct characteristics in temperature and composition. The troposphere, closest to the Earth's surface, contains the majority of the atmosphere's mass and is where weather phenomena occur. The stratosphere, with its increasing temperature, contains the ozone layer that shields the Earth from harmful ultraviolet radiation. The mesosphere is where meteors burn up upon entry. The thermosphere, with its high temperatures, is interesting because phenomena like the Northern and Southern Polar Lights and houses satellites and the International Space Station. Beyond these layers, the exosphere merges with space. Additionally, the atmosphere is crucial for signal propagation in navigation systems like GNNS, with the troposphere and ionosphere being particularly relevant. Understanding the dynamics of the atmosphere, especially the ionosphere, is essential for accurate satellite positioning.[10][11]

2.3. COMPOSITION OF THE IONOSPHERE

The ionosphere is formed due to three main factors: solar characteristics, Earth's magnetic field, and Earth's atmosphere. Solar radiation, including X-rays, ultraviolet light, visible light, and radio waves, interacts with Earth's atmosphere, particularly at the top, where the solar constant is approximately 1370 W per square meter. Earth's magnetic field influences the flow of ionized plasma from the Sun, shaping the ionosphere around the planet. Electric currents in Earth's core create the magnetosphere, extending into space. The atmosphere, spanning from sea level to about 1000 km altitude, is divided into several layers based on temperature, ionization, and signal propagation capabilities. The ionosphere, a dynamic region within Earth's atmosphere, undergoes spatial and temporal changes in electron density, influenced by factors such as altitude, geomagnetic location, solar cycle, and season. It consists of four main layers: D, E, F1, and F2. Geomagnetic latitude significantly affects electron density formation in the ionosphere, with notable differences between equatorial, mid-latitude, and high-latitude regions.

In recent years, ionospheric research has been focused on determining the most accurate Total Electron Content (TEC) coefficient using the IRI and NeQuick models, along with ionosonde data from the DIDB (Digital Ionogram Database) website. Studies such as those by Smith et al. (2021)[1] and Wang et al. (2022) [2] have explored methodologies for improving TEC predictions and assessing model reliability, while works such as those by Jones and Brown (2023) [3] and Chen et al. (2023) [4] have analyzed model performance during geomagnetic storms and seasonal variations. Additionally, research has included the integration of data from various sources, such as combining ionosonde data and models to enhance real-time predictions, as demonstrated by Garcia and Patel (2024) [5]. Model performance evaluations under different geographic and geomagnetic conditions, as well as in urban areas with high levels of electromagnetic interference, have been highlighted in studies such as those by Kim et al. (2024) [6] and Zhang et al. (2024) [7]. These works collectively represent a step towards better understanding ionospheric processes and improving the accuracy of TEC predictions. Furthermore, studies like those by Li and Wang (2024) [8] and Sato et al. (2024) [9] have compared model performance with raw GNSS data to better understand the interactions between the ionosphere and GNSS signals, providing deeper insights into ionospheric dynamics in real terrain conditions.

2.4. THE INFLUENCE OF THE IONOSPHERE ON GNSS SIGNALS

The ionosphere, influenced by various factors including solar electromagnetic radiation and Earth's magnetic field, significantly impacts radio communication, navigation, aviation, and GNSS. Total Electron Content (TEC) is a crucial parameter affecting ionospheric characteristics. GPS measurements are prone to errors categorized into satellite-related, signal propagation environment, receiver, and other errors. Dual-frequency GPS receivers effectively mitigate ionospheric delays, while single-frequency receivers can be accurate with local ionospheric models but less suitable for long baselines. Ionospheric TEC models can correct ionospheric effects for accurate data processing under specific conditions.[10][12][13]

3. IONOSPHERE MODELS

The ionosphere, a complex atmospheric layer, is modeled using various approaches, including empirical, numerical, analytical, and physical models. Empirical models utilize measurements and statistical analyses, while numerical maps represent ionospheric parameters globally or regionally. Analytical models rely on mathematical functions fitted to numerical data, and physical models are based on the physical equations governing electron and ion movement in the ionosphere. Each type of model offers unique insights into ionospheric behavior and is utilized for different applications, such as GNSS signal correction and understanding ionospheric processes.

3.1. NEQUICK MODEL

NeQuick is a sophisticated model designed to predict electron density in the ionosphere. Integrated into the Galileo navigation system, it plays a crucial role in calculating ionospheric effects affecting signal accuracy, particularly for users relying on a single frequency. Based on the ITU-R NeQuick model, it utilizes empirical data to predict monthly average electron density values, considering various parameters like sunspot numbers, solar flux, geographical coordinates, altitude, and universal time. To operate in real-time for Galileo users with single-frequency points, NeQuick uses the "Effective Ionization Level" parameter, derived from coefficients transmitted by Galileo satellites. Its versatility lies in providing corrections for ionospheric delay in vertical and slant directions by integrating projected electron density along the satellite-receiver line. Additionally, NeQuick adjusts for daily changes in solar activity and local geomagnetic conditions, enhancing correction accuracy and navigation precision. The Galileo single-frequency application algorithm involves calculating coefficients and integrating electron density values to obtain Slant Total Electron Content (STEC), which is then converted to meters for compatibility.

$$I_f = \frac{4.3 * 10^{16} 0}{f^2 [Hz]} TEC \tag{1}$$

This formula represents the ionospheric correction factor (I_f) as a function of Total Electron Content (*TEC*) and frequency (*f*). The constant (4.3 times 10^{16}) is multiplied by TEC and divided by the square of the frequency (*f*) in Hertz. This formula quantifies the impact of TEC on the ionospheric correction factor, which is essential for accurate signal propagation in radio communication and satellite navigation systems. These ionospheric corrections obtained from the NeQuick model are universally applicable to any GNSS signal, provided the correct frequency is set. With NeQuick 2, the latest iteration developed in collaboration between ICTP in Trieste, Italy, and the University of Graz, Austria, significant advancements have been made, promising improved performance and accuracy in predicting ionospheric effects for enhanced satellite navigation systems like Galileo.[10][15]

3.2. IRI MODEL

The International Reference Ionosphere (IRI) project, developed under Commitet on Space Research (COSPAR) and International Union of Radio Science (URSI), aims to create a comprehensive model of Earth's ionosphere for global prediction and analysis. Initiated in the 1960s, the IRI model has undergone multiple versions, with significant advancements introduced since its inception, including updates in 1978, 2001, 2007, and 2012. Its structure comprises global models tailored to distinct ionospheric regions (D, E, F1, and F2 layers), factoring in variables such as solar activity, geomagnetic conditions, and geographic location. These models provide detailed electron density profiles crucial for forecasting ionospheric conditions across various Earth locations. Modified CCIR models are utilized to compute peak electron densities in regions like F2, F1, and E, with different coefficient sets for continental and oceanic areas.[10][16]

The height of the F2 peak, is calculated from M(3000)F2 using the empirical formula (Bilitza and Eyfrig, 1979):

$$h_{F2} = \frac{1490}{M(3000)F2+DM} - 176 \tag{2}$$

where the correction factor is calculated as:

$$DM = \frac{f_1 \cdot f_2}{\left(\frac{f_0F2}{f_0E-f_3}\right)+f_4} \tag{3}$$

with solar activity function:

$$f_1 = 0.00232R_{12} + 0.222 \tag{4}$$

$$f_2 = \frac{1-R_{12}}{150expexp} \tag{5}$$

$$f_3 = 1.2 - 0.0116expexp\left(\frac{R_{12}}{41.84}\right) \tag{6}$$

$$f_4 = \frac{0.096(R_{12}-25)}{150} \tag{7}$$

where R12 is the mean annual solar number of sunspots, and Ψ is the magnetic dip latitude.

IRI employs both geodetic and magnetic coordinate systems to capture ionospheric characteristics at different altitudes, enabling accurate modeling of electron density distributions and peak heights. While effective in mid-to-high latitudes, the IRI model faces challenges in equatorial regions during heightened solar activity, necessitating enhancements for better accuracy. To address this, historical satellite data from missions like Alouette and ISIS are integrated to refine parameters and improve predictive capabilities, particularly in regions prone to significant ionospheric variability.

DIDB doesn't use a specific formula itself; rather, it collects, stores, and provides access to ionospheric data obtained from ground-based ionosonde measurements. Ionograms contain information about the time it takes for radio waves to travel through the ionosphere and reflect back to the ground, allowing researchers to derive electron density profiles. Various algorithms and processing techniques may be applied by researchers to analyze ionogram data and derive electron density profiles, but DIDB itself is primarily a repository for this data rather than a tool for data analysis.

3.3. DIGITAL IONOGRAM DATABASE -DIDB

The DIDB is a centralized platform storing digitized ionograms, which represent plasma density profiles in the ionosphere obtained from ground-based ionosonde measurements. This database facilitates access to ionospheric data for researchers worldwide, enabling analysis and utilization for various scientific studies and applications. DIDB contains a vast collection of ionogram records gathered from ionosonde stations globally, offering valuable insights into electron density distribution at different altitudes and times. Researchers can search the database based on specific criteria such as time, location, frequency, and ionosonde type, retrieving ionogram images, raw data, and associated metadata for further analysis. Access to digitized ionogram data via DIDB promotes collaboration and knowledge sharing among the scientific community, contributing to advancements in ionospheric research and space science.

4. COMPARISON MODELS

This section of the paper involves comparing the two models mentioned earlier (NeQuick and IRI) using the TEC coefficient. The results and differences for both models will be compared for each of the following stations in cities (Figure 2.):

- Tromso - Norway (TRO100NOR)

- Prague - Czech Republic (WTZA00DEU)
- Nicosia - Cyprus (ISTA00TUR)

Figure 2. Mape with positions of the cities whose TEC coefficients were compared in these research paper.

Three stations in Europe were selected for comparison, situated at different geographical latitudes: northern, central Europe, and the southern part. The stations were chosen in this manner due to the variation in ionospheric influence based on geographical latitude. The objective is to observe the alignment of these models depending on the different station positions. Since the data-collecting stations were not operational simultaneously, it was necessary to find stations that operated in the same year, day, and time. The NeQuick model displayed the years of operation for each station, while for the IRI model, only the application version available on the official website was allowed to be chosen. Here, IRI 2016 was used, knowing that data was available until 2016. The model for the year 2020 did not yield any results, so the previous 2016 model was chosen for consistency. After comparison and research, the three mentioned cities Tromso, Prague, and Nicosia were selected for the corresponding year.
In addition to comparing these two models, they were also compared with DIDB data directly taken from ionosondes. These data served as reference data for the validation of both models.

4.2. NEQUICK, IRI AND DIDB WEB ENVIRONMENT

The computation of ionospheric coefficients for modeling was conducted using the web applications NeQuick (Figure 3) and IRI (Figure 4), accessible at the following URLs: https://t-ict4d.ictp.it/nequick2/gps-tec-calibration-online
and https://kauai.ccmc.gsfc.nasa.gov/instantrun/iri/, respectively. Accurate station names were obtained from the Ionosondes – DIDB website (https://giro.uml.edu/didbase/scaled.php), facilitating precise identification of each station.
These web applications are open to all users, and their utilization is permitted to everyone. While the NeQuick model link provides access solely to the TEC coefficient, additional coefficients can be obtained within a specified time interval at the following link: https://t-ict4d.ictp.it/nequick2/nequick-2-web-model.
The NeQuick web application features straightforward input and output data procedures. Users are required to input the station name, date, and specified time interval for data retrieval. The output provides TEC coefficients for the designated hourly time interval.

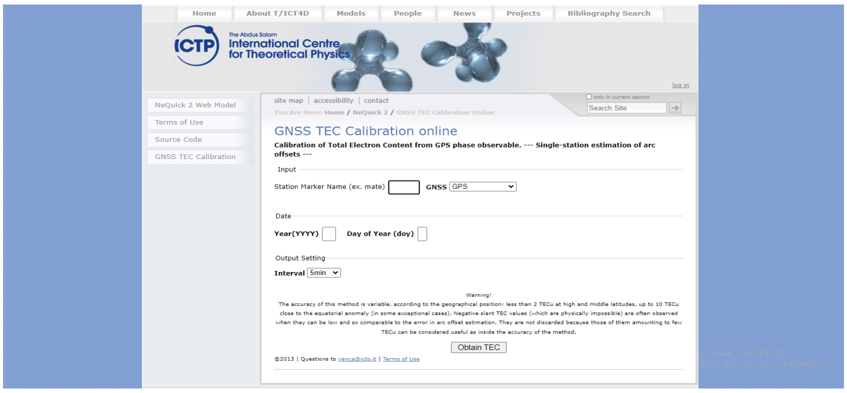

Figure 3. NeQuick web environment

The results were obtained for the specified time interval, with data collected every hour. For each of the three stations and for the onset of each season, TEC coefficients and histograms were generated for every hour.

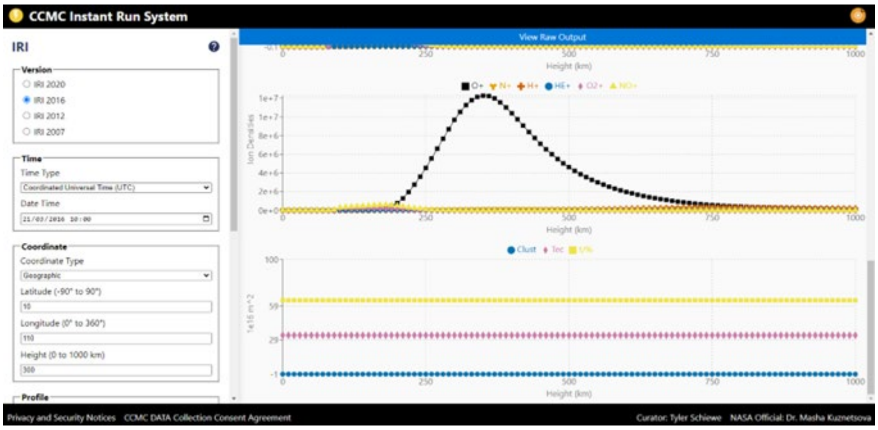

Figure 4. IRI web environment

The IRI web application presents a slightly more intricate interface compared to the previous NeQuick application. Here, users must input the type of time, date, time, coordinate type (including all three coordinates), as well as data related to terrain profile, as the results are obtained by altitude. To obtain data for every hour, it was necessary to continuously adjust the time. While the IRI application averages data over time, it still presents variations by altitude. The need for constant time adjustment was the primary challenge with this web application. Unlike the NeQuick application, all parameters in the IRI model are derived for a single station. In addition to the TEC parameter, various other parameters such as electron density, electron temperature, ion temperature, ion composition (O+, H+, He+, N+, NO+, O+2, ion clusters), equatorial vertical ion drift, F1 probability, F spread probability, auroral boundaries, and the effects of ionospheric storms on F and E density thresholds were also obtained.

On the EPS website, stations can be searched by name or via a map display, where circles mark the cities where stations are located. Clicking on a station name opens a window containing information about its exact position in various reference systems, as well as various other details related to all European stations. The data available on the EPS, along with the use of the aforementioned models, are accessible to all users, downloadable in any format, and free to use. Calculation time intervals occur every hour during the first day of each season.

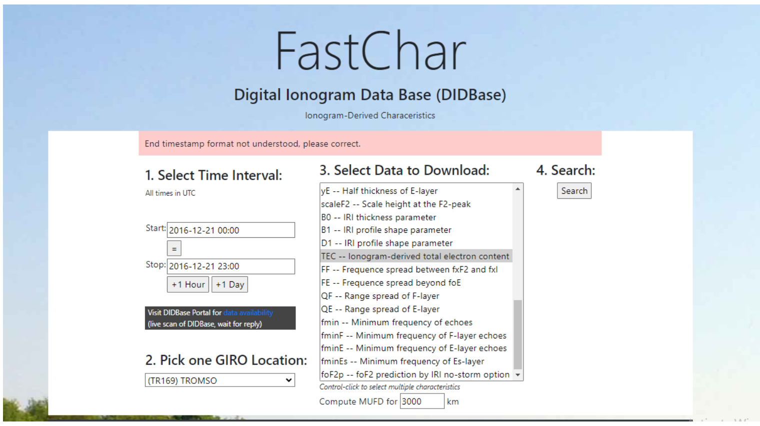

Figure 5. DIDB web environment

The DIDB web interface (Figure 5) offers a user-friendly experience. Users need to specify the required time interval, locate the station, select the data type, and click "Search." Upon searching for the specified time interval, operational stations during that period are displayed. However, the opening of a new window with data does not guarantee data availability. The time interval search provides the TEC coefficient for a specific time, which may not be available for every hour or minute due to sporadic data collection. In cases where exact hourly values are unavailable, they were either approximated to the nearest full hour or marked as missing within a reasonable interval, denoted by "?".

The Digital Ionogram Database (DIDB) does not employ a specific formula itself; instead, it gathers, stores, and offers access to ionospheric data obtained from ground-based ionosonde measurements. Ionograms provide insights into the time taken for radio waves to traverse the ionosphere and reflect back to the ground, aiding in the derivation of electron density profiles. Researchers utilize various algorithms and processing techniques to analyze ionogram data and derive electron density profiles. DIDB primarily serves as a repository for this data rather than a tool for data analysis.

4.3. CALCULATIONS OF NEQUICK AND IRI MODEL TEC COEFFICIENTS FOR THE BEGINNING OF EACH SEASON

Calculations for the first day of each season are chosen because temperature changes are more significant compared to other days throughout the year. In the next subsection, NeQuick and IRI model TEC coefficients will be presented for all four initial days of the seasons during 2016. This year is selected because all the data for all three cities were available during that year.

In the following subsections, the TEC coefficients obtained through calculations in the NeQuick and IRI models will be compared with the data from ionosondes for this city.

The selection of the three cities, Tromso, Prague, and Nicosia, situated at diverse geodetic latitudes, representing the northern, central, and southern regions of Europe respectively, facilitates a comprehensive comparison, enabling the observation of distinct TEC variations corresponding to latitude differences.

Tromso is a city in northern Norway. The name of this station is TRO100NOR and coordinates are:

$\varphi = 69.60$

$\lambda = 18.20$

h = 138.00 m

In the central part of Europe, the Prague is station in Czech Republic - GOPE00CZE. The geodetic coordinates of this city are:

$\varphi = 50.00$

$\lambda = 14.60$

h = 592.60 m

In the southern part of Europe are not find a station, the only one was on the Asian peninsula, Nicosia is the city in Cyprus (NICO00CYP) with coordinates:

$\varphi = 35.03$

$\lambda = 33.16$

h = 190.10 m

which contains data for the first days of the seasons in 2016.

4.3.1. SPRING (20.03.2016)

Based on Figures 6, 7, and 8, depicting the graphs for the first day of Spring for each of the cities where TEC was measured, it can be concluded that the coefficient values in the IRI model were closer to the reference model DIDB compared to NeQuick. Above Prague around 14.00, the TEC coefficient in the NeQuick model was better than in the IRI model, but after that hour, the IRI model performed better.

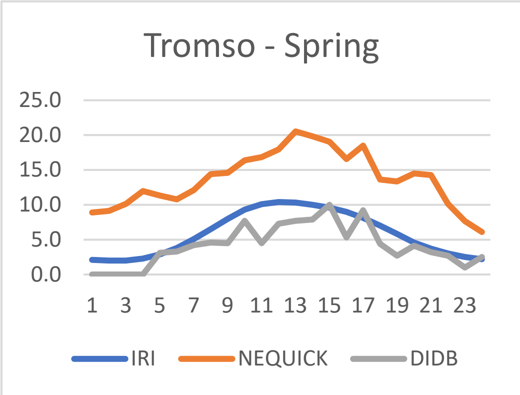

Figure 6. TEC coefficient above Tromso hourly on 1st day of Spring 2016

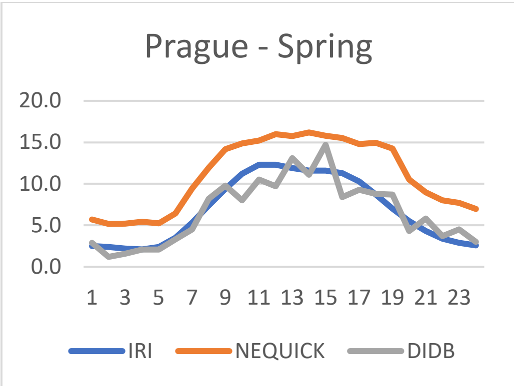

Figure 7. TEC coefficient above Prague hourly on 1st day of Spring 2016

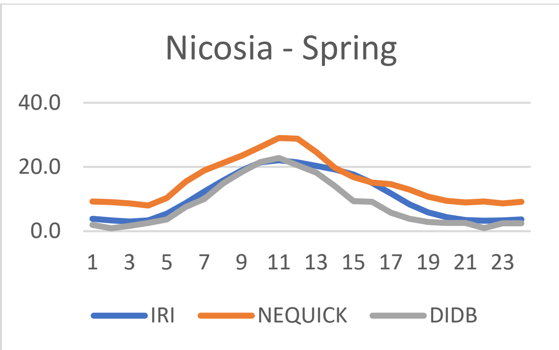

Figure 8. TEC coefficient above Nicosia hourly on 1st day of Spring 2016

Comparing the IRI and NeQuick models:
- The maximum value in the city of Tromso was observed in the NeQuick model at 12.00, with TEC amounting to 20.5. Above Prague in the NeQuick model at 1.00 oclock is TEC value 10.0 and above Nicosia at 13.00 hours, also in the NeQuick model value of TEC is 16.2.
- The minimum TEC value above Tromso was observed in the IRI model at 2.0, occurring at 1.00 and 2.00 during the night. TEC value above Prague was 1.1 at 19.00 in the IRI model, and above Nicosia at 3.00 over the night was 2.1 on the IRI model, too.

4.3.2. SUMMER (21.06.2016)

During the first day of summer (Figures 9, 10, and 11), the IRI model is closer to the DIDB reference model compared to the NeQuick model - this can be observed in the graphs presented immediately below.

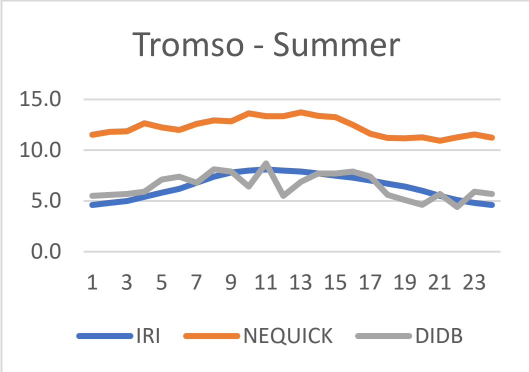

Figure 9. TEC coefficient above Tromso hourly on 1st day of Summer 2016

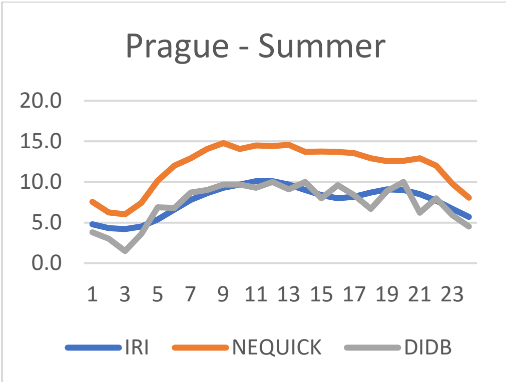

Figure 10. TEC coefficient above Prague hourly on 1st day of Summer 2016

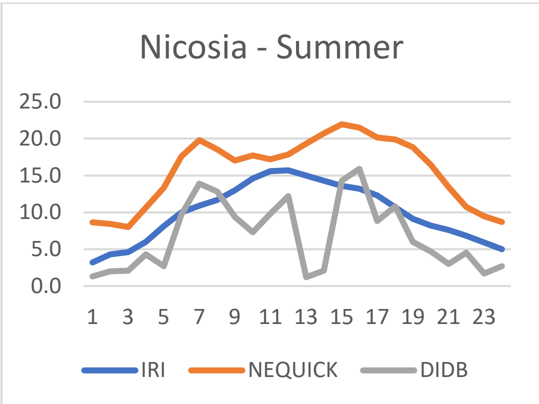

Figure 11. TEC coefficient above Nicosia hourly on 1st day of Spring 2016

The maximum TEC coefficient above the cities was as follows:

- For Tromso, the value was 13.7 in the NeQuick model precisely at noon – 12.00 PM.
- For Prague, the value was 10.0 also in the NeQuick model at 14.8 at 8.00 in the morning.
- For Nicosia, the value was 22.0 (NeQuick) at 14.00.

The minimum TEC coefficient above the cities was as follows:

- For Tromso, the value was 4.6 in the IRI model precisely at midnight – 12.00 AM.
- For Prague, the value was 4.2 also in the IRI model at 2.00 AM.
- For Nicosia, the value was 3.2 in the IRI model, at the same time as Tromso, at 00.00.

4.3.3. AUTUMN (22.09.2016)

On Autumn , te approximation of TEC coefficients by the IRI and NeQuick models above Tromso, Prague, and Nicosia, compared to the values from DIDB - ionosondes, was better with the IRI model. Over the course of 14 hours above Prague, the TEC coefficient in the NeQuick model closely approached the DIDB value, yet once again, the IRI model proved to be a better approximation – Similar situacion in Spring above the Prague in the same time.(Figure 12, 13 and 14)

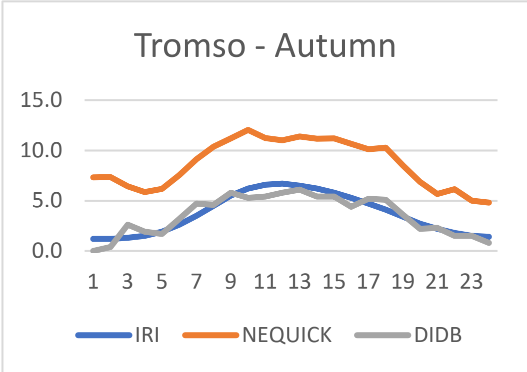

Figure 12. TEC coefficient above Tromso hourly on 1st day of Autumn 2016

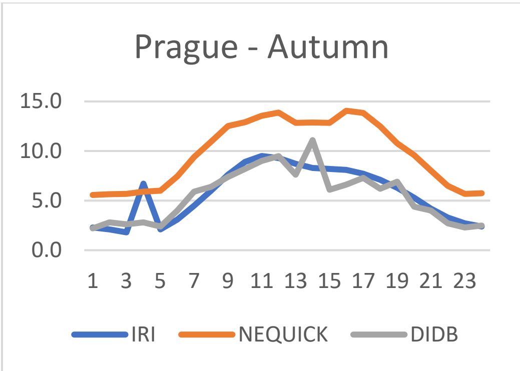

Figure 13. TEC coefficient above Prague hourly on 1st day of Autumn 2016

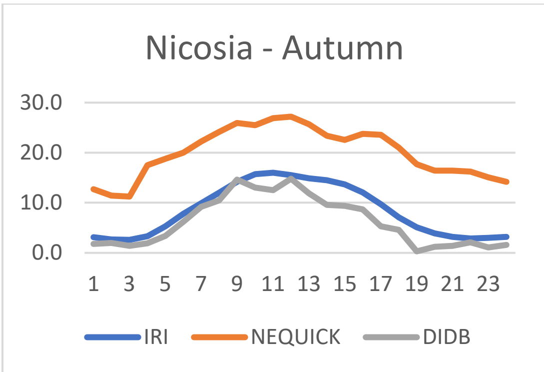

Figure 14. TEC coefficient above Nicosia hourly on 1st day of Autumn 2016

Comparison of the IRI and NeQuick models reveals the highest TEC values above:

- Tromso, with a value of 12.0 at 9.00 a.m. in the NeQuick model
- Prague, reaching 14.1 at 3.00 p.m. in the NeQuick model
- Nicosia, registering 27.2 around 11.00 AM

The lowest TEC values from this comparison above:

- Tromso, recording 1.2 at midnight and 1.00 AM in the IRI model
- Prague, showing 1.8 in the IRI model during the night at 2.00 AM
- Nicosia, indicating 2.6 - in the IRI model also at 2.00 AM

4.3.4. WINTER (21.12.2016)

In winter, as with the other seasons, the IRI model performed better compared to the NeQuick model.

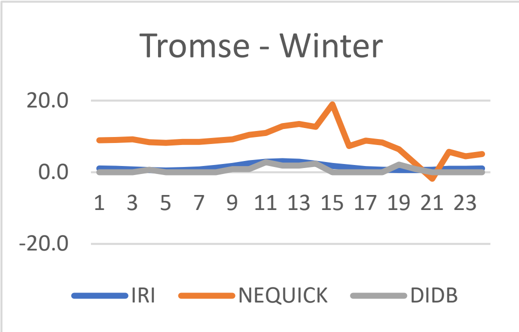

Figure 15. TEC coefficient above Tromso hourly on 1st day of Winter 2016

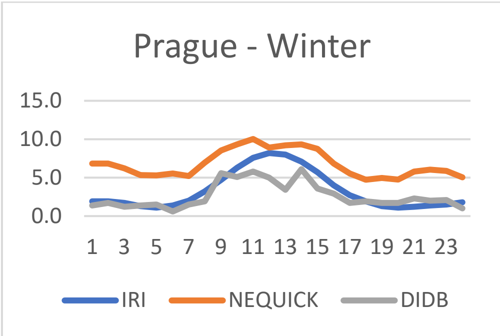

Figure 16. TEC coefficient above Prague hourly on 1st day of Winter 2016

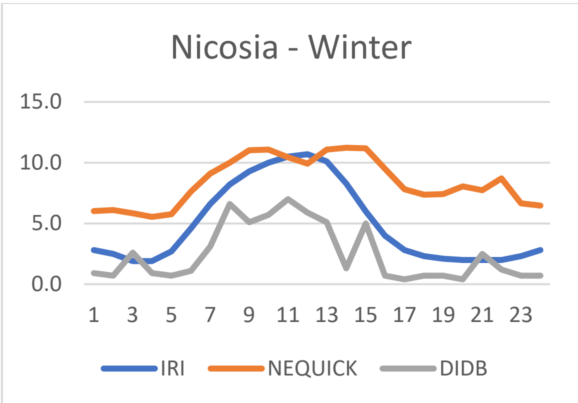

Figure 17. TEC coefficient above Nicosia hourly on 1st day of Winter 2016

On the first day of winter, the maximum value above (Figure 15, 16 and 17):

- Tromso was 13.5 in the NeQuick model at noon, 12.00.
- Prague was in the NeQuick model, specifically 10.0 at 10.00 o'clock.
- Nicosia was around 11.2 at 13.00 and 14.00 o'clock in the NeQuick model.

The minimum values were above:

- Tromso, where the TEC value was 0.55 at 4.00 in the morning according to the IRI model.
- Prague had a TEC coefficient value of 1.1, also at 4.00 in the morning.
- Nicosia had a TEC value of 1.9 at 2.00 and 3.00 in the morning according to the IRI model.

4.3.5. STANDARD DEVIATION IN ALL SEASONS

Table 1 shows the standard deviation between the NeQuick model and the IRI model, between NeQuick and DIDB, and between IRI and DIDB. This table contains data above the city of Tromso in Norway.

Table 1. The table of standard deviation for each first day of the season, above the city of Tromso, comparing both models with each other and both with DIDB data.

Season	MODEL	σ	Max σ	Min σ	Max σ	Min σ
Spring	IRI -NQ	8.78	9.66	2.30	13.06	0.70
	IRI - DIDB	2.30				
	NQ - DIDB	9.66				
Summer	IRI -NQ	5.86	5.86	1.01		
	IRI - DIDB	1.01				
	NQ - DIDB	5.85				
Autumn	IRI -NQ	4.30	5.14	0.70	Winter NQ-IDB	Autumn IRI-DIDB
	IRI - DIDB	1.27				
	NQ - DIDB	4.53				
Winter	IRI -NQ	13.06	13.06	0.95		
	IRI - DIDB	0.95				
	NQ - DIDB	8.60				

From the first table for the city of Tromso in Norway, we can see that the maximum deviation from the reference model was with the NeQuick model, both in the spring, with a standard deviation value of 9,66 and a difference of referent value was 12.8 at 12.00. The minimum standard deviation was in winter with the IRI model, amounting to 0.95, with a difference value of 0.3 at 23.00.

Table 2 shows the standard deviation between the NeQuick model and the IRI model, between NeQuick and DIDB, and between IRI and DIDB. This table contains data above the city of Prague in Czech Republic.

Table 2. The table of standard deviation for each first day of the season, above the city of Prague, comparing both models with each other and both with DIDB data.

Season	MODEL	σ	Max σ	Min σ	Max σ	Min σ
Spring	IRI -NQ	4.30	4.61	1.50	4.61	1.15
	IRI - DIDB	1.50				
	NQ - DIDB	4.61				
Summer	IRI -NQ	4.33	4.56	1.15		
	IRI - DIDB	1.15				
	NQ - DIDB	4.56				
Autumn	IRI -NQ	4.30	4.53	1.27	Spring NQ - DIDB	Summer IRI - DIDB
	IRI - DIDB	1.27				
	NQ - DIDB	4.53				
Winter	IRI -NQ	3.62	4.20	1.46		
	IRI - DIDB	1.46				
	NQ - DIDB	4.20				

In the second table for Prague in the Czech Republic, we see that the maximum deviation from the reference model was either with the NeQuick model in spring, with a standard deviation value of 4.61, and a deviation value of 7.31 at 15.00. The minimum standard deviation is with the IRI model, amounting to 1.15, with a deviation value of 0.2 at 18.00 during first day of summer.

Table 3 shows the standard deviation between the NeQuick model and the IRI model, between NeQuick and DIDB, and between IRI and DIDB. This table contains data above the city of Nicosia in Cyprus.

Table 3. The table of standard deviation for each first day of the season, above the city of Nicosia, comparing both models with each other and both with DIDB data.

<table>
<tr><th>Season</th><th>MODEL</th><th>σ</th><th>Max σ</th><th>Min σ</th><th>Max σ</th><th>Min σ</th></tr>
<tr><td rowspan="3">Spring</td><td>IRI -NQ</td><td>5.11</td><td rowspan="3">7.09</td><td rowspan="3">3.11</td><td rowspan="6">13.96</td><td rowspan="6">0.16</td></tr>
<tr><td>IRI - DIDB</td><td>3.11</td></tr>
<tr><td>NQ - DIDB</td><td>7.09</td></tr>
<tr><td rowspan="3">Summer</td><td>IRI -NQ</td><td>6.15</td><td rowspan="3">9.55</td><td rowspan="3">5.00</td></tr>
<tr><td>IRI - DIDB</td><td>5.00</td></tr>
<tr><td>NQ - DIDB</td><td>9.55</td></tr>
<tr><td rowspan="3">Autumn</td><td>IRI -NQ</td><td>0.16</td><td rowspan="3">13.96</td><td rowspan="3">0.16</td><td rowspan="6">Autumn
NQ - DIDB</td><td rowspan="6">Autumn
IRI - DIDB</td></tr>
<tr><td>IRI - DIDB</td><td>2.612</td></tr>
<tr><td>NQ - DIDB</td><td>13.959</td></tr>
<tr><td rowspan="3">Winter</td><td>IRI -NQ</td><td>3.968</td><td rowspan="3">6.13</td><td rowspan="3">3.01</td></tr>
<tr><td>IRI - DIDB</td><td>3.010</td></tr>
<tr><td>NQ - DIDB</td><td>6.129</td></tr>
</table>

The largest deviation occurred on the first day of autumn between NeQuick and DIDB, amounting to 13.96, with a deviation value of 1.3 at 16.00. The smallest deviation, also in autumn as in other cases, was between the IRI and DIDB models, with a value of 1.61, and the difference was 0.16 at 8.00 in the morning.

Analyzing the results obtained from the IRI and NeQuick models compared to DIDB as the reference model is complex. Initially, the NeQuick model provided data at half-second intervals, but later, the website was updated, and the selected interval was obtained. Initially, the data were for all satellites and were not averaged, but after the update, an averaged TEC coefficient was obtained, which later facilitated work. IRI was calculated based on the profile, and a change in the TEC coefficient at a certain altitude was observed.

From the tables above, it can be seen that the maximum and minimum values are calculated at approximately the same time during the day, but these values differ. This occurs due to parameters that are either included or not included in the model, as models arrive at TEC coefficients in different ways.

From all the graphs, it can be observed that the TEC coefficient curves obtained by the IRI model are smoother than those obtained by the NeQuick model, which have sharper transitions. Generally, the highest TEC parameter values are obtained for all days for the Nicosia area, and the lowest for the Norwegian area. This is expected because the ionospheric impact is more significant at higher at these latitudes, the Earth's geomagnetic field is tilted more vertically, resulting in a greater number of ion particles in the ionosphere.

Additionally, it should be noted that the data from the IRI model were taken at a higher node, 1000 m, but it was noticed that changing the maximum height affects the TEC coefficient. Since in this case, the maximum height of 1000 m was taken, the IRI model was closer. It is assumed that by increasing the height profile in IRI, the difference from DIDB data would increase, and NeQuick would perform better. It should also be added that there were no available data for every moment/hour in the DIDB reference model, so that time was not included in the overall calculation, but only with the data that were available.

5. CONCLUSION

Based on the analysis of ionospheric research in recent years, significant progress has been made in understanding and assessing TEC using various models such as IRI and NeQuick, along with integrating ionosonde data from the DIDB website. These models have been extensively studied in the context of different geographic and geomagnetic conditions, as well as in urban areas with high levels of electromagnetic interference. Studies have also focused on improving the accuracy of TEC predictions, particularly during geomagnetic storms and seasonal variations. Additionally, research has highlighted the importance of integrating data from various sources, such as ionosondes and GNSS, to enhance real-time predictions. These work represent a step towards a deeper understanding of ionospheric processes and increasing the accuracy of TEC predictions, which is crucial for various applications in telecommunications, navigation, and space exploration.

5.1. OBSERVATION AND FUTURE RESEARCH

We need to find the reason why significant changes occur in TEC coefficients at 80 km in the IRI model during certain time periods. We should investigate why specifically at 80 km and what disrupts the calculations there.

Both models follow the trend of increasing TEC during daytime hours and decreasing during nighttime, providing good estimates during different seasons. Regarding simplicity and speed of use, the NeQuick model has an advantage because its input and output data are simpler. The IRI model is more complex in terms of the multitude of input coefficients that need adjustment and output information that is not relevant for these purposes, requiring additional time investment.

In any case, in future research, these data should be validated with TEC data obtained from the same stations using original GNSS observations or ionosonde data. This way, we could assess the level of accuracy of these two models and determine, based on a reference model, which of these two models more accurately approximates TEC coefficients.

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62
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APPLICATION OF GEODETIC AND HYDROMETRIC MEASUREMENTS FOR THE PURPOSES OF DEFINING THE WATER BALANCE – THE EXAMPLE OF “DEDIN MLIN” NEAR SVETI ĐURĐ ON THE PLITVICA RIVER, CROATIA

Abstract

This paper presents the application of geodetic and hydrological measurements to define the water balance in the example of a lake in an alluvial medium. The purpose of the above is to provide insight into parts of the lake's water balance since evaporation from the water surface (evaporation) and precipitation, along with infiltration and surface inputs and outputs from the lake, represent input data for the water balance calculation. An example of a modern approach to geodetic and hydrometric measurements on a lake created by damming the Plitvice watercourse for water inflow to the former mill for grinding grain, called "Dedin mlin", is presented.The emphasis of the work is on the field part, which includes measuring the flow and speed of the Plitvice River on the profile at the exit from the lake, as well as determining the lake's surface using an unmanned aerial vehicle. Using a mini-submarine, insight was obtained into the lake's shape, i.e., the conditions at the bottom and along the edges of the bed. Quality analysis of the water balance is essential for calculating the volume of new reservoirs that will be designed and built and for analyzing the water balance of existing reservoirs and natural lakes.

Keywords: lake, Plitvica river, hydrometry, geodetic measurements, balance sheet

ПРИМЈЕНА ГЕОДЕТСКИХ И ХИДРОМЕТРИЈСКИХ МЈЕРЕЊА ЗА ПОТРЕБЕ ДЕФИНИРАЊА ВОДНЕ БИЛАНЦЕ – ПРИМЈЕР “ДЕДИНОГ МЛИНА” КОД СВЕТОГ ЂУРЂА НА РИЈЕЦИ ПЛИТВИЦИ, ХРВАТСКА

Сажетак

У овом раду приказана је примјена геодетских и хидролошких мјерења за потребе дефинисања водне биланце на примјеру језера у алувијалном медију. Сврха наведеног је увид у дијелове водне биланце језера, будући да испаравање са водне површине (евапорација) и оборине, уз инфилтрацију те површинске улазе и излазе из језера, представљају улазне податке за прорачун водне биланце. Приказан је примјер модерног приступа геодетских и хидрометријских мјерења на језеру насталом преграђивањем водотока Плитвица за потребе дотока воде на некадашњи млин за мљевење житарица, назван "Дедин Млин". Нагласак рада је на теренском дијелу, који обухваћа мјерење протока и брзине тока ријеке Плитвице на профилу код излаза из језера, као и одређивање површине језера кориштењем беспилотне летјелице. Кориштењем мини подморнице добивен је увид у облик језера, односно увјете на дну и уз рубове корита. Квалитетна анализа водне биланце важна је за прорачун волумена нових акумулација које ће се тек пројектовати и градити, као и за анализу водне биланце постојећих акумулација и природних језера.

Кључне ријечи: језеро, ријека Плитвица, хидрометрија, геодетска мјерења, биланца

1. INTRODUCTION

The alluvial substrate is a porous soil created by erosion and accumulation, resulting in sand and gravel particles deposition. River valleys have an erosive character, and their development can be monitored by knowing the morphological and hydrogeological properties of the river terraces. The Plitvica River was formed by depositing sedimentary material from the Drava terraces on alluvial deposits. The processes of deposition of material resulted in a decrease in the flow capacity and volume of the channel, further erosion of the coast and flooding of the terrain, and ultimately, the formation of water bodies that have the characteristics of stagnant water[1].

The Plitvica River began to form on the alluvial deposits of the heterogeneous composition of gravel and sand of the Drava River. The thickness of the sediment increases from west to east, and the amounts of gravel, sand, and pebbly sand are transported by wind and strong water flow. Due to erosion in the higher areas, sediments are transported to the lowlands and deposited during the flood period, which causes the water level in the area to rise..This reduces the volume of the channel, resulting in the creation of meanders and erosion of the channel. Another consequence of accumulation actions is alluvial fans, which are characteristic of wet environments and mountain terrains. Due to the continued deposition of sediment, the channels are prone to clogging, so due to breakthrough, the flow moves to a part of the fan that has a steeper slope. The Plitvica River is a torrential river characterized by a small catchment area, steep falls, and a torrential and short-term inflow. Heavy precipitation as well as sudden melting of snow, contribute to the rapidly rising level of large waters[1]. It should be emphasized that the hydrology and geomorphology of the river Plitvica have not been investigated in the literature. .

In the continuation of the work, the artificial lake created by damming the course of the Plitvice River will be analyzed. The purpose of the field measurements, as well as of the analysis of obtained results was to determine the balance of the lakes in the alluvium media. It is important to get information about the amount of water that can be lost in a way of infiltration or evaporation. This is of importance due to the sizing and building of the accumulations or retentions for the purposes of flooding protection, irrigation, and similar. The hydrological cycle of the lakes or accumulations usually consists of the input and outputs into the volume.[2]. Evaporation and precipitation can be calculated from data from meteorological stations if they are near the observed locations. Also, there is a need to calculate the area of the lake surface, which the drone will do. Because the evaporation and precipitation are expressed in millimeters, i.e., liters per square meter, the amount of evaporated water and precipitation will be calculated by multiplying these values. The same goes for the inflows and outflows in and out of the analyzed accumulations. If such data are unavailable, then field measurements must be provided. The biggest problem is to determine the volume of the accumulation, i.e., the available volume which can store a certain amount of the water. .

2. FIELD MEASUREMENT METHODOLOGY

The methodology for determining the water balance of the lake generally consists of analytical and field research.

The calculation of the water balance is meticulously derived from the inputs and outputs from the lake. At the observed location of the lake, there are no entrances and exits, or natural and/or artificial watercourses. Our comprehensive field survey, coupled with the available basic geological map, reveals that the dominant entrances and exits in the lake itself are not expected, and for a more comprehensive understanding of the lake's profile and geometric characteristics, a mini-submarine will be deployed.

The entrance and exit to the lake are made by the flow of the Plitvice River and precipitation, while the exit is made by evaporation and infiltration. Due to the small areas that gravitate to the lake, i.e., that make up the lake's basin, the flow from the surrounding areas into the lake will be ignored. Since the remaining inlet, i.e., the outlet to that lake is the flow of the Plitvice River, the flows obtained as a result of the application of the FlowTracker2 ultrasonic meter will be used there.

The surface of the lake will be determined using the AUTEL EVO II dual drone. To verify the area obtained by the drone, the area determined using the Geoportal will be compared.

2.1. LOCATION

The rivers Bednja, Drava, Lonja, and Plitvice are located on the territory of Varaždin County. The source of the Plitvice River is connected to the Macelj Mountains, i.e., Vinica Breg, and to the

Bednja River with its tributaries. It belongs to the Drava River basin, which flows into it north of Mali Bukovec Figure 1 [3].

Figure 1. Location of the research area

The Plitvica River is a lowland river that stretches west-east. This paper recorded all photos on May 26, 2023, when the field flow measurement was performed with the FlowTracker2 ultrasonic meter. Figure 2 shows the lake and its left side of the shore, which is visibly more neglected than the right side.

Figure 2. Analyzed lake from the right side of the shore

The input assumption is a constant volume of the lake despite the change in the water flow in the Plitvica River, which is visible in Figure 14. Since the flow is always enabled, the only changes in the water levels in the lake are visible at the dam and the threshold or waterfall. As shown in Figure 2, the change in water flow into the Plitvica River does not change the lake's volume despite the higher flow in a certain period of the year.

2.2. GEODETIC MEASUREMENT

Field research was carried out on 05/22/2022. The surface of the lake was obtained using a drone measurement image that was overlaid with an image from the DGU Geoportal [4]. Since determining the lake's surface is a critical step in defining the amount of evaporation, the recording was done with a drone for this work. The procedure begins with assembling the equipment in protected boxes. Along with the device being in a protected box, there is a remote control for the drone, an additional battery, and a USB connection to transfer data to a computer. The Global Navigation Satellite System (GNSS) receiver used for this measurement was the Trimble R12, designed with increased accuracy and efficiency in demanding GNSS conditions. This device provides at least 30% better accuracy in challenging GNSS areas where the receiver has enough satellites to achieve minimum accuracy requirements but where that signal may be obstructed or reflected by trees or buildings [5]. The drone used to record the lake's surface was Autel EVO II DUAL 640T (Figure 3). This device is equipped with 19 types of sensors that enable the creation of 3D maps and easier route planning through more demanding terrain.

Figure 3. Drone Autel EVO II DUAL 640T [6]

After the equipment is ready, it is necessary to mark the control points above which the drone will record the surface. This procedure was carried out so that the point above which the GPS device is placed was drawn with a spray. In this field recording, more points were determined for more accurate results and to reduce deviations in the final model. Figure 4 shows one of the marked points on the shore of the lake at the revision shaft

Figure 4. Marked point - example on the cover of the inspection window

Two recordings were made with the drone at two different heights. The first height of the flight was 60 meters, and the second height was 100 meters. The reason for shooting at two different heights was to overlap the shots so that a more accurate data cloud could be developed later. Figure 5 shows the result of the recording by an unmanned aerial vehicle, i.e., the obtained recording. The total area of the lake obtained with this model is 747.65 m^2.

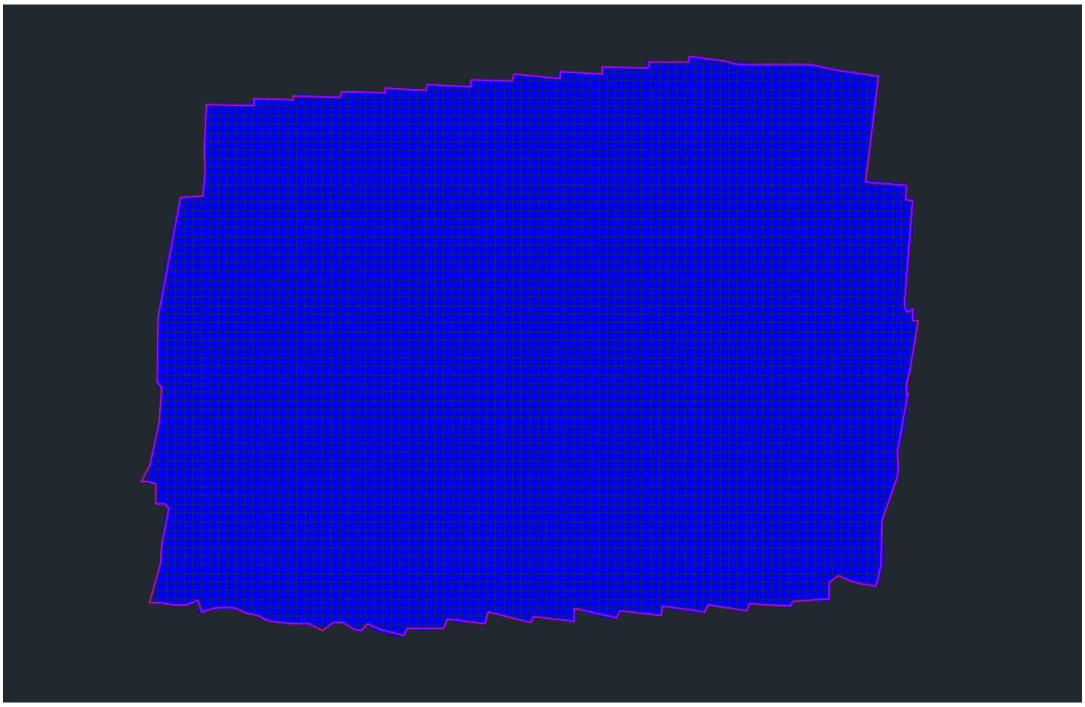

Figure 5. A model of the lake surface obtained by drone imaging

As the drone recording included part of the coast and the surrounding terrain, the area of the lake itself was calculated by overlaying the obtained model with the base taken from the Geoportal page. Figure 76 shows the overlay of the model and the Geoportal base, based on which the area of the surrounding terrain was determined, which is 427.25 m^2.

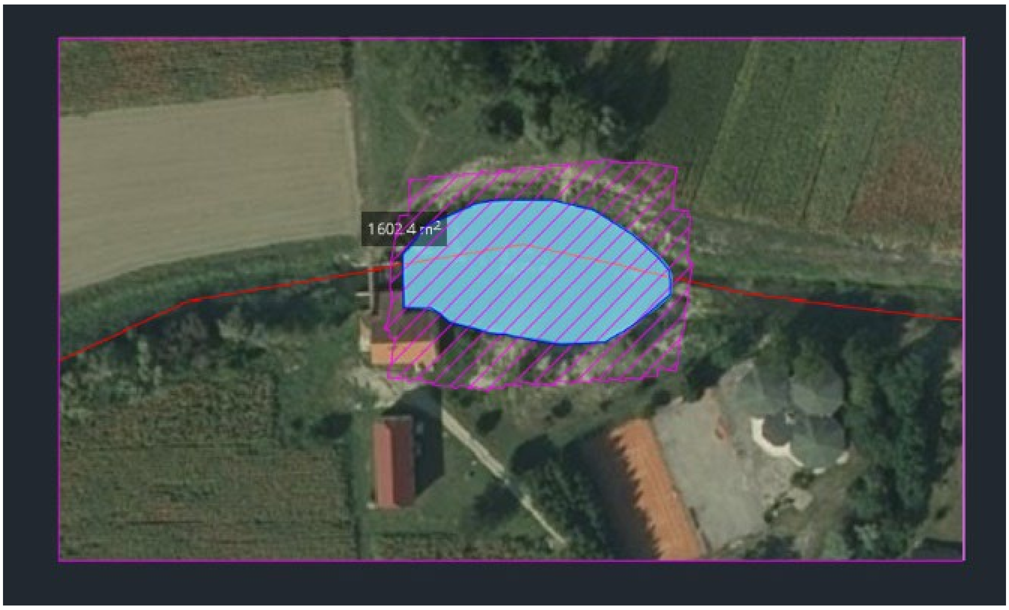

Figure 6. Overlay of images obtained by an unmanned aerial vehicle and the Geoportal digital ortophoto [4]

In the picture, the lake's area is marked with a blue line, which is 1602.4 m^2 on a scale of 1:500 and 320.4 m^2 on a scale of 1:1. The adopted authoritative area of the lake is 320.4 m^2, and it was obtained after processing the drone footage and the Geoportal base in AutoCad.

2.3. HYDROMETRIC MEASUREMENT

For this work, one measurement was performed on May 26, 2022. where the FlowTracker 2 Handheld-ADV portable field device was used, Figure 7.

Figure 7. FlowTracker 2 Handheld-ADV [7]

This instrument belongs to the ultrasonic meters, which obtain flow rates, velocities, water temperatures, and possible deviations. The collected data were transferred via a USB connection to a computer where the FlowTracker2 application was used for their analysis. Figure 8 shows the graph of flow values obtained on 5/26/2022 for each measured point.

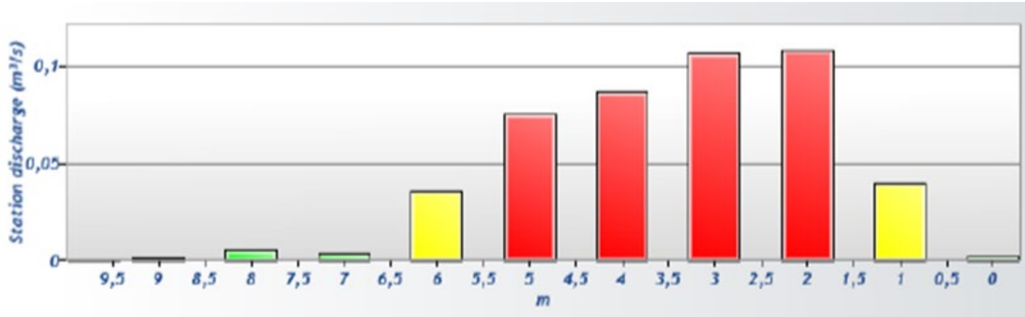

Figure 8. Display of obtained flow values, measurement on May 26, 2022

Figure 9 shows the speed values for each measurement point, while Figure 10. graphically shows the depths of individual points on the field measurement on May 26, 2022.

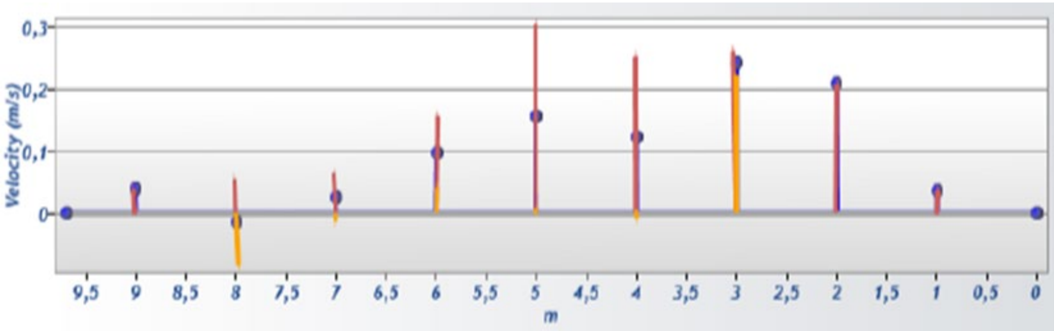

Figure 9. Velocity values for each measured point

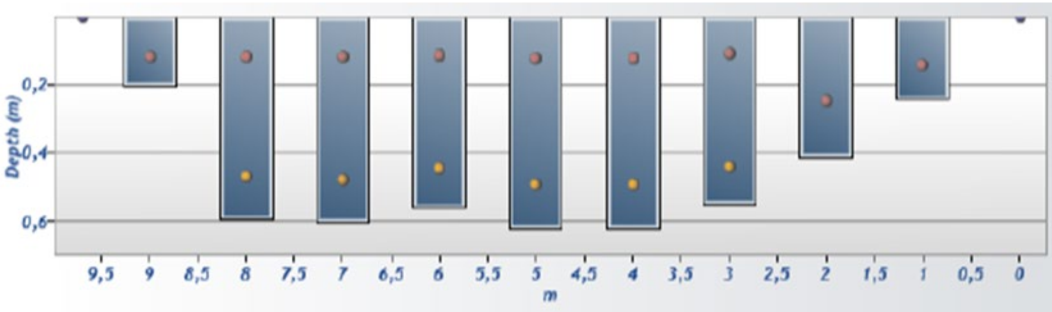

Figure 10. Depths of individual points

Due to the ISO standard of the measurement procedure, an under 0.5 m measurement is provided at one point, between 0.5. and 1 m in two and above the 1 m in three points. Also, the ISO standard defines, as well as procedure rules, the distance between the stations in cross profiles, which is 20 percent of the total width.

2.4. BATIMETRIC MEASUREMENT

The bathymetric measurement took place on June 21, 2022, at the analyzed location near St. Đurđ, near the Ludbreg. The measurement aimed to determine the depth of the lake with a mini-submarine. A bathymetric map was to be created based on the submarine images, showing the relief of the bottom of the observed lake. On bathymetric maps, depths are marked with different shades of a specific color to distinguish changes in terrain height.

The Chasing M2 Mini Submarine is an underwater drone that can move in all directions. The weight of the device is 4.5 kg, which makes it easily portable. The length of the submarine is 380 mm, the width is 267 mm, and the height is 165 mm. This type of mini-submarine performs recordings in temperature conditions with a limit of -10 °C to 45 °C. This mini-submarine's highest speed of movement is 3 knots or 1.5 m/s, and the largest horizontal radius is 200 m. A 4K/1080p camera and an additional EIS camera for image stabilization are installed in the device itself. An LED light on the front of the device is equipped with four propellers on each side. The device can be lowered into water up to 100 m deep. On the remote control, there is an insert for the device on which the Chasing GO1 application is installed, through which the path of the mini-submarine can be seen. [8].

The measurement began by marking the spot on the shore of the lake where the mini-submarine would be lowered into the water. After that, we started assembling the device, which is in a protective box (Figure 11). After attaching the cable to the mini-submarine, we started our measurements. Results were not obtained due to the bad visibility of the lake bottom due to the underwater grass and all other vegetation. Great blurred bottoms also go in favor of that.

Figure 11. Mini submarine Chasing M2

Due to unfavorable water turbidity conditions, the bathymetry could not be entirely performed. Problems encountered during the bathymetry also included raising material from the bottom of the lake, such as fine gravel and sand, which prevented the operation of the device's propellers. In other words, insight into the spatial characteristics of the lake's shape and volume was not possible.

3. DISCUSSION

Calculating the evaporation and precipitation amount is possible because data about it exists and is available from the Croatian Meteorological Service, i.e., from the meteorological stations. Inflow and outflow values in and out from the observed lake can be obtained only from the hydrometry measurements, i.e., by using the measurement device. Unfortunately, continued river flow data does not exist because no limnigraph station is near the analyzed locations. Because the inflow and outflow water flow was almost equal at the measurements, it was concluded that the infiltration into the ground was neglected. Also, for this preliminary analysis, because the surrounding relief does not have a sloping area that is too big or the surface area, the inflow of precipitation from these areas will not be considered.

Because determining the lake's volume by mini-submarine has not been possible, the total water balance of the lake could not be determined.

4. CONCLUSION

Geodetic and hydrometric measurements are vital when defining water balance. Numerous developed models for the above are unreliable unless compared with the measurement results obtained in the field. Also, input data for models are often assumed or estimated. Reliable measurements also increase the precision of modeling outputs. Also, the accuracy of the water balance of the observed lake is higher.

Due to the complexity of hydrological tasks, an interdisciplinary approach to solving the problem, including other scientific branches, is necessary to apply the correct procedures in the management of water assets. Continuous monitoring of changes in the water level and flow of the analyzed rivers, along with the analysis of hydrometeorological data, represents the basis of all such further research.

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63 | Professional paperI
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APPLICATION OF LASER SCANNING IN THE BASIC GEODETIC WORKS DURING THE RECONSTRUCTION OF THE THERMAL SPA GUBER COMPLEX

Abstract

Laser scanning is one of the most modern technologies used for the mass collection of spatial data in the form of coordinates of points in space. Given that laser scanning is often used during the restoration of buildings and building facades, the paper describes the application of mobile laser scanning in the example of the reconstruction of the Banje Guber complex. In the practical part of the work, the cloud of points obtained by scanning the Banja Guber complex was processed and the computer software used for data processing was presented. A 3D model of the terrain and the classic geodetic situation of the Banja Guber complex was created.

Keywords: mobile laser scanning, point cloud, control points, 3D model of the terrain.

ПРИМЈЕНА ЛАСЕРСКОГ СКЕНИРАЊА КОД ОСНОВНИХ ГЕОДЕТСКИХ РАДОВА ПРИ РЕКОНСТРУКЦИЈИ КОМПЛЕКСА БАЊЕ ГУБЕР

Сажетак

Ласерско скенирање представља једну од најмодернијих технологија која се користи за масовно прикупљање просторних података у форми координата тачака у простору. С обзиром да се ласерско скенирање често користи приликом рестаурације објеката и фасада објеката, у раду је описана примјена мобилног ласерског скенирања на примјеру реконструкције комплекса Бање Губер. У практичном дијелу рада је обрађиван облак тачака добијен скенирањем комплекса Бање Губер и представљени су кориштени рачунарски софтвери за обраду података. Израђен је 3Д модел терена те класична геодетска ситуација комплекса Бање Губер.

Кључне ријечи: мобилно ласерско скенирање, облак тачака, оријентационе тачке, 3Д модел терена.

1. INTRODUCTION

LiDAR (Light Detection and Ranging) technology is based on the collection of three different sets of data. The position of the sensor is determined using GNSS (Global Navigation Satellite System), using phase measurements in the relative kinematics mode, while the orientation is determined using the IMU (Inertial Measurement Unit). The last component is a laser scanner that sends an infrared beam towards the ground that is reflected to the sensor. The time elapsed from the transmission to the reception of the signal, along with the knowledge of the sensor's position and orientation, enables the precise calculation of three-dimensional coordinates on the ground [1]. Scanning takes place by measuring the distance and angle to a certain point in the recording area. The result of this recording method is a set of three-dimensional X, Y, and Z coordinates of points called a point cloud. One of the main advantages is the collection, processing and delivery of data in digital format [2]. The point cloud is most often saved in ASCII (American Standard Code for Information Interchange) format. The point cloud can be loaded into several specialized software tools and GIS (Geographic Information System) applications (PointTools, MicroSurvey CAD [3], MicroStation, ArcGIS).

Based on the platform used as a base for the laser scanner, laser scanning is divided into TLS (Terrestrial Laser Scanning) and ALS (Airborne Laser Scanning). Terrestrial recording methods use classic tripods or mobile MLS (Mobile Laser Scanning) vehicles as a platform. For the method of aerial photography, an aircraft (plane) is used, with a laser scanner attached to it [4].

In mobile laser scanning, a laser point or line is projected onto the object from a hand-held device and a measuring sensor that measures the distance to the surface. The data is collected in a local coordinate system, and therefore the position of the scanner must be determined for accurate data collection. The position of the scanner can be determined using reference points on the surface to be scanned or by an external means of determination. External determination often takes the form of a laser tracker (to ensure sensor position) with an integrated camera (to determine scanner orientation) or a multi-camera photogrammetry solution [5]. Both techniques tend to use infrared light-emitting diodes attached to the scanner, which the camera sees through filters that provide resistance to ambient lighting. Mobile laser scanning does not use a static point from which to shoot, but a mobile base. Road or railway tracks are often recorded with a mobile laser scanner attached to a car or a train car.

Today, we are witnessing the constant development of spa tourism [6]–[8]. By using natural resources in combination with architectural, construction and medical achievements in Bosnia and Herzegovina, it is possible to attract a large number of tourists. The development of the economy of each country can be significantly influenced by raising the quality level of tourist and tourism-like content. The starting point of this work is a laser scan of the Banje Guber complex. Before scanning, it is necessary to properly mark and record orientation points using classic terrestrial recording methods. The starting point of every architectural or construction project is the geodetic basis, that is, a quality "geodetic situation" for design. Given that during the development of spa tourism, the positions of the thermal springs must also be taken into account and that the surrounding terrain of Banja Guber is extremely steep, inaccessible and overgrown with tall forest, the creation of a detailed geodetic situation will be done based on laser scanning with a mobile laser scanner. The geodetic survey will be created in the form of a 2D plan with written elevations of characteristic points and drawn contour lines, as well as in the form of a 3D view overlaid with a point cloud.

Although the spa has a large number of hot springs and mineral waters, as well as untouched nature, the construction of a spa-climate treatment centre is in the process of being put to rest. The construction of this complex started in 2010, and it is planned to be completed by 2011. In the meantime, the spa was privatized, but due to disputes over the company, the construction of the spa and hotel facilities did not continue. Considering the potential it possesses, it was crucial to record the current state to create an action plan for the restoration of this natural wealth (Figure 1).

Figure 1. Conceptual solution of the Banje Guber complex [9]

2. MATERIALS AND METHODS

2.1. THE STUDY AREA

Banja Guber is a medicinal spa in Republika Srpska (Figure 2). It is located in the municipality of Srebrenica, at 560 m above sea level. The municipality of Srebrenica occupies an area of 527 km^2, and together with the area of Osat, covers the central marginal area of the eastern part of the Republika Srpska. Part of the eastern and the entire southern part of the municipality lies in the bend of the Drina and is an integral part of the wider, colorful geographical mosaic of Podrinje. Its eastern part descends to the Drina, which is also the border with the Republic of Serbia. The urban area of the city of Srebrenica extends on the northern slopes of the Zeleni Jadar area, around the narrow valley plain of the Crvena Rijeka and the Ćićevačko Potok, a component of Križevica.

At the beginning of the 19th century, doctor Hans Duler was the first to point out that the Srebrenica springs have healing properties, while the first scientific analysis of the water was made by the Viennese chemist Prof. Dr Ernest Ludwig. From 1886 to 1888, he analyzed the majority of about a hundred mineral sources in Bosnia and Herzegovina. He also analyzed five of the 48 mineral springs in the vicinity of Srebrenica and declared them "the pearl of all springs on Earth", and proposed their exploitation, which began in 1889. Until 1901, the Viennese firm "H. Maoni" filled and exported 2 818 199 bottles of Guber water to the world [10].

In terms of chemical properties, Guber water is similar to Levico in Italy [11], Val Sinestra in Switzerland and La Bourboule in France. Compared to them, Guber water has a more complete representation of minerals and less arsenic and is used in its natural composition without any dilution. Guber water, from the Crni Guber spring, was declared a cure for hypochromic anaemia in 1956 and has since been sold in pharmacies bottled in 400-millilitre plastic bottles.

In the surroundings of Banja Guber, there are deciduous and coniferous forests, as well as a walking path. There are also five healing springs in the spa, the Guber picnic spot, was a favourite picnic spot of the residents of Srebrenica, as well as the guests of the spa. The name Guber was born after it was established that the springs in this area achieve healing of skin diseases, especially leprosy.

Centuries ago, this location was known for its healing springs, and the best evidence is the fact that the Romans still had a bath in this area, while the Austro-Hungarians during the occupation of Bosnia and Herzegovina examined these healing springs in detail, which turned out to be of exceptional quality, so bottled water and sold it in Europe. In the second half of the 17th century, the famous Turkish travel writer Evlija Čelebija wrote about the mineral and medicinal water in the area of today's Banja Guber. The people who lived in this area at that time did not believe in the medicinal properties of these waters and believed that they caused some diseases. At the beginning of the 19th century, doctor Hans Duler drew attention to the medicinal waters in this area. Dr Ludwig examined the local waters in 1887 and claimed that some of the springs were more precious than all others in Austria-Hungary.

Figure 2. Banja Guber used to be (left)[12], remains of Banja Guber (right)

There are a large number of springs in the spa, however, due to low investment in scientific research, only a part of them has been examined. Some of the well-known springs are: Crni Guber (Figure 3), Mali Guber, Sinus Voda, Očna Voda and Ljepotica Spring.

Figure 3. Spring Crni Guber

A large number of scientific analyses were carried out in the area of Crni Guber, while the first detailed analysis in this area was carried out in 1894 when it was declared one of the best natural springs in Europe. Every-day consumption of the healing water from Crni Guber has to be under medical control [11]. The Mali Guber spring contains large amounts of calcium and magnesium. The water is clear, colourless and sour. It contains the most iron, as well as arsenic. The source popularly called Sinus water reduces sinus pain in the forehead area [11]. South-east of Crni Guber, there is Očna Voda. This spring has a small capacity, but it contains more mineral ingredients than all other springs in this area. Očna Voda helps with diseases of the eyes and mucous membranes, as well as conjunctivitis [11]. The spring is popularly called Ljepotica because it contains a certain number of minerals that reduce skin problems [13].

2.2. INPUT DATA

At the very beginning, it is necessary to collect data on the existing geodetic base to be able to calculate the necessary transformation set for the recording area. Due to the lack of transformation parameters verified by the Republic Administration for Geodetic and Property Legal Affairs, for the area of the Srebrenica municipality, the transformation parameters were determined for the wider area of the Srebrenica municipality, based on the coordinates of known points of the geodetic network. There are nine trigonometric grid points in the area (Table 1), and based on their WGS84 and national coordinate system coordinates, a transformation set was calculated for the subject area. The coordinates of the trigonometric points were taken from the horizontal transformation on the territory of the Republic of Srpska.

Table 1. Coordinates of the trig points used

Point mark	DKS			WGS84		
	E[m]	N[m]	H[m]	X[m]	Y[m]	Z[m]
T277	6602326.87	4892222.53	448.94	4326015.60	1512784.72	4421792.65
T280	6607392.49	4892278.70	301.16	4324256.48	1517536.39	4421672.22
T20	6609968.78	4892121.20	383.67	4323590.33	1520029.94	4421585.82
T353	6602391.11	4887804.02	600.45	4329025.09	1513832.39	4418727.41
T310	6607156.55	4888830.52	600.46	4326819.07	1518126.17	4419409.43
T295	6613035.65	4886105.19	519.11	4326683.70	1524261.66	4417326.61
T163	6603195.70	4883224.14	578.18	4331784.85	1515574.38	4415414.59
T59	6608819.05	4882750.44	939.47	4330541.81	1521088.85	4415261.69
T360	6613447.61	4881524.88	883.02	4329829.77	1525723.59	4414285.15

When creating the report and determining the parameters, certain points were excluded from the set because they showed greater deviations, and as final trigonometry for creating the trigonometric set, T20, T310, T353 and T360 were retained for creating the transformation set. Table 2 presents the calculated transformation parameters. The points may show greater deviations due to measurement errors, systematic errors or the influence of external factors. Excluding points with larger deviations from the data set helps ensure greater accuracy of the analysis or model. The final decision on which points to retain depends on the need for reliable data and its importance in the analysis.

Table 2. Transformation parameters and RMS (Root Mean Square)

Number	Parameter	Value	RMS
1	Translation dX	-1068.3925 m	77.1478 m
2	Translation dY	120.2115 m	69.4919 m
3	Translation dZ	71.1233 m	68.8484 m
4	Rotation about X	2.26627 "	1.92049 "
5	Rotation about Y	-22.06708 "	2.84151 "
6	Rotation about Z	-2.76142 "	2.12772 "
7	Scale	-16.5176 ppm	8.0619 ppm

For the laser images to be georeferenced, i.e. oriented, it was necessary to mark signals measuring 30 x 30 (square) on the ground. The marking was done with white paint (white paint for roads, is extremely important because of the reflection) and the signals were placed approximately every 150 m. Signal no. 1 is placed on the left side of the road, signal number 2 on the right side, and signal no. 3 on the left and so alternately. The end of the route was signalled according to the same principle (left-right), with the fact that the signal was not placed at the very beginning and end of the route, but was terminated 10 m from the beginning, that is, the end. Then the signal was recorded, ie. measurement. It was measured with a GNSS receiver Leica1230GG three times for 30 seconds with a change in the height of the instrument. The signal was measured at the ends (edges) of the square, and when measuring each signal, it was also photographed.

After the geodetic survey, the Rinex data for the survey period were downloaded (the virtual station was downloaded from the website of the Republic Administration for Geodetic and Property Legal Affairs based on the nearest permanent stations of the Republic of Srpska) [14]. The coordinates of the recorded points were transformed into the ECEF (Earth-Centered, Earth-Fixed) system for the orientation of the recordings. The ECEF coordinate system, also known as the geocentric coordinate system, is a three-dimensional coordinate system used in geodesy, navigation, and astronomy to describe the position of objects on or near the Earth. In the ECEF system, the coordinate origin is set at the centre of the Earth, so the coordinates of all objects are expressed relative to that centre. Using ECEF coordinates, it is possible to precisely determine the position of an object in three-dimensional space. This coordinate system is often used in GPS (Global Positioning System) navigation as well as in other applications where it is necessary to precisely determine the position of objects on the surface or near the Earth. The terrain was scanned using the mobile laser scanning method. The Riegl VUX-1 UAV scanning device was fixed on the vehicle (Figure 4).

Figure 4. Riegl VUX-1 UAV scanner

The maximum range of this device is 920 m, the minimum range is 3 m, the accuracy/precision is 10 mm/5 mm, the maximum effective measurement speed is 500,000 points/second, the maximum scanning speed is 200 points/second, and the recording angle is 330° [15].

The scan was performed on 23.12.2022. year. Data acquisition was performed, i.e. The LiDAR device scanned the terrain by emitting laser beams and measuring the time it took for those beams to reflect to the sensor. This data is recorded and stored.

2.3. METHODS

2.3.1. ORIENTATION OF IMAGES

Given that the area in question included several LiDAR images, it was necessary to perform data processing. It involves georeferencing different shots to create a unique point cloud. After that, the recorded material was exported to .las files. Most laser recording devices have software for processing recorded material and exporting data. Also, there are software specialized for processing, such as TerraScan, CloudCompare, Lastools, Pix4D and many others. This software offers various functions and capabilities for the analysis and visualization of LiDAR data.

LAS (LiDAR Data Exchange Standard) is a file format [16] that is often used to store and exchange data obtained using LiDAR technology. The LAS format is particularly popular in geodesy, cartography, geoinformatics and other areas where data accuracy is important. This format is used to store three-dimensional points that represent measured distances to the surface of terrain or objects. These points often form a "point cloud" that describes the actual terrain. Each point in the .las file can be classified to indicate whether it represents land, buildings, vegetation, or other objects. This is useful for data analysis and interpretation. The LAS format can also contain RGB (red, green, blue) colours for each point, which allows the visualization of point clouds in colour. These files often contain geographic information, including coordinates and elevations of points. This enables georeferencing point clouds in real-world situations. Also, each point can have information about the intensity of reflected light, which can be useful for determining surface characteristics.

Based on such data, there is the possibility of various applications such as DTM (Digital Terrain Model), terrain analysis, urban planning, detection of changes in the landscape and many other geospatial analyses. There are multiple versions of the LAS format, from LAS 1.0 to LAS 1.4, which support different features and capabilities.

Based on the coordinates of the recorded orientation points, the transformation parameters and the recorded material, the orientation of the recordings was made. Each point in the point cloud has three-dimensional spatial coordinates (width, length and height) that correspond to a specific point on the Earth's surface from which the laser pulse was reflected in the form of .las files. Given that the MicroSurveyCAD program was used for the vectorization of the obtained point clouds, it was necessary to convert the .las files into .pci files before the vectorization. The conversion was done in the aforementioned Pix4D software.

2.3.2. MICROSURVEYCAD MICROSURVEYCAD MAPPING, MODELLING AND CLASSIFICATION PROCESS

MicroSurveyCAD is a CAD (Computer-Aided Design) focused platform for surveyors and engineers, designed to maximize efficiency and value by supporting a variety of workflows and data formats in a single program [3]. In AutoCAD, a model was created in which all symbols for plotting were entered in the corresponding Layers, as well as the Layers themselves, in which plotting will be done. Then we load a point cloud based on which we want to plot the recorded area. To plot objects and detailed geodetic situations in the MicroSurveyCAD program, a smaller point size (1 or 2) is recommended, while a larger size can only be used for easier identification of higher objects. As for the colour of the points, monochrome and RGB scales are offered, so that all the points can be the same colour, or for the colours to be graduated depending on the height of the recorded point. Often, point clouds are placed in files that require advanced graphics and computer RAM, and it is difficult to vectorize them on computers with lower performance, in those cases, it is possible to cut a certain part of the point cloud.

After setting the point cloud display, point cloud vectorization is performed (Figure 5). Given that the existing condition of the buildings is of key importance for the reconstruction of Banja Guber, the breaking points of the buildings were taken and by connecting these points with a line, the contour of the building was obtained (Figure 5).

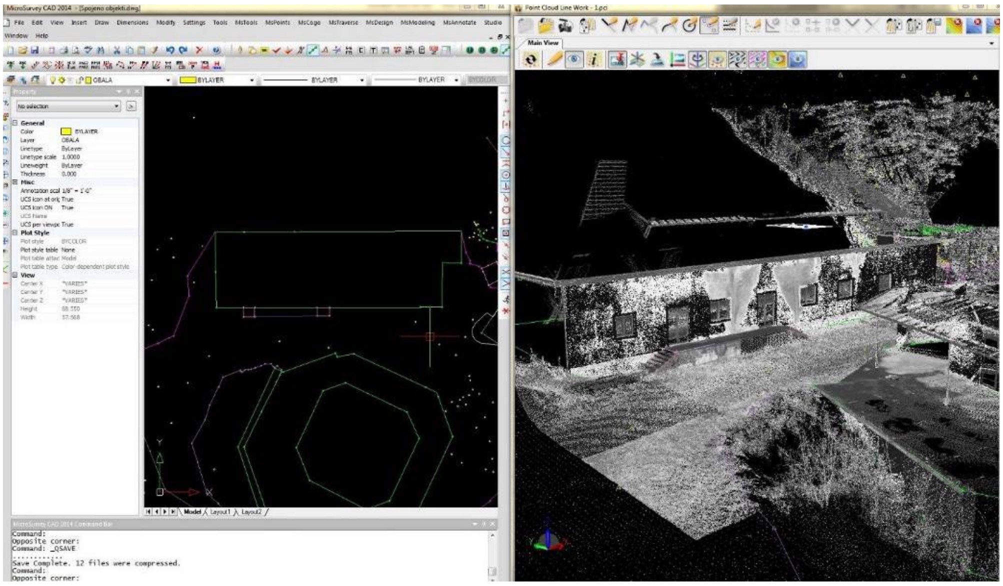

Figure 5. A vectorized object (left) and its appearance in a point cloud (right)

For the objects, all the characteristic breaking points were taken as if it was recorded using one of the classic terrestrial recording methods (contours, stairs, terraces, balconies, foundations, number of floors, etc.). In addition, the characteristic points of the terrain were chosen on the same principle. These points are used to draw TINs and countour lines. In addition, the upper and lower scarp, the edge of the road, and the water mirror were drawn from line elements. From the point elements, information was collected about springs, flags, substations, traffic signs, manholes and drains.

3. NUMERICAL RESEARCH

3.1. PREPARATION OF DETAILED GEODETIC SITUATION

After data preparation, marking and recording of orientation points, laser recording, processing, georeferencing and conversion of data into .pci format, it is necessary to perform vectorization, i.e. modelling of the recorded terrain. The following images show photos of the facility with different display options (Figure 6, Figure 7 and Figure 8).

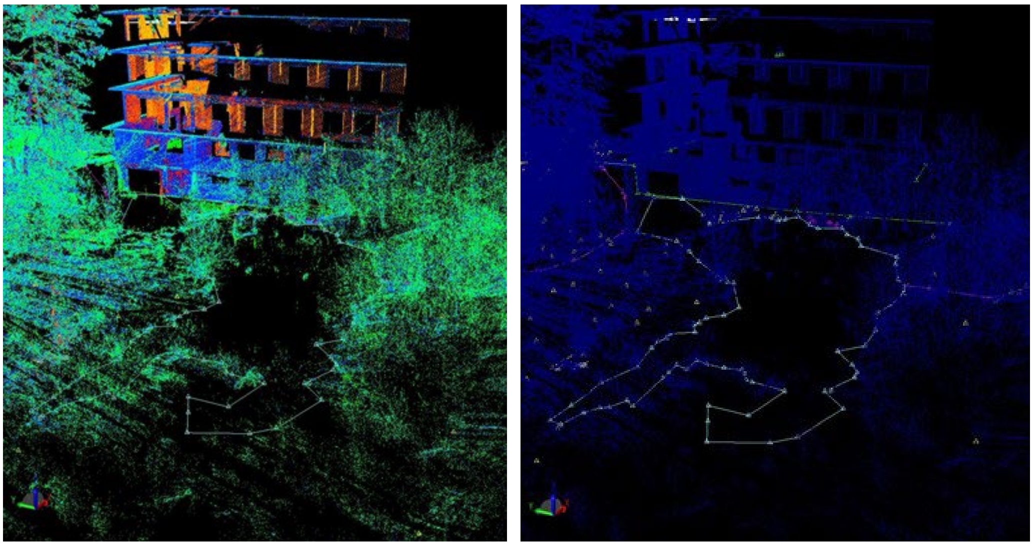

Figure 6. Captured object, Color map rainbow option (left), Elevation mapping option (right)

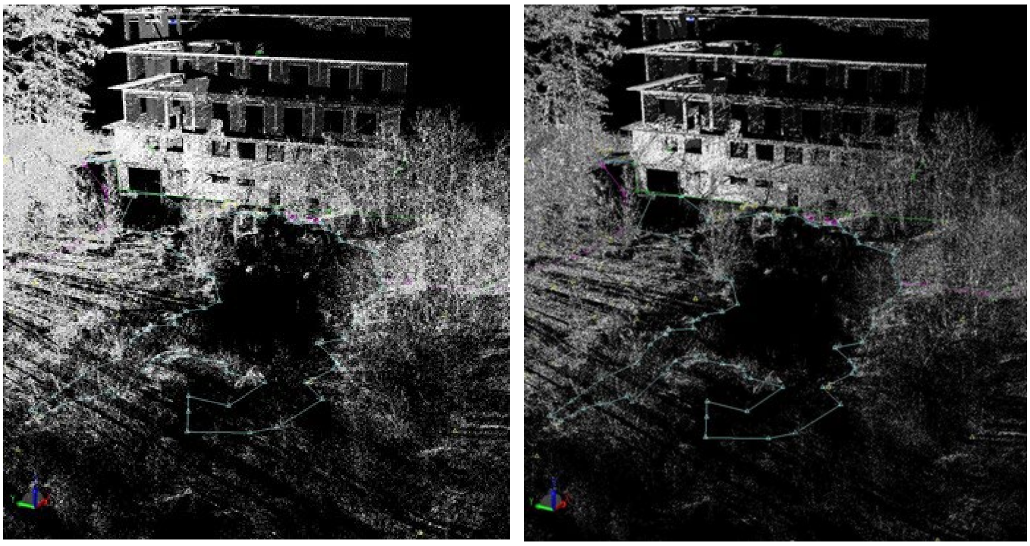

Figure 7. Captured object, Grayscale option (left), Multi Grayscale option (right)

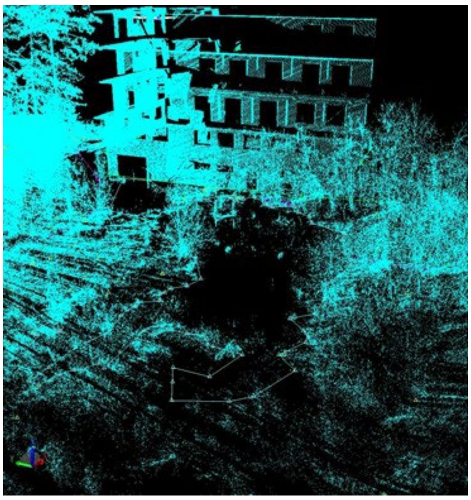

Figure 8. Captured object, One colour option

Since there is not a large range of heights on the ground, the Multi Grayscale option was chosen for further work and plotting. Selecting Multi Grayscale for visualization suggests using shades of gray to display data. The goal is to emphasize the differences in the data. It is important to ensure clarity and contrast so that data can be easily interpreted. This approach allows accurate information to be conveyed without the need for complex colors.
Figure 9 shows a comparison of a part of the video of the recorded location and the obtained cloud of points in MicroSurveyCAD.

Figure 9. Actual situation (left), captured point cloud (right)

Given that the largest and most healing source is Crni Guber, it is shown according to the same principle (Figure 10).

Figure 10. Actual situation on source Crni Guber (left), captured point cloud (right)

3.2. 2D GEODETIC SITUATION

To create a 2D situation, the elevations of the points were written, their distribution was carried out, and the corresponding hatches were assigned to the objects according to their purpose. All of the above was done in AutoCAD, as it would have been done with data obtained by classical recording methods. The cadastral base containing the borders of the existing parcels and their numbers were copied onto the obtained data so that a cadastral-topographic plan with written elevations of the points was obtained. At the end, a description and a legend were added to the sketch (Figure 11).

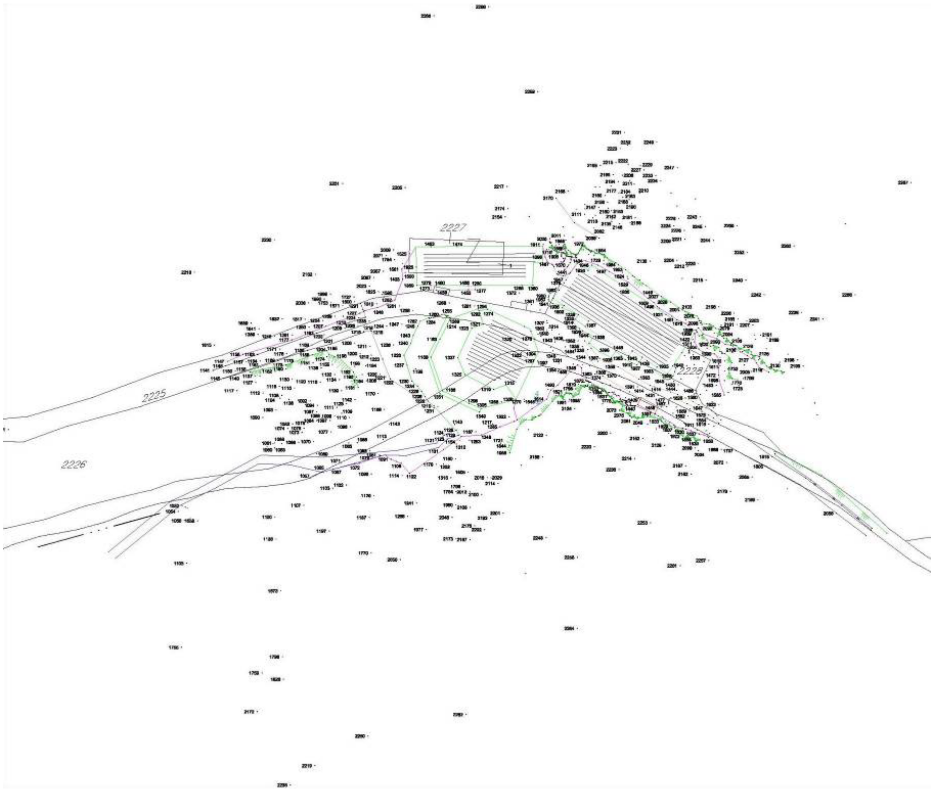

Figure 11. The 2D situation of objects near the source Crni Guber

3.3. 3D GEODETIC SITUATION

To create a 3D situation, a TIN model (Figure 12) was created, based on which the contour lines of the area in question were extracted. It was mentioned in the program add-on for AutoCAD called Survey.

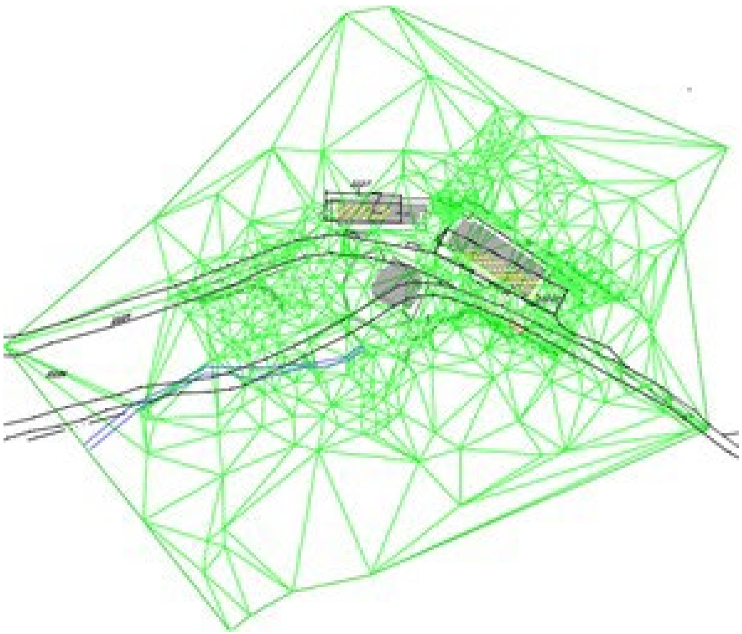

Figure 12. TIN model of the location near the source Crni Guber

It is interesting to check the recorded details and plotted contour lines by opening the drawings and clouds again in MicroSurveyCAD. Figure 13 shows how the obtained contour lines from the 3D situation follow the contours of the terrain. The layout of 3D situations is given in Figure 14.

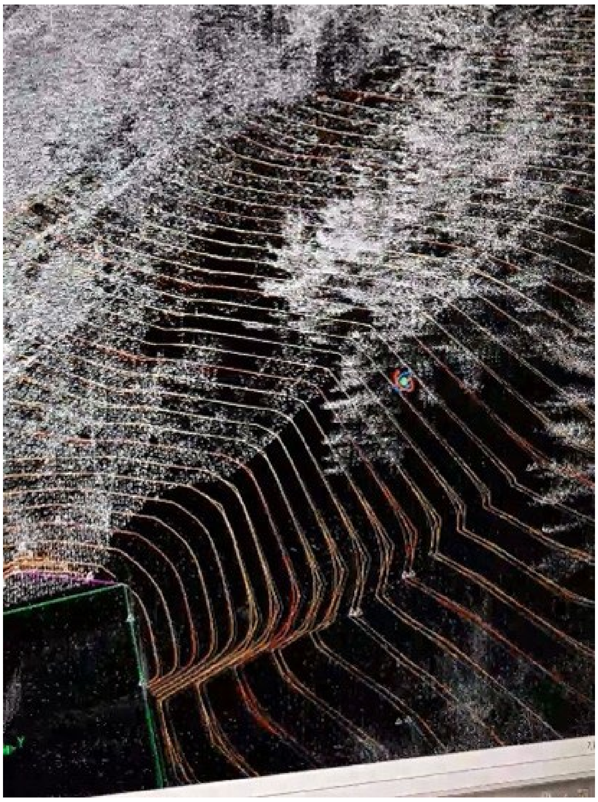

Figure 13. Point cloud and contour lines

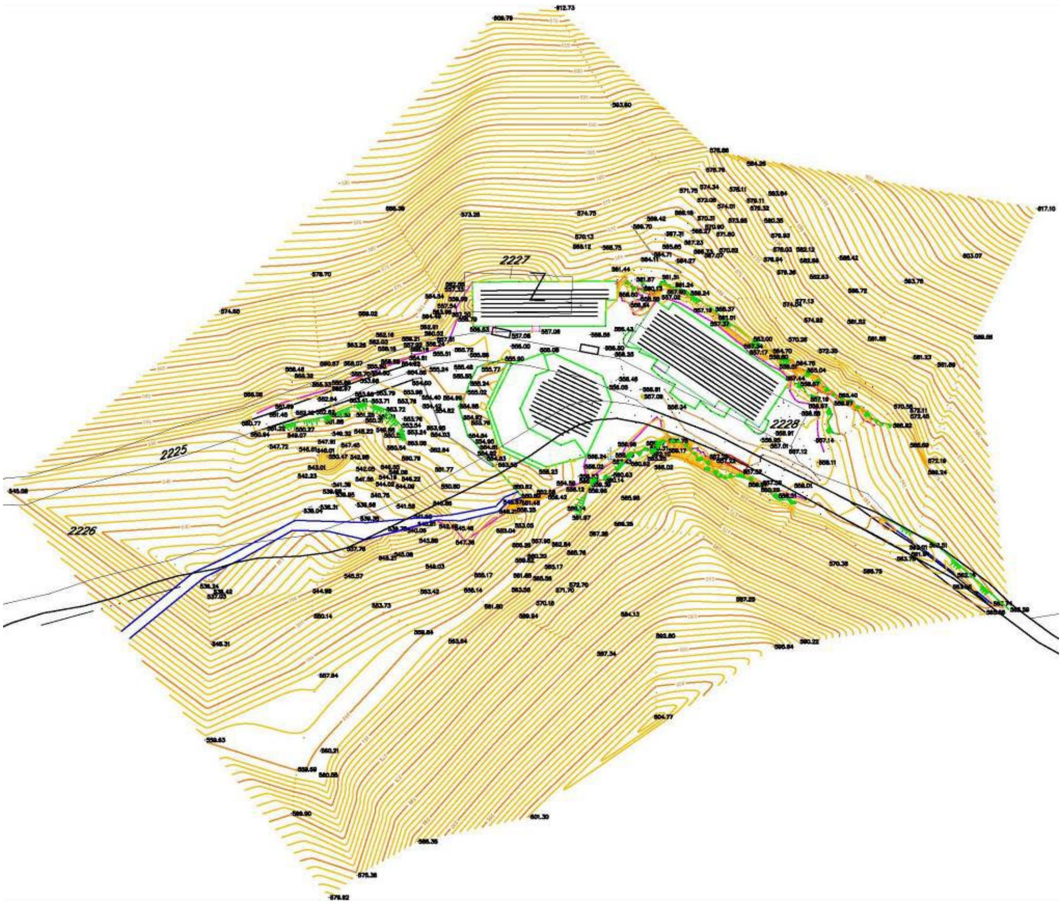

Figure 14. The 3D situation of objects near the source Crni Guber

4. CONCLUSION

Laser scanning can be successfully used to design and restore objects so that it can largely replace classical recording methods. The volume and quality of data obtained by laser scanning in the process of object restoration are superior to the volume and quality of data obtained by classical recording methods and can replace them in most situations.

What does not belong to the positive side of the laser scanning method is the high cost of the scanning equipment and the scanning process itself. Also, given the large amount of data involved, data processing often requires additional financial, hardware, personnel and time capacities.

In this paper, with the help of mobile laser scanning, a faithful representation of the current state of the facilities of the Banja Guber complex and part of the steep and inaccessible terrain surrounding was obtained. Some of the details captured in this way would be very difficult to capture with traditional recording methods. The resulting point cloud can be reloaded and vectorized for more detail as needed. It could be said that the point cloud contains all the essential information about the state of the terrain on the day of the shooting.

The advantages of this method far outweigh its disadvantages, so it is necessary to consider it and use it more and more often to reduce the danger for workers in the field and damage to equipment in risky situations, and to monitor world trends in the matter of geodesy and the creation of three-dimensional representations of objects (BIM models) and the cities themselves.

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CRUSTAL DEFORMATIONS AND THEIR IMPACT ON THE REALIZATION OF A NATIONAL COORDINATE REFERENCE SYSTEM: CASE STUDY AETOLIA-ACARNANIA, WESTERN GREECE

Abstract

Geodesy and crustal deformations are closely related. On the one hand, geodetic techniques are used to estimate deformations contributing in this way to geology, seismology and geodynamics. On the other hand, deformations consist a major challenge in the maintenance of geodetic reference frames. In this work we use GNSS (Global Navigation Satellite System) data and geodetic methods to estimated crustal deformations in the area of Aetolia-Acarnania, western Greece. The analysis of measurements that have been conducted in 2007 and 2023 on trigonometric points showed significant horizontal deformations up to 16.8 cm. The revealed deformations are presented and discussed in terms of their impact on the realization of the national coordinate reference system.

Keywords: crustal deformations, reference system, GNSS networks, Aetolia-Acarnania, Greece.

ДЕФОРМАЦИЈЕ ЗЕМЉИНЕ КОРЕ И ЊИХОВ УТИЦАЈ НА РЕАЛИЗАЦИЈУ НАЦИОНАЛНОГ КООРДИНАТНОГ РЕФЕРЕНТНОГ СИСТЕМА: СТУДИЈА СЛУЧАЈА НА ПОДРУЧЈУ ОКРУГА ЕТОЛИЈА-АКАРНАНИЈА, ЗАПАДНА ГРЧКА

Сажетак

Геодезија и деформације земљине коре су блиско повезане. Са једне стране, геодетске технике се користе за процјену деформација и на тај начин доприносе геологији, сеизмологији и геодинамици. Са друге стране, деформације представљају значајан изазов у одржавању геодетских референтних оквира. У овом раду користимо податке и геодетске методе ГНСС-а (Глобални навигациони сателитски систем) како бисмо процијенили деформације земљине коре у подручју округа Етолија-Акарнанија, у западној Грчкој. Анализа мјерења која су изведена 2007. и 2023. године на тригонометријским тачкама показала је значајне хоризонталне деформације до 16,8 cm. Откривене деформације су приказане и разматране у смислу њиховог утицаја на реализацију националног координатног референтног система.

Кључне ријечи: деформације земљине коре, референтни систем, ГНСС мреже, Етолија-Акарнанија, Грчка.

1. INTRODUCTION

Numerous fields of earth sciences, such as geology and tectonic geodesy, study the deformation of the Earth's crust. Many countries are not subject to tectonic deformations while some others are significantly affected. This depends mainly on the location of the country with respect to the boundaries of the tectonic plates (or microplates) or other deformation sources like e.g. active volcanos. For example, most of the European countries are not affected by tectonic deformations. In Europe, significant active horizontal deformations take place in a limited number of countries, mainly at the southern borders of the Eurasian plate, while vertical motions occur in northwestern Europe due to post-glacial rebound. As far as horizontal distortions are concerned, Greece is mostly affected, followed by Italy. The Greek region is characterized by intense and complex tectonic phenomena, as it is located close to the convergence boundaries of the Eurasian and African plates. As known, the African plate subducts beneath the Eurasian plate with a convergence rate of ~3 cm/year. Moreover, a number of microplates are distinguished in the area like the Aegean, the Anatolian, and the Apulian (Adriatic) plates. Thus, the Earth's crust in (and around) Greece is not uniform but it consists of distinct plates. Moreover, these plates are moving in different directions and with different velocities. Therefore, the crust in Greece undergoes continuous (mostly horizontal) deformations.

Due to the afore-mentioned deformations, the geodetic networks are constantly changing in terms of their shape. In general, the realization of a geodetic reference system in the presence of crustal deformations is a challenging task. As the crust is deforming, the relative positions and, consequently, the coordinates are changing with time. From a geodetic point of view, the question arising here is how these changes affect the realization of a national geodetic reference frame. Here, one should distinguish between the two different ways of realizing a geodetic reference frame, i.e. the conventional realization using geodetic control points and the modern approach, which is based on permanent GPS/GNSS reference stations. A few decades ago, the national Coordinate Reference Systems (CRS) were realized by means of trigonometric points which were established at distances of about 3-5 km. At such distances long time is needed for the crustal deformations to significantly alter the coordinates of neighboring control points. Nowadays, the realization of a national CRS is made by means of permanent GNNS reference stations spaced at several tens of kilometers apart. At such distances the coordinates' changes due to crustal deformations become significant over much shorter timeframes.

In this study we investigate the crustal deformations in the Aetolia-Acarnania region, western Greece. This area is surrounded by a number of regions of different tectonic regimes like the Cephalonia Transform Fault and the gulfs of Patras and Corinth. Although there are no studies focusing exclusively in Aetolia and Acarnania, indications for deformations in the area can be found in more regional studies in western Greece. In our study we use GNSS measurements conducted in 2007 and 2023 to estimate the deformations in Aetolia and Acarnania.

2. SEISMOTECTONIC SETTING OF THE AREA

As depicted in Figure 1, the wider area of Aetolia and Acarnania, is surrounded by a number of significant tectonic features with different characteristics: a) the gulf of Patras and the Corinth gulf in the south known for extensional tectonics and high seismic activity [1], b) the dextral Cephalonia Transform Zone (CTF) in the southwest which accommodates the transition from the subduction of the African plate under the Aegean plate to the continental collision in the north [2], c) the Kyllini Cephalonia Fault (KCF) and d) the Movri-Amaliada Fault Zone (MAFZ) in the northwest Peloponnese. Moreover, the sinistral Katouna-Stamna Fault (KSF) runs across Acarnania and Aetolia close to their common boundary.

The above-mentioned faults play a crucial role in the kinematics of the region. The areas east of Cephalonia and Lefkada and the western part of Aetolia-Acarnania appear aseismic [3, 4]. According to Brooks et al. (2007) this region is considered to be an independent rigid block having different kinematics [5]. More specifically, Vassilakis et al. (2011) and Pérouse et al. (2017) proposed the existence of a region bounded by the Hellenic subduction zone, the CTF, the MAFZ and the KSF delimiting the margins of the Ionian Acarnania block [6, 7]. However, the exact boundary of this block is under discussion. For example, other researchers consider that the margins of this block are represented by the subduction front, the CTF, the Amvrakikos gulf, the KSF and the MAFZ [2**].** Chousianitis et al., 2015 using GPS data revealed two clockwise rotating blocks (curved arrows in Figure 1), one of those affecting the study area [8].

The complex tectonic regime in Aetolia-Acarnania outlined above is expected to lead to crustal deformations. Nevertheless, only few studies provide geodetic evidence of deformations in the area. Hollenstein et al. 2008 [9] analyzed campaign GPS data from the time period 1993-2003 and computed velocities on several points. The estimated velocities of selected points in and around Aetolia-Acarnania are depicted with blue arrows in Figure 1 [9]. The differences among the magnitude and the direction of the arrows indicate the deformations taking place in the area.

In this study we estimate coordinate changes in Aetolia-Acarnania by analyzing GPS data collected in 2007 and 2023. During this time period, a number of strong earthquakes occurred around the study area. Their epicenters are shown with stars in Figure 1 and their characteristics are outlined in Table 1 [10-13]. Based on the published works studying the deformation of these events, no one of these earthquakes is expected to have caused significant displacements (e.g. few cm) in Aetolia and Acarnania. To the best of our knowledge, the longest GPS slip vector in Aetolia-Acarnania is reported during the 2018 earthquake that occurred 45 km SSW from Zakynthos island; it refers to the city of Messologi (south-west Aetolia) and amounts ~5 mm [13]. However, as even small displacements that could have been caused by these earthquakes would lead to biased velocity estimations, in this work we estimate displacements rather than velocities.

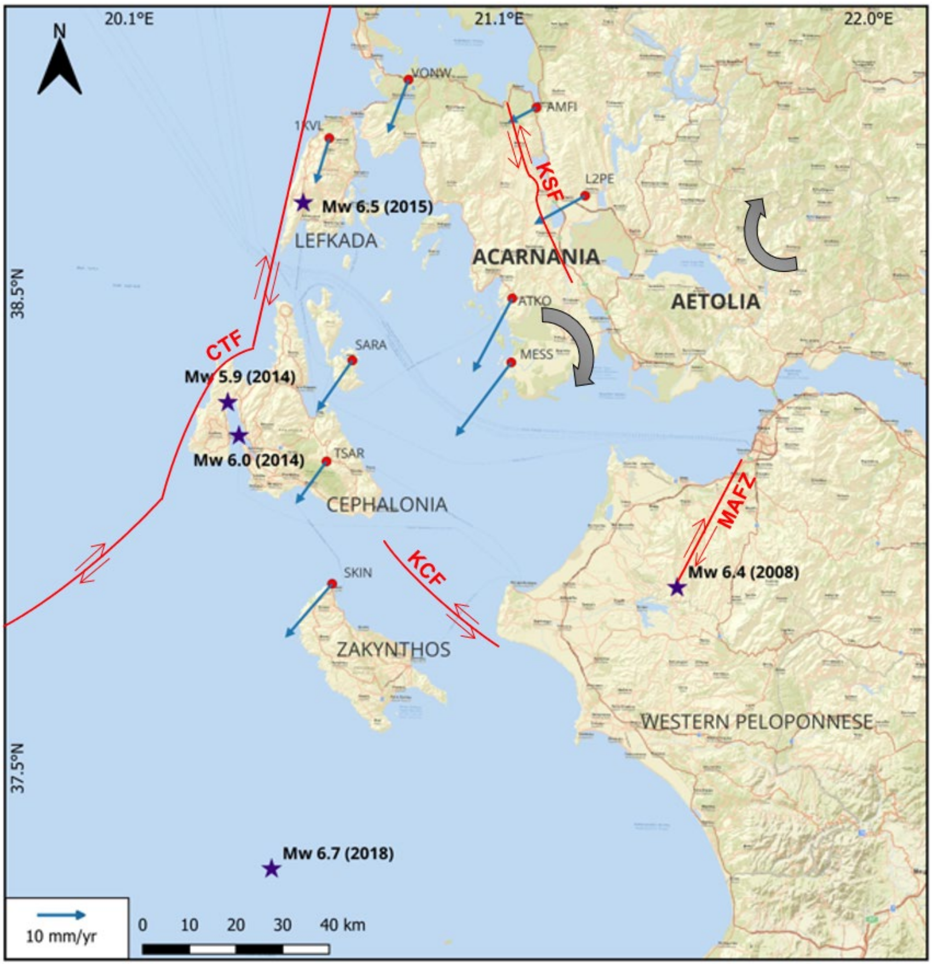

Figure 1. Seismotectonic setting of the wider area of Aetolia and Acarnania. Red lines indicate the major faults and are based on Haddad et al. 2020 [2]. Blue vectors are velocities (relative to Eurasia) on selected points after Hollenstein et al. 2008 [9]. Blue stars depict epicenters of strong earthquakes between 2007 and 2023 [10-13]. Gray curved arrows denote rotation patterns and are after Chousianitis et al. 2015 [8]. CTF: Cephalonia Transform Fault, MAFZ: Movri Amaliada Fault Zone, KCF: Kyllini Cephalonia Fault, KSF: Katouna-Stamna Fault

Table 1. Characteristics of strong earthquakes occurred in the wider area of Aetolia and Acarnania from 2008 to 2023 [10-13]

Date	Area	Magnitude (Mw)
08.06.2008	Movri (NW Peloponnese)	6.4
26.01.2014	Cephalonia	6.0
03.02.2014	Cephalonia	5.9
17.11.2015	Lefkada	6.5
25.10.2018	Zakynthos (45 km SSW offshore from Zakynthos island)	6.7

3. GNSS MEASUREMENTS AND DATA PROCESSING

For the purpose of assessing the crustal deformations in the study area we have conducted new measurements on 15 points which had been measured in 2007 during a nation-wide GPS campaign made for the establishment of HEPOS, the national RTK network of Greece [14]. During the 2007 campaign, a total of 2470 points of the national trigonometric network (i.e. ~10% of the complete network) have been occupied with GPS for the purpose of establishing the official coordinate transformation model between the national CRS and the geodetic reference frame of HEPOS (HTRS07: Hellenic Terrestrial Reference System 2007) [15], which consists a realization of ETRS89 (European Terrestrial Reference System 1989) in Greece [16]. In the 2007 campaign the determination of the HTRS07 coordinates was done by means of static GPS measurements of at least 1-hour duration, ensuring ~1 cm accuracy [14]. Following the same scheme, we re-occupied with GNSS receivers in 2023 15 points located in the study area. These points are shown in Figure 2 together with HEPOS station 001A, which was used as reference station and held fixed during the processing of the baselines using least squares adjustment. The measurements were conducted between 18 and 23 May 2023 using a Hi-Target iRTK5 geodetic receiver capable of tracking GPS, GLONASS, Galileo and BeiDou. The receiver at the station 001A was a Trimble Alloy receiver capable of tracking all GNNSs, as it is the case for all HEPOS stations after the system modernization [17]. The baseline length ranged from 11 to 47 km. A calibrated tribrach was used at the rover site to ensure precise leveling and centering of the GNSS antenna. Three typical examples of the points measured in 2023 are shown in Figure 3. The GNSS data were collected using a cut-off mask of 10 degrees and a sampling interval of 15 s. The observation duration at points with open sky view was one hour. An extended occupation time of

Figure 2. Locations of the HEPOS station 001A (red pin) and the trigonometric points (orange triangles) used in the study

Figure 3. Examples of the measurements conducted in 2023 (points from left to right are: 110024, 214009 and 110038)

1.5 hours was adopted at points 015024, 015041, 110039, 117012 and 214036 where tree canopies are slightly limiting the satellite visibility. The GNSS data processing was done using Trimble Business Center ver. 5.20 office software. A fixed solution was obtained for each baseline. The horizontal precision ranged from 0.003 to 0.011m, while the mean horizontal precision was 0.006 m (1-sigma).

4. RESULTS

The HTRS07 coordinates obtained from the 2023 measurements were compared to those of the 2007 campaign. The differences are given in Table 2. As the official HTRS07 coordinates of the HEPOS stations did not change since 2007 (static nature of HTRS07), the coordinate differences for station 001A are zero. On the contrary, significant coordinate differences were found for the trigonometric points, ranging between 1.5 and 16.8 cm (2D). These values reflect the horizontal displacements (from 2007 to 2023) relative to station 001A. Special attention should be paid in the case of point 110004, as its pillar has been found damaged, exhibiting an inclination. The deviation of the pillar w.r.t. the vertical was measured in the field and was found to be 4.5 degrees, whereas the

Table 2. Coordinate differences between 2007 and 2023

Point	dE (m)	dN (m)	dS (m)
001A	0.000	0.000	0.000
015024	-0.069	0.124	0.142
015041	-0.070	0.153	0.168
056025	0.002	-0.015	0.015
108011	-0.063	0.083	0.104
110004*	-0.101	-0.037	0.108
110011	-0.055	-0.020	0.059
110024	-0.040	0.001	0.040
110029	-0.035	-0.005	0.035
110038	-0.033	0.006	0.034
110039	-0.074	0.041	0.085
117012	-0.087	0.065	0.109
214006	-0.059	0.004	0.059
214009	-0.073	0.082	0.110
214036	-0.016	-0.001	0.016
214039	-0.087	0.086	0.122
(*) Inclined pillar: Results should be considered carefully.			

azimuth of the inclination was estimated to be 71°. Using these values, the coordinates obtained from the baseline processing were corrected to refer to a non-inclined pillar. The coordinate differences given in Table 2 for point 110004 were computed from the reduced coordinates, so they can be considered as approximate displacement of the pillar as if it had not been inclined.

To visualize the spatial distribution of the estimated horizontal displacements, the displacement vectors are shown in Figure 4. It becomes obvious that the eastern part of the study area (Aetolia) is characterized by big displacements exceeding 10 cm. The western part (Acarnania) is characterized by considerably smaller displacements, but, in contrast to Aetolia, they are inhomogeneous. The estimated displacement vector of point 110004 (dashed arrow) generally fits with the displacement pattern in its neighborhood. This consists an indication that the reduction of the pillar inclination was successful.

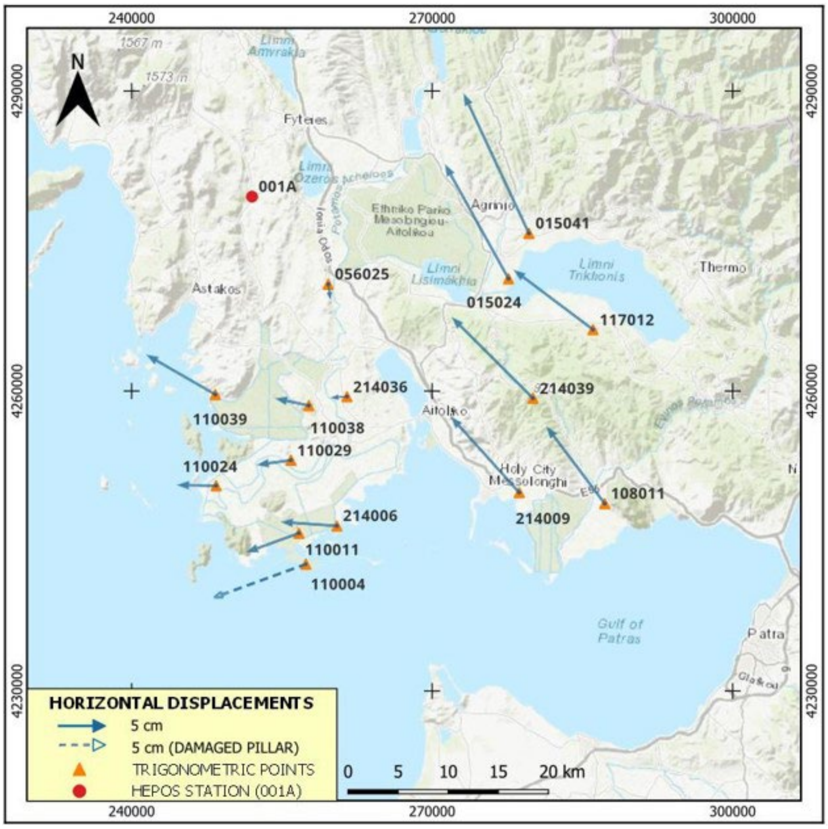

Figure 4. Horizontal displacements relative to station 001A (2007-2023)

Figure 4 illustrates well the cumulative deformations that took place in the study area between 2007 and 2023. This information is important for seismotectonic interpretations. However, from a geodetic point of view, the interest is in the differences between the coordinates of the trigonometric points that were estimated in 2023 and their official national coordinates. These deviations are shown in Figure 5. Comparing Figures 4 and 5 we see similar, but not identical, patterns. This is due to the fact that the national coordinates are biased by inherent errors of the triangulations made in the 60s and 70s when the national trigonometric network was established.

Figure 5 shows the deviations of the 2023 coordinates of the trigonometric points from the official coordinates. To demonstrate how the deformations in the area degrade over time the determination of national coordinates using a GNSS network, Figure 6 illustrates the differences between official values of the trigonometric points and the coordinates estimated in 2007. As we see in Figure 6, in 2007 the horizontal deviations were on the cm level for the vast majority of the points (with the exception of points 214039 and 015024 deviating 3.5 and 8.2 cm, respectively. These small deviations of the 2007 coordinates were expected as the transformation model between HTRS07 and the national CRS was established based on the 2007 campaign. Comparing Figures 5 and 6, the effect of the deformations that took place between 2007 and 2023 become obvious.

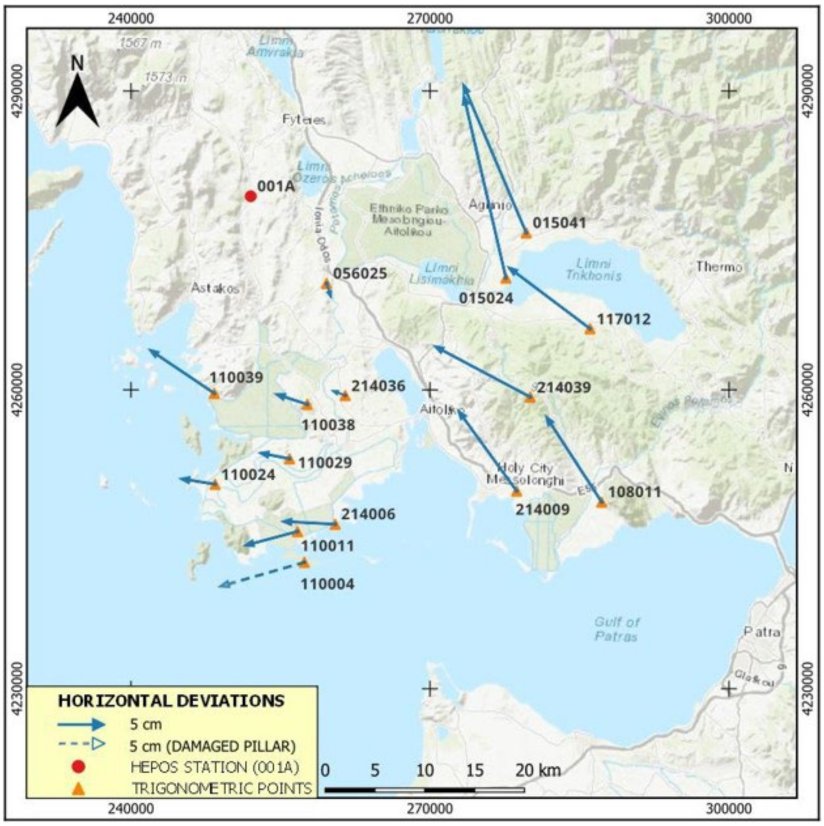

Figure 5. Horizontal deviations between the official national coordinates of the trigonometric points and the coordinates estimated from the 2023 measurements

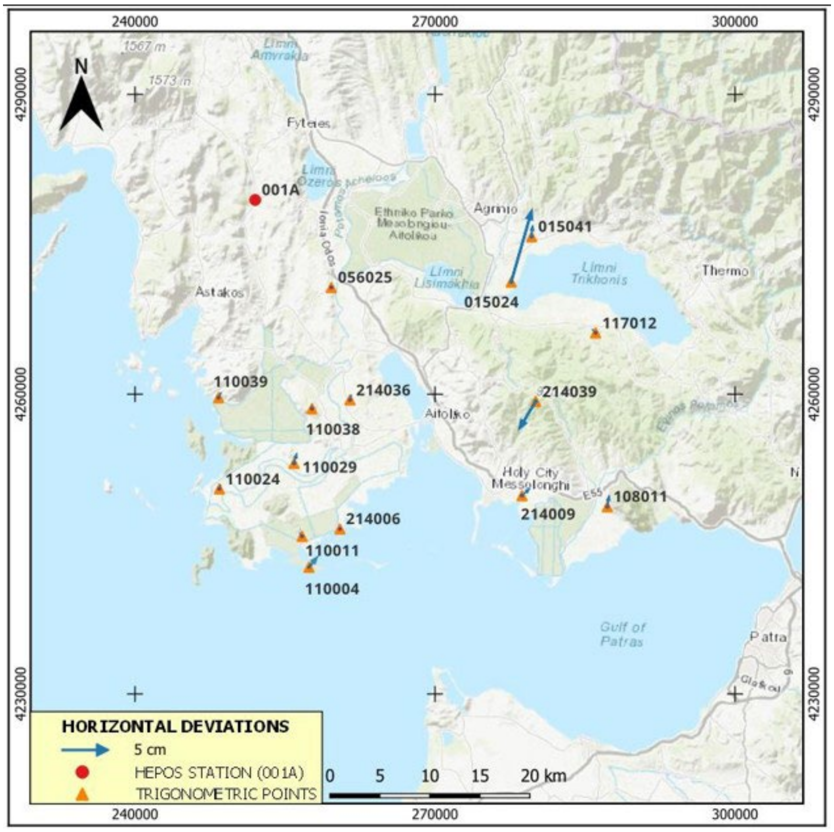

Figure 6. Horizontal deviations between the official national coordinates of the trigonometric points and the coordinates estimated from the 2007 measurements

5. DISCUSSION-CONCLUSIONS

The analysis of the previous section revealed the significant crustal deformations that took place in the study area between 2007 and 2023. On seven of the fifteen examined points the horizontal displacement relative to station 001A exceeded 10 cm, reaching a maximum value of 17 cm. The estimated displacements incorporate the effects of both the constant motions of the involved crustal blocks and the earthquakes occurred within the study time period. However, as mentioned in section 2, no one of these earthquakes is expected to have caused significant displacements (e.g. few cm) in Aetolia and Acarnania. Thus, the revealed displacements can mainly be attributed to ongoing deformations that are taking place in the area due to the complex tectonic regime described in section 2. In any case, the estimation of accurate velocities requires the existence of a dense network of permanent GNSS stations carefully constructed with solid foundations (ideally on bedrock), which would be very useful for understanding and precisely describing the local kinematics.

The inspection of the estimated displacements shown in Figure 4 revealed that the points in Aetolia are characterized by big displacements, whereas the points in Acarnania are exhibiting considerably smaller displacements. Thus, one may assume that the study area is divided into two main crustal blocks with different kinematics. These two blocks are on either side of the left lateral Katouna-Stamna Fault, which appears to be responsible for the abrupt velocity change. This outcome is in accordance with the findings of a recent study by Chousianitis et al., 2024 [18] which demonstrates the key role of the KSF. However, a denser network of points would be required in order to confirm if the KFS is precisely the boundary of the two blocks.

Another observation resulting from the data analysis is that the displacements in Acarnania area are not homogeneous neither in direction nor in magnitude. This finding is in accordance with the velocities reported by Hollenstein et al (2008) indicating a deforming area. However, as between 2007 and 2023 several strong earthquakes stroke between around Acarnania (Table 1), much more data are needed to draw firm conclusions about whether the revealed inhomogeneity is solely due to ongoing deformations or whether it is (also) due to displacements induced by the earthquakes.

From a geodetic point of view, active deformations consist a serious problem as they lead to coordinate changes. For the reasons explained in section 1, the modern way of realizing a national CRS using GNSS reference stations is more susceptible to deformations than the classical realization of a CRS using trigonometric networks. This becomes more obvious based on the results presented in Figure 4. For example, if a surveyor sets every year a GNNS base receiver on point 108011 and checks the coordinates of point 214009, he/she will always find values close to the nominal coordinates of the point, as the relative positions of the two points remain more or less unchanged. In contrast, if the surveyor uses the reference station for this purpose, he/she will find coordinate differences that increase with time.

The maintenance of a national CRS in the presence of crustal deformations is a demanding task. From a theoretical perspective the solution to this problem would be the adoption of a semi-dynamic datum. However, in the presence of both constant and abrupt (due to earthquakes) deformations, the modelling of time-dependent corrections becomes very challenging, as it requires immediate modelling of the deformations caused by each strong event and incorporation into the time-dependent transformation procedure. As long as no decision to adopt a semi-dynamic datum is taken, a way to mitigate the implications of crustal deformations would be the densification of GNSS reference stations in deforming areas.

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65
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GEODETIC CONTROL OF THE GEOMETRY OF THE BRIDGE IN KULA USING TERRESTRIAL LASER SCANNING TECHNOLOGY

Abstract

In this paper, the control of the geometry of a bridge located in Kula, Serbia, was performed. This bridge bridges the Danube-Tisa-Danube canal and is a part of road 108 that runs from Bačka Topola to the Croatian border. In order to perform the geodetic control of the bridge's geometry, terrestrial laser scanning of the bridge was conducted, where a point cloud was obtained as a product. The geometry control procedure involved controlling the verticality of the grooves that enabled the movement of the weights used to raise the bridge and allowed for navigation in the canal. The geometry control of the two horizontal beams of the bridge was also examined. The results that were obtained were interpreted tabularly and graphically.

Keywords: terrestrial laser scanning, bridge geometry control, point cloud

ГЕОДЕТСКА КОНТРОЛА ГЕОМЕТРИЈЕ МОСТА У КУЛИ ПРИМЈЕНОМ ТЕХНОЛОГИЈЕ ТЕРЕСТРИЧКОГ ЛАСЕРСКОГ СКЕНИРАЊА

Сажетак

У овом раду извршена је контрола геометрије моста који је смјештен у Кули, Србија. Овај мост премошћује канал Дунав – Тиса – Дунав и дио је пута 108 који се простире од Бачке Тополе до државне границе са Хрватском. У циљу геодетске контроле геометрије моста извршено је терестричко ласерско скенирање моста, гдје је као продукт добијен облак тачака. У поступку контроле геометрије извршено је испитивање вертикалности жљебова, који омогућавају кретање тегова помоћу којих се врши подизање моста и тиме омогућава пловидба каналом, као и контрола геометрије двеју хоризонталних греда моста. Добијени резултати су интерпретирани табеларно и графички.

Кључне речи: терестичко ласерско скенирање , контрола геометрије моста, облак тачака

1. INTRODUCTION

The field of geodetic works in construction has become more complex due to the rapid development of civil engineering and other technical disciplines. A specialized field called engineering geodesy was established to address the numerous challenges faced by the geodetic profession during the construction and exploitation of engineering facilities. Engineering geodesy involves planning, organizing, and implementing geodetic works to ensure the correct spatial location and realization of the geometry of the built object following the designed geometry within the limits of construction tolerances [1, 2]. Geodetic works in engineering geodesy involve various tasks. These include establishing geodetic networks, creating the geodetic basis for designing objects, expropriating land, setting out the geometry of the objects, monitoring displacements and deformations of objects, controlling the geometry of objects during construction and exploitation, shaping construction land, and surveying the state of objects after construction [1]. The focus of this paper is a very challenging task of engineering geodesy – control of the geometry of objects during exploitation.

The traditional approach to controlling the geometry of objects involves the establishment of a geodetic network and the application of conventional measurement methods, which include the use of total stations, GNSS receivers, and geodetic levels. However, an alternative approach to this is using terrestrial laser scanning technology. This technology has come a long way since its introduction. It is now highly effective for capturing a large number of three-dimensional points of objects or areas that are the subject of observation. The main advantage of terrestrial laser scanning is the possibility of mass acquisition of geospatial data, which is very important in procedures for controlling the geometry of objects, where one tries to interpret the geometry of objects in the best possible way.

In the past decade, numerous studies have explored the potential application of terrestrial laser scanning in engineering tasks. Terrestrial laser scanning can be used in testing the verticality of objects [3, 4, 5, 6], creation of as-build projects of objects [7, 8, 9], creation of 3D models of objects [10, 11, 12], projects of reconstruction and rehabilitation façade [13, 14], deformation monitoring of engineering facilities [15, 16, 17], as well as in numerous other geodesy tasks. These studies confirm the justification for applying terrestrial laser scanning technology to control objects' geometry. In this paper, the control of the geometry of the bridge in Kula was performed using terrestrial laser scanning.

2. TERRESTRIAL LASER SCANNING TECHNOLOGY

Terrestrial laser scanning technology is currently considered an exceptionally attractive method for acquiring geospatial data. A terrestrial laser scanner detects and collects geometric information about the scanned object. Due to its high resolution, it also collects data regarding the object's texture, reflecting electromagnetic energy. A collection of points in space created by scanning is called a point cloud. The point cloud represents a digital representation of the shape of the scanned object, enabling detailed visualization and analysis of its geometric characteristics. Terrestrial laser scanners function akin to total stations, and the terrestrial laser scanning method of collecting data resembles the polar (tachymetric) technique for detail acquisition. The measurement results of distances using the terrestrial laser scanning method correspond to the distances obtained using a total station. In contrast, the horizontal and vertical deviation of the laser beam matches the horizontal and vertical angle of sight in the total station. Generally, in the data collection process, what differentiates these two instruments is the significantly high speed of collecting a large volume of data with the terrestrial laser scanner, whereas, on the other hand, it concerns the high accuracy of individual total stations [18]. The measurement results in the terrestrial laser scanning include the slope distance ρ, horizontal direction θ, vertical angle α, and the intensity of the registered radiation I (Figure 1). In geometric terms, scanning an object produces a set of points with high density and regular arrangement, known as a point cloud, in which each point is defined by three spherical coordinates ρ, θ, and α. The relationship between spherical and Cartesian coordinates can be expressed as follows [18, 19]:

$$x_j = \rho_{ij} \cdot \cos\theta_{ij} \cdot \cos\alpha_{ij}, \tag{1}$$

$$y_j = \rho_{ij} \cdot \sin\theta_{ij} \cdot \cos\alpha_{ij}, \tag{2}$$

$$z_j = \rho_{ij} \cdot \sin\alpha_{ij}. \tag{3}$$

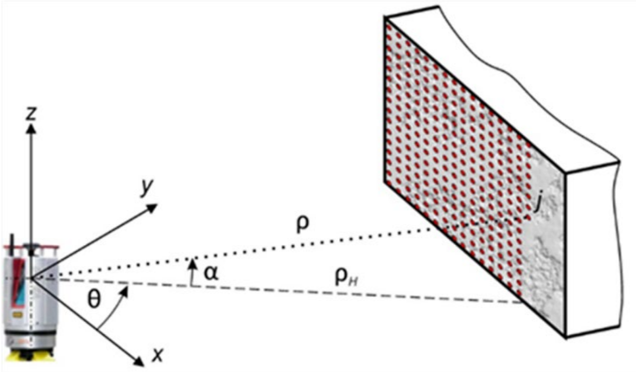

Figure 1. The principle of terrestrial laser scanning [18].

In this manner, a detailed point cloud is obtained, representing the position of each scanned point in a 3D coordinate system. The coordinates of the points are located within the scanner's coordinate system.

2.2. TERRESTRIAL LASER SCANNING PROCEDURE

There is no standard procedure for scanning, as each object requires a different approach and method of capture and level of detail in the presentation of results. Due to the complexity of the object and the terrain's topography, it is necessary to conduct reconnaissance of the terrain and create a plan for terrestrial laser scanning. The terrestrial laser scanning method requires scanning from selected positions that can cover the object within their field of view. In the scanning process, markers were used, which, due to their simple production, are very commonly used in practice. Markers primarily serve to register point clouds scanned from different scanner positions. The procedures for registration and georeferencing of point clouds are a significant step in the data processing of the terrestrial laser scanning method. To create a comprehensive representation of the scanned object, the point clouds must be registered, aligning them to a common coordinate system (e.g., the coordinate system of a chosen scan) [10]. Following that is the process of georeferencing the point cloud. In practice, indirect georeferencing is usually applied, which, using known 3D coordinates of control points determined by the conventional survey methods, such as the GNSS RTK method, places a point cloud in the desired coordinate system. Detailed analysis and manipulation of the point cloud can be initiated based on the registered and georeferenced point cloud. It is of great importance that the point cloud registration is achieved with the highest possible accuracy. The precision of the registration process directly influences the control of the geometry of objects.

3. GEODETIC CONTROL OF THE GEOMETRY OF ENGINEERING FACILITIES

Geodetic control of the geometry of engineering structures is an extremely important task performed directly during the construction of structural elements and on tasks of exploitation and maintenance of engineering facilities. Monitoring the structure and functionality of an object involves a set of activities that include precise continuous geodetic measurement of the geometric characteristics of engineering facilities. Calculations such as hydraulic, dynamic, and static are related to the shape and size of structural elements. The consequences of stress changes lead to the occurrence of plastic deformation of the structure, and the forces causing them are considered disturbances [1]. To avoid the impact of disturbances, it is essential to accurately position the structure within the defined tolerances in absolute and relative systems. Geodetic methods allow for precise object positioning in both systems, whereas other methods typically ensure accuracy only within the relative system [2].

The objective of engineering-geodetic works during the construction of objects is their accurate positioning and the alignment of the object's geometry with the design within the defined boundaries of construction tolerances. This ensures that the structures will have geometry of the necessary quality, facilitating their successful and efficient use. Quality positioning of an object and the realization of its designed geometry depend on fundamental planning, proper organization, and precise execution of geodetic works using appropriate geodetic instruments [1, 2].

3.1. CONTROL OF THE GEOMETRY OF STRUCTURAL ELEMENTS AND OBJECTS

During the quality control of a structural element's geometry, it is necessary to approximate the element with a sufficient number of points. The object can form a straight line, a figure with vertices (triangle, quadrilateral, n-gon), a plane, or a surface of an appropriate shape [2]. Verifying the point's affiliation to a particular geometric figure involves testing appropriate mathematical hypotheses (the null hypothesis H_0, asserting that the tested figure conforms to a certain mathematical shape, and the alternative hypothesis H_a, indicating that the tested figure is not a defined mathematical figure). Testing the congruence between the controlled and the designed geometric element includes:

H_0: the controlled geometric element matches the designed one;

H_a: the controlled geometric element does not match the designed one.

Structural elements are shaped like ideal figures that can be mathematically defined. During the examination of already manufactured structural elements, it is essential to assess geometric shapes based on a discretized set of points for the most accurate approximation of the structural element [2]. This paper does not define a mathematical model for verifying the congruence of the controlled geometric element with the designed one. As a result of this method, it is possible to determine control over the points belonging to a straight line, control of horizontality, control of verticality, control of inclination, and other possible relational affiliations [1]. The methodology used in this study enables the discretization of a large number of points on certain elements of the bridge under examination. In this study, the control of the geometry of certain bridge elements is reduced to checking the verticality of the bridge's grooves and controlling the geometry of the bridge's horizontal beams.

4. CONTROL OF THE GEOMETRY OF THE BRIDGE IN KULA

The subject of the geodetic control of the geometry is the bridge in Kula, Serbia, which is located at 45.611456 degrees north latitude and 19.525444 degrees east longitude. The structure of this bridge was damaged in an accident caused by a cargo truck carrying an excavator that hit the bridge. The bridge is part of road 108 and bridges the Danube – Tisa – Danube canal. It is a movable bridge of steel construction, which is raised using weights and other accompanying equipment and enables navigation on the canal. To control the bridge geometry, a terrestrial laser scanning was performed using a Trimble TX 8 scanner, known for its speed, long range, and precision. The first phase of the work began with a tour of the field and creating a terrestrial laser scanning plan. Terrestrial laser scanning of the bridge was performed with 12 different positions defined within the scanning plan. Since the point clouds obtained during scanning at each of the scanner positions need to be connected into a unique point cloud, during field scanning, tie points (markers) that will be used in the point cloud registration procedure were materialized. Figure 2 shows the positions of the scanner from which the scan was performed, while Figure 3 shows the first position of the scanner.

Figure 2. Scanner positions during terrestrial laser scanning of the bridge.

Figure 3. Bridge in Kula, scanner position 1.

The first step in processing the captured data is registering the point cloud. The point cloud registration procedure was carried out in the Trimble Business Center software package using a combination of two methods: a manual one that involves tie points (markers) and an automatic Cloud to Cloud method. After manual registration with markers, Cloud to Cloud registration was performed. The point cloud registration procedure was carried out with very high accuracy, where the total point cloud registration error was 4.8 mm. In this case, there was no need for georeferencing the point cloud because the bridge geometry control procedure is carried out in the object's local coordinate system. The product of laser scanning of the bridge in Kula is the point cloud, that is, a set of a large number of three-dimensional points that provides a very high-quality 3D representation of the bridge. The bridge point cloud has 690,541,681 points, indicating how detailed each bridge segment is captured. Figure 4 shows a point cloud of the bridge from scanner position 6.

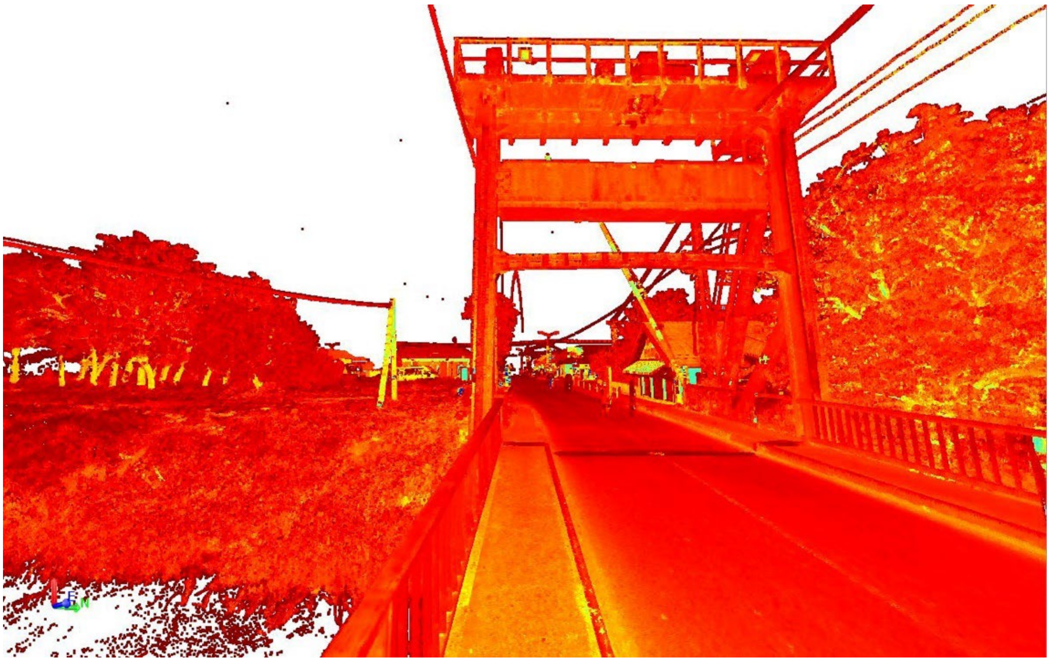

Figure 4. Point cloud of the bridge in Kula, scanner position 6.

After laser scanning and processing of the captured data, the product of which is the point cloud of the bridge, the control of the geometry of certain elements of the bridge is performed. In this procedure, it is necessary to examine the verticality of the grooves that enable the movement of the weights that are used to raise the bridge and to examine the geometry of the horizontal beams of the bridge, one of which is visibly deformed because the excavator, which was transported by truck, drove directly into it. Figure 5 shows a deformed horizontal beam and one of the grooves.

Figure 5. Horizontal beam (left) and groove (right).

Horizontal beams and grooves, i.e., their geometry, were extracted from the point cloud using the TerraSolid software package within MicroStation. Figure 6 shows the shape of the bridge, the horizontal beams, and the position of the grooves.

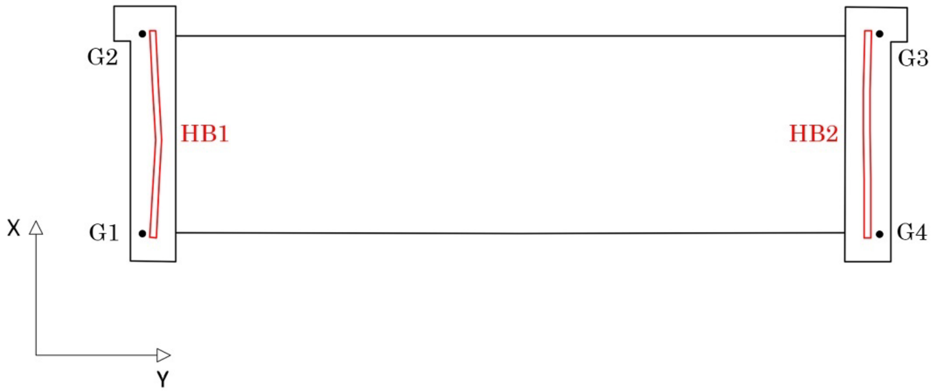

Figure 6. Horizontal beams and grooves along which the weights move.

In order to examine the verticality of the grooves, the edges of the grooves were extracted from the point cloud in the form of broken lines consisting of 5 points at a distance of about 2 meters. These points are numbered from 1 to 5, starting from the point of lowest height, for each groove independently. The deviations of the grooves from the vertical are determined by comparing the coordinates of points 2, 3, 4, and 5 with the coordinates of point 1 independently for each groove. Values of deviations from the vertical of grooves G1, G2, G3, and G4 are shown in Tables 1, 2, 3, and 4.

Table 1. Values of deviation from the vertical groove G1.

Deviations	ΔY [mm]	ΔX [mm]	Δ [mm]
1-2	8	12	14
1-3	24	34	42
1-4	25	35	43
1-5	22	31	38

Table 2. Values of deviation from the vertical groove G2.

Deviations	Δ*Y* [mm]	Δ*X* [mm]	Δ [mm]
1-2	15	-1	15
1-3	33	-5	33
1-4	38	7	38
1-5	41	16	44

Table 3. Values of deviation from the vertical groove G3.

Deviations	Δ*Y* [mm]	Δ*X* [mm]	Δ [mm]
1-2	-5	-15	16
1-3	-7	-27	28
1-4	-6	-36	36
1-5	-2	-40	41

Table 4. Values of deviation from the vertical groove G4.

Deviations	Δ*Y* [mm]	Δ*X* [mm]	Δ [mm]
1-2	3	-1	3
1-3	-3	-15	15
1-4	-7	-25	26
1-5	-2	-20	20

Figure 7 shows a comparative analysis of the deviations of the grooves from the vertical Δ. The deviation values from the vertical are very close for grooves G1, G2, and G3, while in the case of groove G4, the deviation values are significantly smaller.

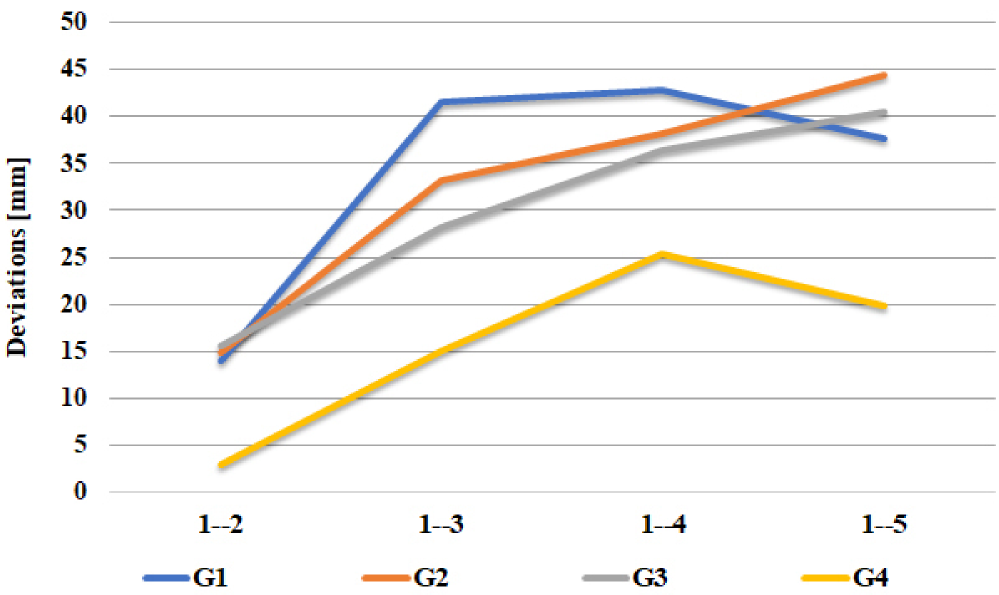

Figure 7. Diagram of deviations of the grooves from the vertical.

Control of the geometry of horizontal beams is based on determining the deviation of the geometry of the beams from the original geometry. To determine these deviations, 29 points were analyzed, located 30 centimeters from each other on both horizontal beams. Figure 8 shows the positions of these points on the horizontal beams. For each of the 29 points, the deviation Δ from the original position was determined in the case of both beams. The obtained deviation values are shown in Table 5.

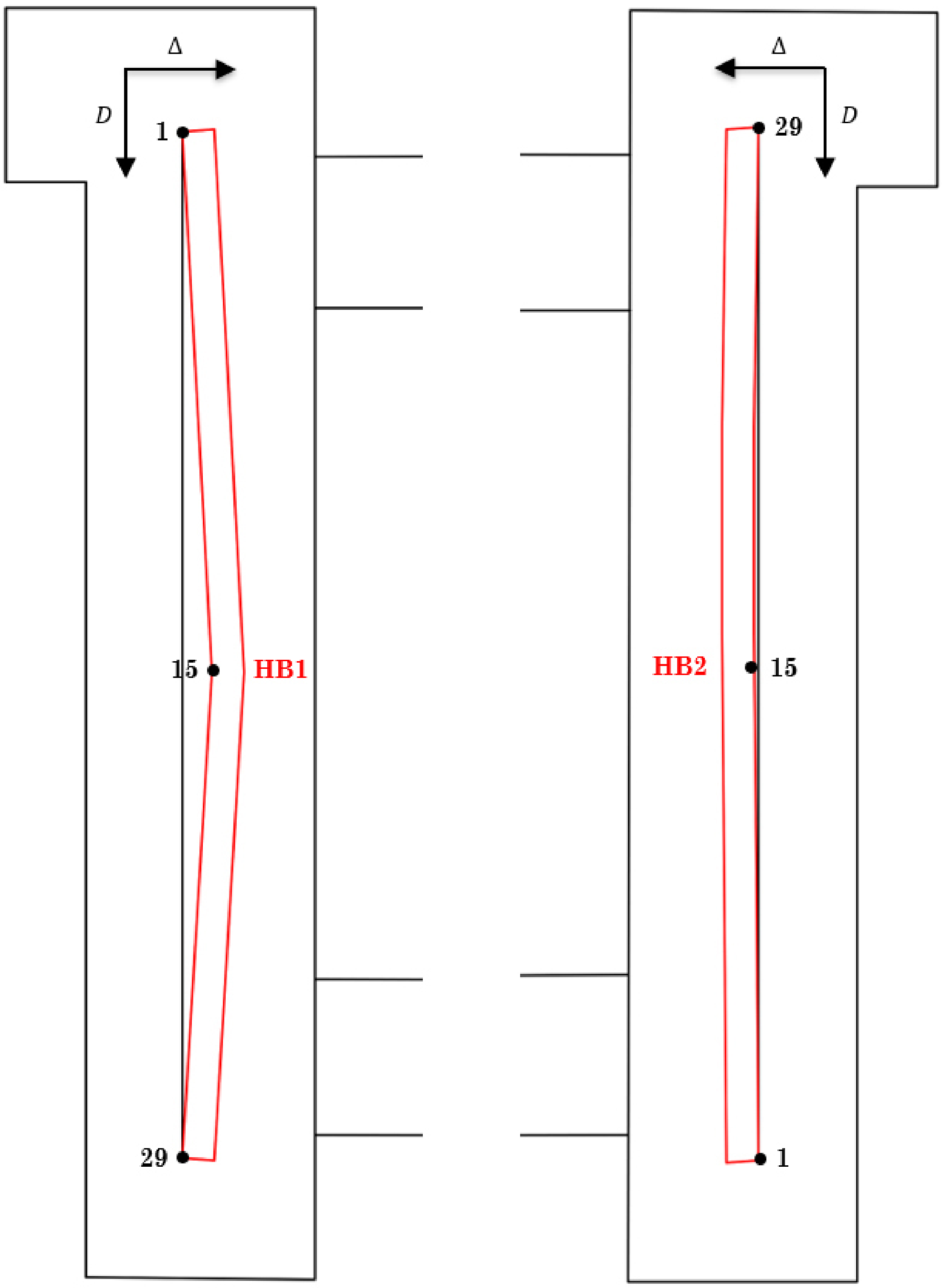

Figure 8. Positions of control points on horizontal beams.

Table 5. Deviations of the geometry of horizontal beams.

Points	HB1		HB2	
	D [m]	Δ [mm]	*D* [m]	Δ [mm]
1	0.00	0	0.00	0
2	0.27	15	0.27	2
3	0.54	29	0.54	4
4	0.81	44	0.81	7
5	1.08	59	1.08	9
6	1.36	73	1.35	11
7	1.63	88	1.62	13

Points	HB1		HB2	
	D [m]	Δ [mm]	*D* [m]	Δ [mm]
8	1.90	103	1.89	15
9	2.17	117	2.16	17
10	2.44	132	2.46	21
11	2.71	147	2.76	24
12	2.98	161	3.06	27
13	3.25	176	3.36	30
14	3.52	191	3.66	33
15	3.79	205	3.96	36
16	4.06	220	4.21	36
17	4.34	203	4.47	36
18	4.62	187	4.72	36
19	4.90	170	4.97	35
20	5.18	153	5.23	35
21	5.46	137	5.48	35
22	5.74	120	5.76	31
23	6.02	102	6.04	26
24	6.30	85	6.32	22
25	6.58	68	6.60	18
26	6.85	51	6.88	13
27	7.13	34	7.16	9
28	7.41	17	7.44	4
29	7.69	0	7.72	0

A comparative analysis of deviations of horizontal beams is given in the form of a diagram in Figure 9. It is evident that the deviations of beam HB1 are significantly greater than the deviations of beam HB2.

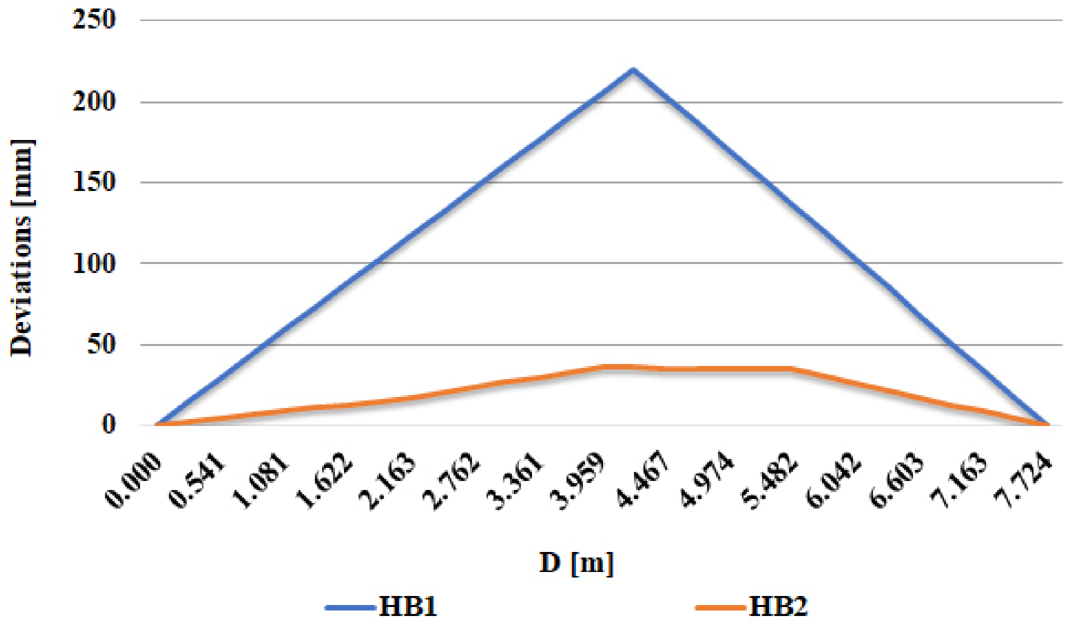

Figure 9. Diagram of deviations of horizontal beams.

5. CONCLUSION

Geodetic control of the geometry of objects is a very important and challenging task of engineering geodesy, which involves comparing the geometry of the constructed object with the designed geometry of the object. Control of the geometry of the objects is carried out by analyzing the corresponding horizontal and vertical sections of certain elements of the objects that are the subject of the analysis. In addition, in this procedure, it is very often necessary to examine the verticality of certain parts of the object, the horizontality, which implies checking the belongingness of the characteristic points of the object to a horizontal plane and the like. The paper presents a methodology for controlling the geometry of the bridge in Kula using terrestrial laser scanning technology. Based on the point cloud, which represents the product of the application of the mentioned technology, the control of the verticality of the four grooves that enable the movement of the weights used to raise the bridge was carried out, as well as the control of the geometry of the two horizontal beams. An analysis of the deviation from the vertical of the grooves revealed that all four grooves are twisted. The tops of the grooves G1, G2, and G3 deviate from the vertical by about 40 mm, while the top of the groove G4 deviates from the vertical by about 20 mm. The deviation values of the horizontal beam HB1 range from 0 to 220 mm, while the deviations of the horizontal beam HB2 range from 0 to 36 mm. It is important to point out that the minimum deviation values refer to the ends of the horizontal beams, while the maximum deviation values of the horizontal beams correspond to their middles. The obtained results unequivocally confirm the justification for the application of terrestrial laser scanning technology in the process of controlling the geometry of engineering facilities.

ACKNOWLEDGEMENT

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66
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LASER SCANNING AT THE LOCATION OF DEVILS' TOWN FOR THE PURPOSE OF DETECTING THE DEGREE OF EROSION OF EARTH PILLARS

Abstract

The detection of erosion was carried out on a characteristic rocky pillar, with the localization and quantification of differences between two surfaces. For this purpose, based on the defined area and spatial configuration of the scanning object, scanner positions, arrangement of control points, and appropriate spatial scanning resolution were planned. The spatial resolution of the point cloud is 1 cm, with a standard deviation of individual points up to 3 mm. Based on the collected data, registration of adjacent scenes was performed using typical scanner signals and the surface matching method. Georeferencing of the second epoch was carried out using the surface matching method. Locations where erosion of the rocky mass occurred were detected, amounting to 0.036 m^3 (36 dm^3).

Keywords: terrestrial laser scanning, 3D modelling, erosion, earth pillars

ЛАСЕРСКО СКЕНИРАЊЕ НА ЛОКАЦИЈИ ЂАВОЉА ВАРОШ ЗА ПОТРЕБЕ ДЕТЕКЦИЈЕ СТЕПЕНА ЕРОЗИЈЕ ЗЕМЉАНИХ ПИРАМИДА

Сажетак

Детекција ерозије спроведена је на једној карактеристичној стјеновитој фигури, са лоцирањем и квантификовањем разлика две површи. За ту сврху, на основу дефинисаног подручја и просторне конфигурације објекта снимања, планирана су стајалишта скенера, распоред контролних тачака и одговарајућа просторна резолуција скенирања. Просторна резолуција облака тачака износи 1 cm, а стандардно одступање појединачне тачке до 3 mm. На основу прикупљених података извршена је регистрација сусједних сцена на основу типских скенерских маркица и методом најбољег уклапања површи. Геореференцирање друге епохе извршено је методом најбољег уклапања површи. Детектована су мјеста на којима је дошло до ерозије стјеновите масе у износу од 0.036 m^3 (36 dm^3).

Кључне ријечи: терестричко ласерско скенирање, 3Д моделовање, ерозија, земљане пирамиде

1. INTRODUCTION

Terrestrial laser scanning (TLS), as one of the technologies applied in geodesy, offers solutions for various tasks within the field of surveying [1, 2]. The TLS method has shown promise in detecting changes and monitoring structural deformations, but improvements in registration, georeferencing, and point cloud processing are necessary for more precise results [3]. By employing TLS monitoring, it is possible to track deformations preceding landslides through routine detection on an annual basis [4]. Additionally, TLS can enhance the characterization and monitoring of rock slopes, enabling precise quantification of rockfalls [5], effectively detecting and analyzing structural damages, providing consistent results, and serving as a virtual sample for testing and post-testing analysis [6]. Yermolaev et al. [7] asserts that TLS offers several advantages: it can register different types of erosion in temporary water streams, enables non-invasive distance measurements without disturbing the surface being studied, and ensures work safety. Furthermore, it facilitates the calculation of morphometric parameters using a high-precision digital topography model. Based on observations in sample areas, the study demonstrates that autumn rains significantly impact soil erosion. Additionally, a study by Li et al. [8] analyzed the erosion and deposition patterns within the gully using two TLS surveys. They found erosion and deposition reserves of 11.0 and 8.2 m^3, respectively, at a DEM resolution of 2 cm. Due to its features, TLS enables data collection and analysis at sites such as "Devils' town". The process of monitoring the geometry of an object involves collecting data about the object (performing geodetic surveying) at different time intervals (epochs) and then comparing the obtained results. Comparison is typically made relative to the zero epoch (initially recorded state), but depending on the required information, subsequent epochs can also be compared. By collecting data in different temporal epochs and comparing them, erosion detection can be conducted. It is necessary to locate the areas where erosion has occurred and determine the degree of erosion by quantifying the differences between the two surfaces. The TLS method is suitable for capturing lateral details of pillars from both the observer's perspective and top-down, from multiple positions [9]. The scanning of the site was conducted in two epochs, the first epoch being in 2017 and the second one year later in 2018. This procedure was carried out within the scope of this study on a characteristic rocky pillar at a site known as "Barjaktar".

2. STUDY AREA

The natural phenomenon consists of Earth pillars, as well as specific relief forms, and two sources of highly acidic water with high mineralization. Devils' town comprises 202 pillars, formed by erosion, of various shapes and dimensions, ranging from 2 to 15 m in height and 0.5 to 3 m in width, with stone caps of various shapes and dimensions at the top (Figure 1). This process has been ongoing for centuries, as the towers form, grow, change, shorten, disappear, and reappear. The earth columns are composed of three layers of different compositions: the base layer is sandstone, up to one meter thick, the middle layer is yellowish clay, up to three meters thick, and above it is the thickest layer of sandstone, covered with andesite plates that protect the loose substrate from destruction and erosion. These specific relief forms were created by the action of rain on the former topographic surface. The site "Devils' town" has been under state protection since 1959, and in 1995, it was declared a natural monument of exceptional importance and placed in the first category of protection [12].

By washing away sand and gravel from underneath smaller or larger stone blocks, pillars in the form of towers and pillars remain. However, external forces (rain, snow, ice, wind) gradually erode the "towers," causing them to collapse, while new ones are formed due to soil washing. Thus, the earth pillars "move," gradually retracting deeper into the interior of the mountain slope [11].

Figure 1. Natural monument Devils' town [9]

This geomorphological phenomenon is unique in our country and very rare in the world. In Europe, there are several similar sites, while in America, the "Garden of the Gods" is known, but in "Devils' town", the pillars are more numerous, larger, and considerably more enduring.

The task of this study is the detection of erosion on characteristic rocky pillars. The pillar whose analysis is presented in this paper is the "Barjaktar" pillar (Figure 2). The name "Barjaktar" comes from the legend associated with "Devils' town", which states that the rocky pillars are petrified wedding guests. "Barjaktar," as the most prominent pillar, has an andesite cap weighing around 3.4 t [7].

Figure 2. Position of "Barjaktar"

3. METHODOLOGY

Terrestrial laser scanning represents a method for collecting spatial data, resulting in a set of 3D points, known as a point cloud. For each point, four pieces of data are collected: three spatial coordinate data and a fourth piece of data representing additional information about the intensity of the return signal. Certain TLS models are designed for high-precision measurements and are applied in the field of engineering geodesy, where the accuracy of 3D point positions needs to exceed 1 cm. The choice of scanner to be used primarily depends on the nature of the specific surveying task, as well as requirements regarding accuracy and scanning speed.

To obtain a unified point cloud of the scanned area, it is necessary to register all point clouds, ensuring the necessary overlap of individual point clouds of the scanned object. Point cloud registration can be performed based on typical signals, morphological details, etc. In this study, registration was performed using typical signals, where the object was marked before scanning. Identifying the typical signal and determining its position requires determining the signal center with satisfactory precision. The precision of determining the center depends on the point density of the terrain [12]. Therefore, data quality is represented by positional accuracy and resolution.

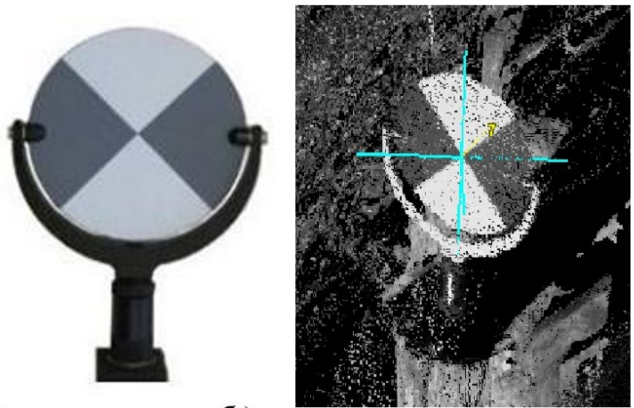
The data processing phase of the collected data is also a complex process and often requires much more time than the data collection itself. Data processing involves several steps, primarily including registration and georeferencing of point clouds obtained through scanning.

3.1. INSTRUMENT AND ACCOMPANYING EQUIPMENT

During scanning, the Leica Scan Station P20 scanner was used (Figure 3). The combination of pulsed time-of-flight distance measurement with Waveform Digitizing (WFD) technology enables high scanning speeds with the Leica P20 scanner (1,000,000 points/s), as well as the capability of distance measurement (up to 120 m), justifying the choice of this scanner to survey the Devils' town site. The declared accuracy of this scanner is 3 mm at 50 m. The laser belongs to Class 2, with a wavelength range from 658 nm (visible) to 808 nm (invisible). The ideal operating temperatures for this scanner range from -20˚C to +50˚C [13].

Figure 3. Leica Scan Station P20 [13]

As accompanying equipment for materializing tie points for registration purposes, Leica standard targets shown in Figure 4 were used.



a.) б.)

Figure 4. a.) Leica standard target b.) Appearance of scanned signal

3.2. LAYOUT OF STATIONS AND SIGNALS

Based on the defined scanning area and the terrain configuration, the stations must be arranged in such a way that the pillar of interest ("Barjaktar") is scanned from all sides to identify areas where erosion has occurred. The scanner stations were selected to ensure the scanner was positioned on a stable surface, in this instance, a wooden platform. Placing the scanner on an unstable surface was avoided due to the significant risk of movement. The layout of standard signals is defined to ensure a sufficient number of signals are captured in each scene for registration to be performed with the required accuracy. All signals are stabilized to prevent their movement until scanning is completed from all stations. In the first epoch, 12 signals were used, and in the second epoch, 9 were used. The smaller number of signals in the second epoch is due to the smaller number of stations (Figures 5 and 6). In both epochs, stations numbered from 2 to 5 are used (Figures 5 and 6), because within those scenes, the "Barjaktar" is scanned.

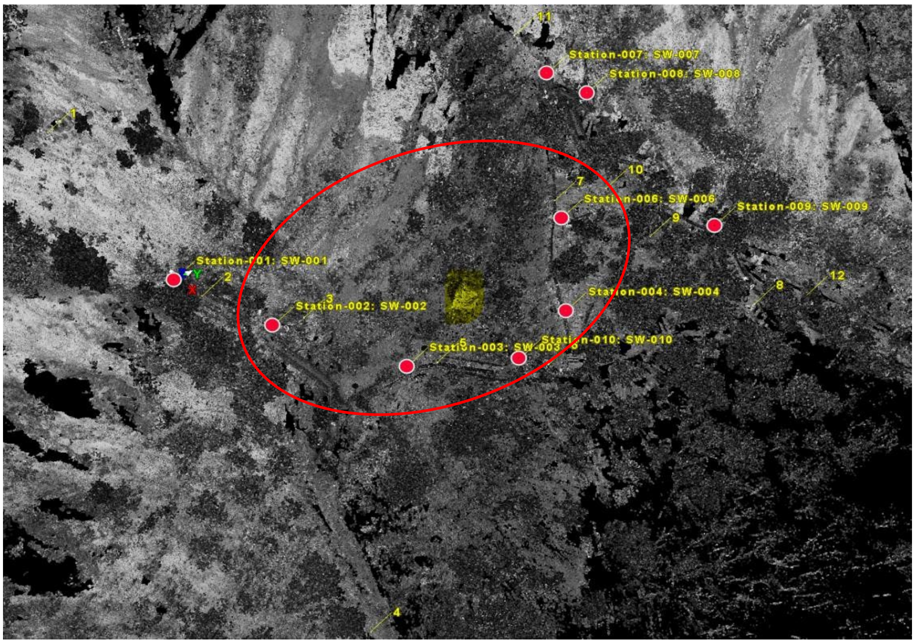


Figure 5. Layout of stations and signals for the first epoch (2017)

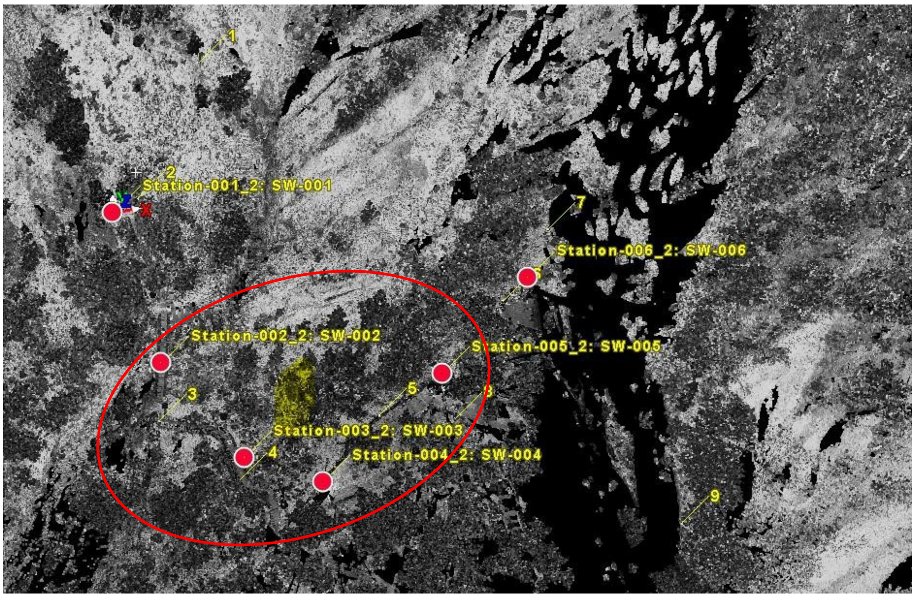


Figure 6. Layout of stations and signals for the first epoch (2018)

3.3. REGISTRATION AND GEOREFERENCING

Data registration was performed using the *Leica Cyclone 9.0* software [14], which enables the manipulation and processing of point clouds.

The method used for registration in both epochs is registration using standard signals. Additionally, an analysis was conducted when both standard signal registration and surface matching were used simultaneously, and it was observed that for this specific case, better accuracy is achieved only with standard signal registration.
Georeferencing was carried out using the surface matching method. The point cloud from the second epoch, which was previously registered, was georeferenced by transforming the coordinate system of the second epoch's point cloud into the coordinate system of the first epoch's point cloud.

4. RESULTS

The recordings were carried out in November 2017 as part of the first epoch and in September 2018 for the second epoch, as part of the pilot project MEĐA, which was realized by a part of the research team in 2017-2018 [7].

Result of the registration for the first epoch:

As a result of the registration, in addition to the merged point cloud, a registration report is obtained. It contains all relevant data about the registration, including accuracy, the number of signals, and the error in their determination. From the analysis of the report, it was concluded that if all signals that can be used for registration between all scenes are included in the registration, its global uncertainty amounts to 9 mm, which is not sufficient in this case. Further analysis revealed that during the scanning of scene number 10, marker number 3 was displaced. This was concluded because the errors in the registration of the 10th scene with all other scenes using that marker (scenes number 1, 2, 3, and 5) were significantly larger (7-9 mm) than the rest (0-4 mm) (Table 1).

Table 1. Errors on marker number 3

No. signal	Scene “i”	Scene “j”	Error (mm)
3	001	010	9
3	002	010	9
3	003	010	9
3	005	010	7

After marker number 3 was excluded from the mentioned scenes and registration was performed again, the accuracy of the registration was 2 mm.

Result of the registration for the second epoch:
The accuracy of the registration in this epoch, when all signals are used, is 7 mm, which, like in the first epoch, is not satisfactory accuracy. Analysis of the report revealed that the error on marker number 4 during registration between scene number 2 and scene number 4 is 7 mm, which is also the largest error. When it is excluded and the registration process is performed again, the accuracy of the registration, like in the first epoch, is 2 mm.
Georeferencing was conducted utilizing the optimal surface matching. The point cloud from another epoch, over which the registration was previously performed, is georeferenced, i.e. the point cloud coordinate system of the second epoch is transformed into the point cloud coordinate system of the first epoch. This entails transforming the coordinate system of the point cloud from the second epoch into that of the first epoch. Following georeferencing, a report indicated that the accuracy of georeferencing is 3 mm.
In addition to the aforementioned georeferencing accuracy of 3 mm, 319 400 overlapping points were used for the transformation process. In this case, a four-parameter transformation was performed. The scanner allows for the compensation of the Z-axis inclination with an accuracy of 1.5", thereby nullifying the parameters of rotation around the X and Y axes. The surface matching method is an iterative process, and according to the report, 7 iterations were performed in this case.

4.2. ANALYSIS OF REGISTRATION USING STANDARD SIGNALS AND THE SURFACE MATCHING

The registration analysis was performed on the registration data of the second epoch (2018). Registration using the standard signals method has a mean absolute error of 2 mm, while registration using both standard signals and the surface matching method has a mean absolute error of 3 mm.

4.3. EROSION DETECTION (LOCATING AND QUANTIFYING DIFFERENCES)

After georeferencing the point cloud of the entire site for both recording epochs, the pillar of interest ("Barjaktar") was "cut out" (Figure 8), and the point cloud resolution was adjusted to 1 cm (using the *Unifi cloud* function) to enable the comparison of two georeferenced point clouds of the same pillar, captured in two epochs.

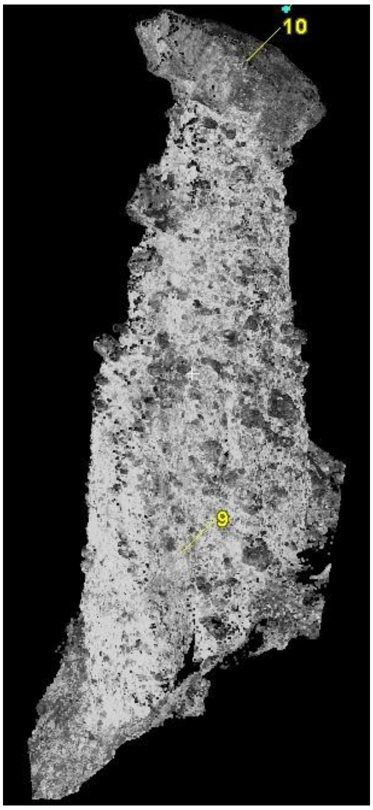


Figure 7. The pillar "Barjaktar" after extraction

For the next analysis, the CloudCompare software [15] (an open-source program) was used. Figure 8 shows the point clouds from the first and second epochs within this program.

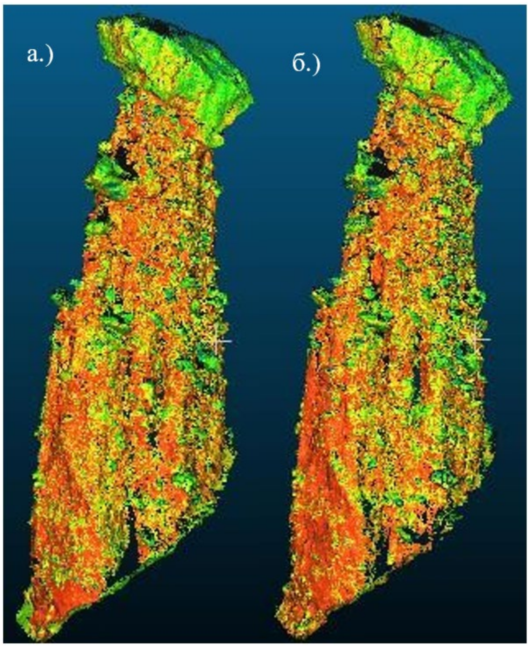


Figure 8. The pillar of "Barjaktar" a) first epoch b) second epoch

After loading both point clouds, the next step involves computing deviations between the two epochs. The Cloud/Cloud Distance function was used for this step. The point cloud from the first epoch serves as the reference for comparison, while the point cloud from the second epoch is the one being compared. The basic idea is to determine distances using the nearest neighbor distance method. Calculating distances using the nearest neighbor method sometimes isn't precise enough if the point cloud isn't dense enough or has gaps. Increasing precision can be achieved by defining local models. When comparing point clouds of interest, the local Height Function model was employed. This choice was made based on the recommendation of the program creators, particularly when dealing with point clouds exhibiting "high curvature" [15]. The result of comparing the two epochs is shown in Figure 9. The figure displays a color scale representing the distance between the epochs.

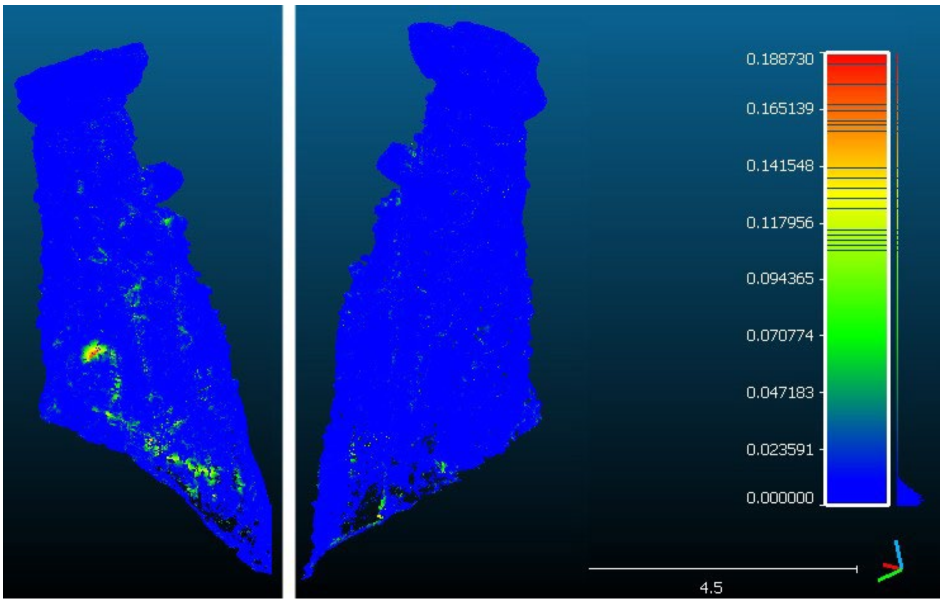


Figure 9. The result of comparing the first and second epochs

Visual inspection and comparison were conducted on areas marked by the color scale ranging from green to red, indicating areas where erosion occurred. As seen in Figure 10, there are areas where erosion has occurred, while the appearance in other places is due to the lack of points from the first recording epoch. These areas were not further considered. The area where erosion occurred is shown in Figure 10 and will be the subject of further consideration.

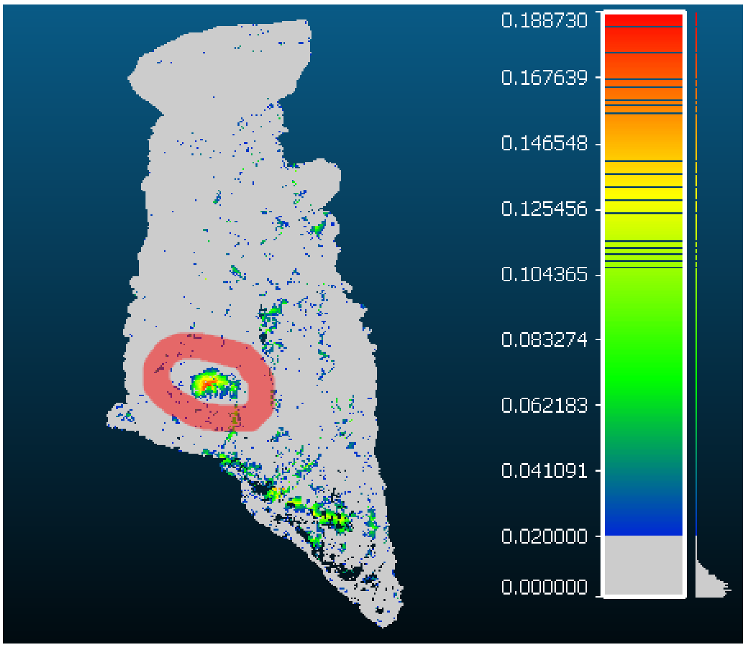


Figure 10. The area (outlined in red) where erosion has occurred

The area of interest has been isolated from the point cloud, and an analysis has been conducted on it. Figure 11 shows the area where the analysis was conducted. One part of the image displays the point cloud from the second epoch, while the other part shows the point cloud where the first epoch recording is also depicted. It is evident here that there was a significantly more rocky mass in the first epoch compared to the second.

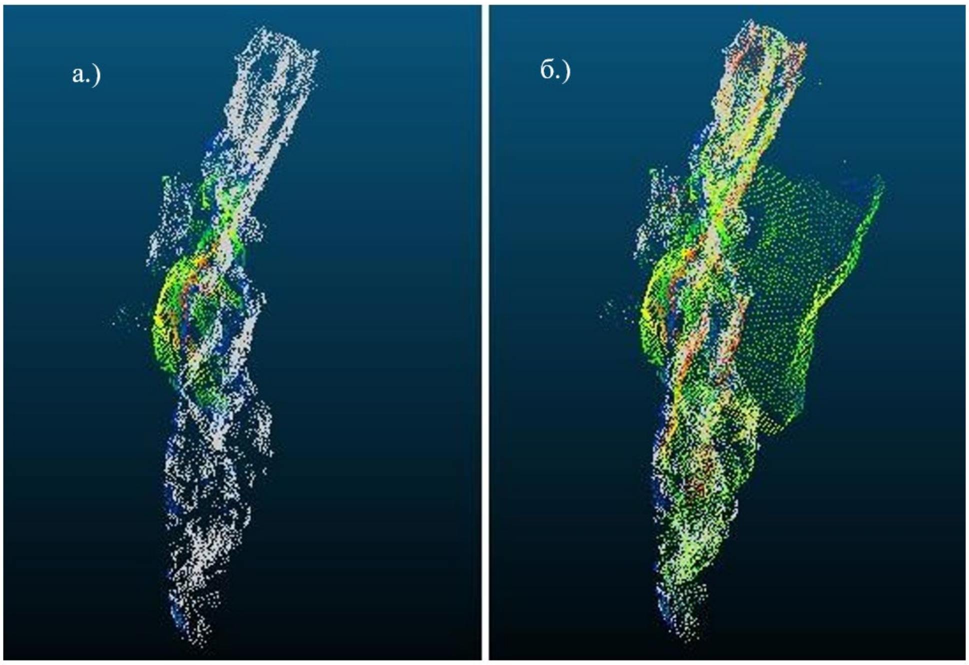


Figure 11. a) Point cloud from the second epoch. b) Point cloud with the first epoch included.

The CloudCompare software [15] offers the ability to calculate volume based on a grid between two point clouds. When initiating the volume calculation function *Compute 2,5D Volume*, it's necessary to input the projection direction value. The function *Compute 2.5D Volume* calculates the volume based on the grid In this specific case, the direction of the Y-axis was used. The appearance of the grid based on which the volume of the landslide was calculated is shown in Figure 12.

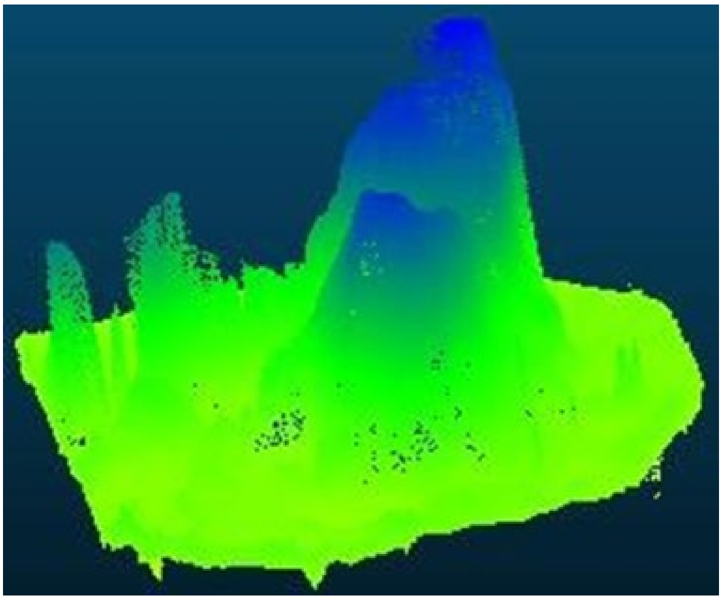


Figure 12. The grid based on which the volume was calculated

The following lines present the volume calculation report. The report indicates that the volume of the landslide material amounts to 0.036 m^3 (36 dm^3).

Volume: -0.036
Surface: 0.641

Added volume: (+)0.001
Removed volume: (-)0.037
Matching cells: 99.2% Non-matching cells:
ground = 0.0%
ceil = 0.8%
Average neighbors per cell: 8.0 / 8.0

5. CONCLUSION

During the detection and quantification of erosion of the rocky pillars, data from two scanning epochs of the "Devils' town" site were compared. The scans were conducted in November 2017 and September 2018 as part of the "MEĐA" project. Registration and georeferencing processes were performed on each epoch, followed by georeferencing of the second epoch using the surface matching method. After isolating the pillar of interest ("Barjaktar"), a comparison of the pillar from both epochs was conducted using the CloudCompare software. Deviations between the two point clouds were detected and analyzed. It was revealed that erosion of the rocky mass occurred at one location. Through analysis and comparison, it was determined that the quantity of rock mass that eroded amounted to 0.036 m^3 (36 dm^3). This represents the initial phase of research and monitoring changes occurring within the "Devils' town" site. The presented methodology can be successfully utilized for analysis and comparison within the newly acquired project of the Science Fund DEMONITOR, within which all members of the project "MEĐA" are involved. In the scope of future research, the presented epochs will serve as a baseline for further analyses, and the same methodology can be used for other planned epochs. Within the DEMONITOR project, six site visits are planned to survey the area using TLS and aerial photogrammetry with unmanned aerial vehicles (UAV), where significant results are expected already after the first site visits, considering the seven years.

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LITERATURE

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67

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DEFINITION OF THE EXPOSURE MODEL FOR THE CASE STUDY KARPOSH IN SKOPJE ACCORDING TO TWO URBAN SCENARIOS

Abstract

The application of seismic design codes is crucially important for the seismic safety of the built environment developed in earthquake prone regions. However, there are also buildings built before the introduction of seismic design codes. Seismic risk assessment is a useful process which can help identify the seismic safety of the urban regions with buildings belonging to different periods. Defining the components of seismic risk; hazard, exposure and vulnerability is a very important step in order to obtain reliable seismic risk assessment results. The focus of this research paper is on defining the exposure model attributes in the case study Karposh. Characteristic for the case study is the fact that it consists of buildings built in different periods, before and after the introduction of seismic design codes. There are also buildings which have been structurally modified and resulted with mixed structures. The approach in the definition of the exposure model is based on urban planning aspects as well and the exposure model is defined according to two urban scenarios, scenario 1 - the existing site and scenario 2 - the planned site.

Keywords: exposure model, urban scenarios, case study

ДЕФИНИЦИЈА МОДЕЛА ИЗЛОЖЕНОСТИ ЗА СТУДИЈУ СЛУЧАЈА КАРПОШ У СКОПЉУ ПРЕМА ДВА УРБАНА СЦЕНАРИЈА

Сажетак

Примјена кодова за сеизмичко пројектовање од кључне је важности за сеизмичку безбједност изграђеног окружења у подручјима склоним земљотресима. Међутим, постоје и зграде изграђене прије увођења кодова за сеизмичко пројектовање. Процјена сеизмичког ризика користан је процес који може помоћи у идентификацији сеизмичке безбједности урбаних подручја са зградама које припадају различитим периодима. Дефинисање компоненти сеизмичког ризика; опасности, изложености и рањивости, врло је важан корак како би се добили поуздани резултати процјене сеизмичког ризика. Фокус овог истраживачког рада је на дефинисању атрибута модела изложености у студији случаја Карпош. Оно што је карактеристично за ову студију случаја је чињеница да се састоји од зграда изграђених у различитим периодима, прије и послије увођења кодова за сеизмичко пројектовање. Постоје и зграде које су конструктивно модификоване и резултирале мјешовитим конструкцијама. Приступ дефинисању модела изложености заснован је и на урбанистичким аспектима, а модел изложености дефинисан је према два урбана сценарија, сценарио 1 - постојеће мјесто и сценарио 2 - планирано мјесто.

Кључне ријечи: модел изложености, урбани сценарији, студија случаја

INTRODUCTION

Earthquakes as natural phenomena represent a serious threat to the seismic safety of the built environment. The seismic safety of human settlements developed in earthquake prone regions in first place relies on the use of seismic design codes in the process of design and construction of the buildings. However, not all buildings are designed and built according to seismic design codes. Namely, urban tissues consist of buildings belonging to different periods, built before and after the introduction of seismic design codes. Non-seismically designed and constructed buildings pose danger to their urban environment because their seismic stability is unknown [1].

In order to identify such buildings which are vulnerable to seismic risk it is recommended to apply seismic risk assessment at urban scale [2]. Based on the definition of risk in Sendai framework for action, the seismic risk can be defined as function of interrelated components of hazard, exposure and vulnerability. The hazard component refers to the ground shaking caused by earthquake while all the entities in the area affected by the earthquake make up the exposure component. The characteristics of the exposed entities to get damaged or to endure losses during an earthquake is referred to as vulnerability. Besides the mentioned components also there is the component of resilience, the capacity of the exposed entities to overcome an adverse situation and get back to normal state [3].

As part of the doctoral dissertation research of the first author, an urban region consisting of mixture of buildings from different periods was taken as a case study to assess the seismic risk level. The case study is a residential urban region in the Municipality of Karposh in the City of Skopje. The territory of Skopje is well known for its seismicity and the greatest natural catastrophe in the history of the city was the earthquake of 1963 where 1.070 people lost their lives, 3.300 were injured and many were left homeless [4].

The focus of this research paper is the development of exposure model, the component of seismic risk with most dynamic nature. In the seismic risk assessment of the case study in Karposh, beside understanding the seismic risk level, the aim was to identify the urban planning parameters which have influence on the seismic risk. For this purpose, the exposure model of the urban region was prepared in two urban scenarios, in scenario 1 the site was treated in its existing condition, while in scenario 2 the exposure model was prepared according to Detailed Urban Plan.

1. BRIEF REVIEW OF THE SELECTED CASE STUDY KARPOSH

The Municipality of Karposh is one of the four largest municipalities in Skopje. Karposh, founded as a municipality in 1976, extends to area of 35 km^2 and has approximate population of 60.750 residents according to census data from 2021 [5]. Most of today's territory of Karposh was built after the 1963 earthquake but some areas closer to the center of the city existed also prior to this earthquake. The case study area (figure 1) is an example of urban planning and construction practice in the City of Skopje.

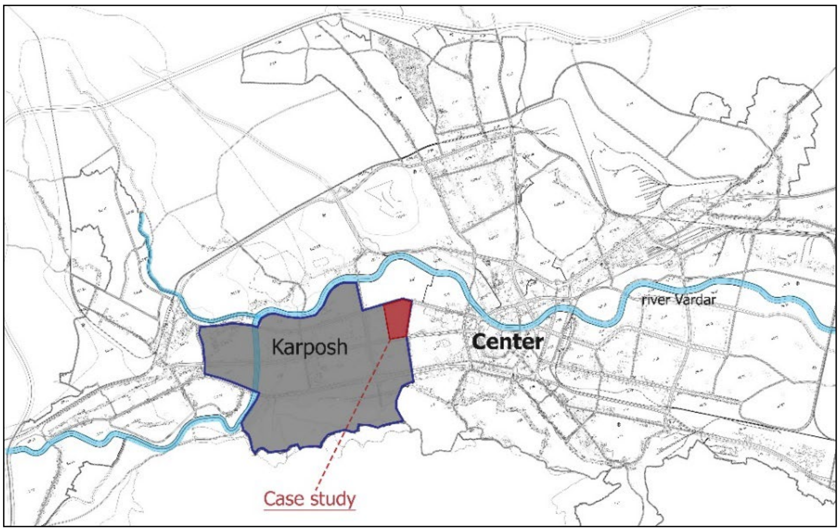

Figure 1. The urban territory of Municipality of Karposh. Map prepared by author based on the General Urban Plan of City of Skopje for plan period of 2011-2022. Source: [6]

Between 1950 and 1963 in the West side of the City of Skopje, today's territory of Karposh, to ensure the accommodation requirements triggered by the rapid urbanization due to industrial development of the country, many residential buildings with standardized typology of masonry structure with height between 3 to 5 floors were built with low to moderate construction quality. The first seismic design codes were introduced in 1964 [7] followed by more advanced seismic design code of 1981 [8] which is still in use. Buildings constructed before these seismic design codes are considered to be seismically vulnerable [9]. Expectedly, these buildings endured big damages in the aftermath of the 1963 earthquake. Masonry structures were the most heavily damaged, while reinforced concrete buildings showed less damages [10].

After the earthquake with the purpose to increase the speed of construction industry to meet the housing requirements the factory for production of concrete building blocks named "Karposh" was established in the Municipality of Karposh [10].

Starting from 1990's the trend of making structural changes to existing buildings, such as increasing living space by enclosing balconies into rooms, adding roof floors to flat roofs, became a regular practice [11;12]. This type of modifications, annexes to existing buildings, leads to creation of built environment with unknown seismic stability and safety.

Even though at the beginnings adding annexes to existing buildings was considered illegal, this practice got recognized by the building law in 2008 and since then structural interventions to existing buildings are subject to building permit approval, whereas, illegally constructed annexes prior to this law were legalized with the amendments in 2011 and 2013 [12].

The urban region selected as case study consists of buildings built in different periods, before the 1963 earthquake, according to two different seismic design codes and has examples of buildings with mixed structures as result of annexes.

2. KARPOSH CASE STUDY AND URBAN SCENARIOS

The case study building stock was subject to seismic risk assessment for two urban scenarios, scenario 1 – existing site and scenario 2 – planned site. The exposure model was prepared for both scenarios, scenario 1 based on the previous field studies by IZIIS [11; 13] and scenario 2 based on the Detailed Urban Plan [14] and estimation of buildings' structures.

The seismic risk assessment was conducted by using the Open Quake engine, developed and maintained by GEM [15]. Accordingly, all the information about the entities formulating the exposure model was analyzed and translated into GEM's classification of attributes defining the exposure model.

2.1. EXPOSURE MODEL FOR SCENARIO 1

In urban scenario 1, the existing site of the case study, the exposure model was prepared based on previous field studies by IZIIS [11; 13]. The data about the building stock in the case study area was collected with rapid visual inspection approach with use FEMA-154 methodology [16]. Based on visual inspection as well as buildings' plan and section drawings the following information was compiled in the report of IZIIS: the typology of structural system, year of construction, height of building, structural modifications made on building and damages endured by the building [11]. During the visual inspection process by IZIIS, some of the buildings were identified as seismically vulnerable and they were denoted to be analyzed in more detail [11]. The total number of buildings in the case study area is 203 while 159 were subject to visual inspection. In order to simplify the process of seismic risk assessment smaller size buildings such as garages and buildings with wooden structure were eliminated. In this way, in scenario 1 the total number of buildings is 147 while the number of structures is 173. The difference between the number of buildings and structures is due to the structural interventions applied on the existing buildings which results in buildings with mixed structures (see 4.1.1). Figure 2 (left image) shows the mapping of the buildings and annexes in QGIS [17] according to scenario 1 of the case study.

Figure 2. Case study Karposh, mapping of buildings and their annexes in scenario 1 (left image) and scenario 2 (right image).

2.2. EXPOSURE MODEL FOR SCENARIO 2

The exposure model in urban scenario 2 for the case study was prepared based on the Detailed Urban Plan (DUP) [14] developed for the region Z 08 where the case study location is situated. The structural system of each entity of the exposure model to which a certain change was foreseen with the DUP was defined taking into consideration the construction practice in the city, seismic design codes and experts' opinion. Regarding the existing buildings which are foreseen to have changes in terms of urban parameters, the DUP doesn't define if the existing building should be demolished and rebuilt or the spatial area of the existing building can be increased by annexes (structural interventions). In order to solve this dilemma each entity was analyzed from the following aspects:

- What is the difference in the gross area and number of floors between the existing and the planned version of the building?
- What is the year of construction of the existing building?
- What is the structural system of the existing building?

Considering all these aspects it was decided whether the building should be demolished and rebuild or it can be upgraded with annexes. In scenario 2 exposure model 50 buildings were decided to be demolished and rebuilt with structures in line with modern seismic design code. Changes to existing buildings were also allowed but with use of annexes with expansion joints in most of the cases. However, adding a single story to an existing building was considered as annex without use of expansion joints. Beside the changes applied to existing buildings, the DUP proposes 9 new buildings of which the structural system was decided to be best suitable for the number of floors and gross area of the buildings. By deciding about the construction status of the buildings and their structural system the exposure model in scenario 2 regarding the taxonomy of the exposed entities is improved compared to exposure model of scenario 1. There are in total 155 buildings and 204 structures in scenario 2 (figure 2, right image).

3. KARPOSH CASE STUDY EXPOSURE MODEL

The exposure model consists of taxonomy and additional attributes which define the characteristics of the exposed entities. The taxonomy is the most important part of the exposure model since it is used to correlate the exposed entity to the fragility and vulnerability functions in the calculation processes by Open Quake engine [15]. Since in the seismic risk assessment of the case study Karposh existing fragility and vulnerability curves were selected from the database of ESRM20 [18], the taxonomy attributes were defined in accordance with the attributes of these fragility and vulnerability functions. Beside the taxonomy, urban planning attributes and structural cost for replacement of buildings were included as additional attributes in the exposure model. The urban planning attributes considered in the exposure models are: plan shape of buildings, placement of buildings in urban block, occupancy type of buildings and number of occupants.

3.1. TAXONOMY

Each entity in the exposure model is defined with different attributes which formulate the taxonomy. For the building stock of the case study area in Karposh the taxonomy was constituted from the following attributes: material and structural system of the buildings, construction period, alignment with the seismic design codes and ductility level, height of the buildings (table 1). For reinforced concrete frame and infilled frame structures also the coefficient of lateral force was taken into account when defining the taxonomy.

Table 6: Description of the attributes in taxonomy of the entities from the exposure models.

Material	CR: reinforced concrete	MCF: confined brick masonry	MUR: unreinforced brick masonry
Lateral load resisting structural system	LDUAL: dual frame-wall system	LWAL: load bearing wall	LWAL: load bearing wall
	LFINF: infilled frame	/	/
	LFM: frame	/	/
Seismic design code /coefficient of lateral force (applies only for LFINF and LFM)	CDL: low code	/	/
	CDM: medium code	/	/
Ductility	DNO: no ductility	DNO: no ductility	DNO: no ductility
	DUL: low ductility	DUL: low ductility	DUL: low ductility
	DUM: moderate ductility	DUM: moderate ductility	DUM: moderate ductility
Height (number of floors)	LDUAL_H: 1-12	1-6	1-5
	LFINF_H: 1-6		
	LFM_H: 1-6		

As result of structural interventions made on existing buildings in the case study area there are also buildings with mixed structures which results in having greater number of structures compared to the number of buildings. Each structure in the exposure model is defined with the appropriate taxonomy. The simplified version of the different taxonomies and their numbers in different scenarios of the exposure model are shown in table 2. In scenario 2 the structures with taxonomies known to be more vulnerable to seismic risk were replaced with structures which have better seismic performance.

Table 7: Number of structures per taxonomy in scenario 1 and 2.

Taxonomy	**Number of structures**	
	Scenario 1	**Scenario 2**
CR_LDUAL_DUL	10	7
CR_LDUAL_DUM	18	26
CR_LFINF-CDL-10	3	3
CR_LFINF-CDM-10	30	53
CR_LFM-CDL-10	1	1
CR_LFM-CDM-10	15	64
MCF_LWAL-DUL	27	17
MCF_LWAL-DUM	4	4
MUR-CL_LWAL-DNO	65	29
Total number of structures	**173**	**204**

3.1.1. MATERIAL AND STRUCTURAL SYSTEM OF BUILDINGS (DUCTILITY, COEFFICIENT OF LATERAL FORCE)

The material and structural system of the buildings present in the case study area can be defined in three groups: unreinforced brick masonry load bearing wall structures (MUR_LWAL), confined brick masonry load bearing wall structures (MCF_LWAL) and reinforced concrete structures (CR). Within the category of reinforced concrete structures there are moment frame structures (CR_LFM), infilled moment frame structures (CR_LFINF) and dual structures consisting of frame and load bearing wall (CR_LDUAL).

The mapping of the different structures on the case study for scenario 1 and 2 is shown in the figures 3 and 4 respectively.

Figure 3. Mapping of structural system of buildings and annexes in scenario 1.

Figure 4. Mapping of structural system of buildings and annexes in scenario 2.

Within the exposure model there are also buildings with mixed structures which is result of structural interventions made on existing buildings. Buildings which were subject to structural interventions were defined as two categories. In the first category, structural interventions were directly constructed on the existing structure without use of expansion joints (figure 5). Whereas, in the second category, structural modifications were applied by using expansion joints (figure 6). In the ERSM20 model there are no fragility or vulnerability functions which correlate to buildings with mixed structures. In order to define the taxonomies of such buildings in more reliable way the following criteria was applied; if the structural modification was done with use of expansion joints the taxonomy was defined separately, for the original (existing) structure and for new built ones, whereas if the structural modification was done without use of expansion joints then the taxonomy was defined as one structure based on the properties of the existing building (more conservative solution).

Figure 5. Buildings with mixed structure without use of expansion joints. Sources: photos by K. Edip.

Figure 6. Buildings with mixed structure with use of expansion joints. Source: photos by K. Edip.

3.1.2. CONSTRUCTION PERIOD AND ALIGNMENT WITH SEISMIC DESIGN CODES

According to the year of construction the buildings in the case study area, with respect to the application of seismic design codes, can be grouped in the following three categories:

- Buildings constructed before 1964
- Buildings constructed between 1964-1981
- Buildings constructed after 1981

Until 1964 buildings were constructed without taking into consideration the seismic forces because there was no seismic design code. Structures of the buildings constructed before 1964 in their taxonomy are defined as CDN (no seismic design) or DNO (no ductility). In 1964 the first seismic design codes were introduced which required structures to be designed and constructed according to method of allowable stress design. In 1981 the modern seismic design codes were adopted and the design of the structures was according to the method of modern limit state design and partially applying the method of capacity design [19].

The presence of structures belonging to different periods of construction in scenario 1 and 2 are shown in the figures 7 and 8 respectively.

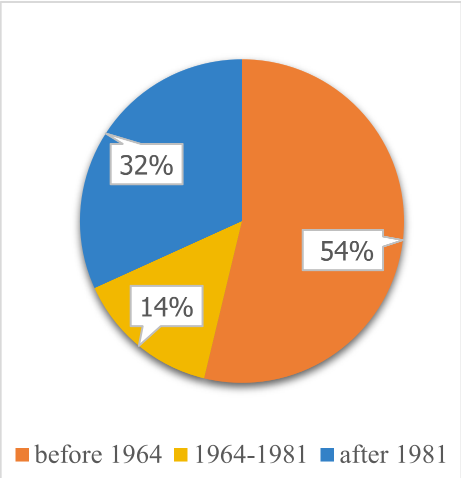

Figure 7. Scenario 1 – construction period of structures

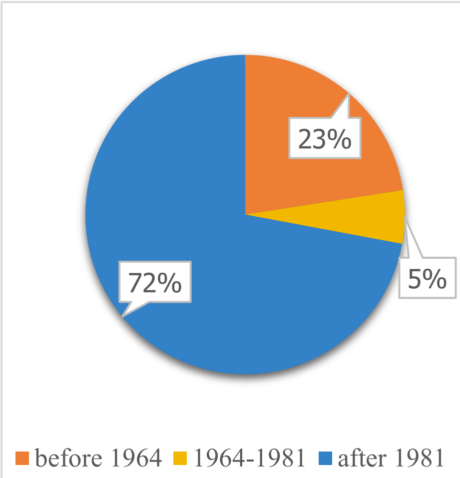

Figure 8. Scenario 2 – construction period of structures

In scenario 2 the number of structures designed and built according to the modern seismic design codes of 1981 is increased compared to scenario 1 where most dominant are the structures built prior to the introduction of the seismic design codes of 1964. Distribution of building entities per structural system and period of construction, in both scenarios, is shown in figures 9 and 10 respectively.

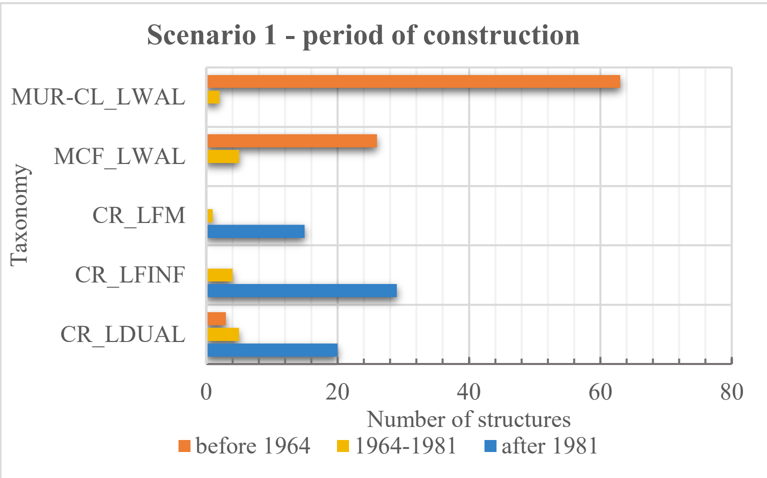

Figure 9. Structural system and period of construction in scenario 1.

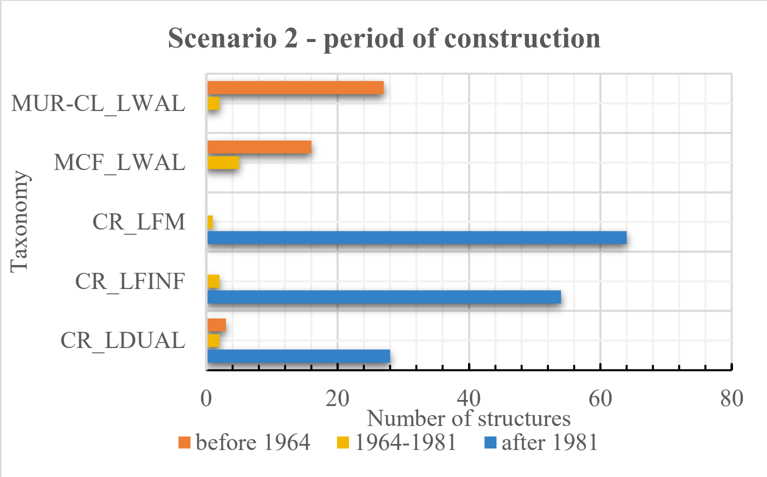

Figure 10. Structural system and period of construction in scenario 2

3.1.3. HEIGHT OF BUILDINGS

According to the height of the building, the entities in the exposure model are divided in three categories: low rise buildings with height up to 3 floors above ground, midrise buildings with 4 to 7 floors and high rise buildings with more than 8 floors height. In both scenarios there are just a few high rise buildings, there are 6 structures in scenario 1 and 12 structures in scenario 2 considered as high rise buildings, while the maximum height is 18 floors. As shown in figure 11, in scenario 1 mostly dominate the low rise structures, while in scenario 2 these are replaced by midrise structures.

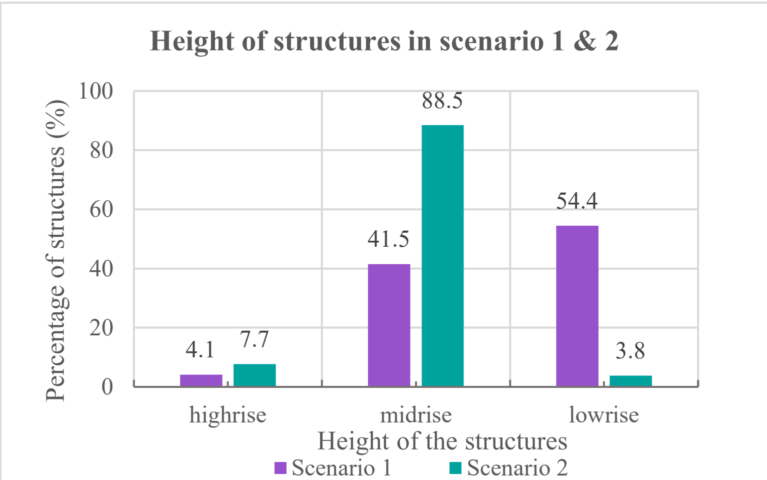

Figure 11. Height of structures in scenario 1 and 2.

In scenario 1 the low rise buildings are mostly unreinforced masonry (MUR) and confined masonry (MCF) structures. Also, there are midrise buildings with MUR and MCF structures in scenario 1. The number of midrise structures increases in scenario 2 where most of the buildings are with reinforced concrete structures (CR_LFM, CR_LFINF). High rise buildings in both scenarios are with reinforced concrete dual structures consisting of frame and wall (CR_LDUAL).

3.2. URBAN PLANNING ATTRIBUTES

Beside the attributes defining the taxonomy of the entities other attributes considered to be important in the overall seismic risk assessment were added into the exposure models of scenario 1 and 2. Attributes important from urban planning point of view are the plan shape of the buildings, placement of the buildings in urban block and the occupancy type of the buildings. The urban planning parameters were considered together with the taxonomy in order to have more comprehensive overview of the exposure model.

3.2.1. PLAN SHAPE OF THE BUILDINGS

According to the type of plan shape in the case study there are rectangular solid, rectangular with opening, square solid, polygonal solid and “L” shapes of plans. The presence of different types of plan shapes in scenarios 1 & 2 are shown in figures 12 and 13 respectively.

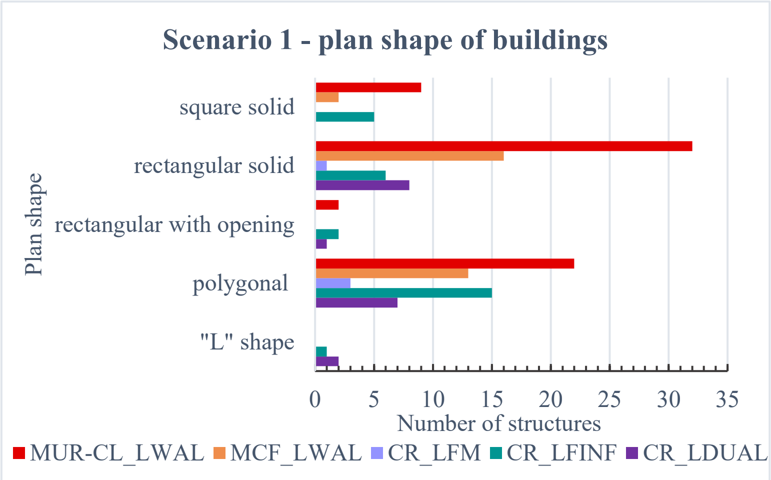

Figure 12. Taxonomy and plan shape in scenario 1.

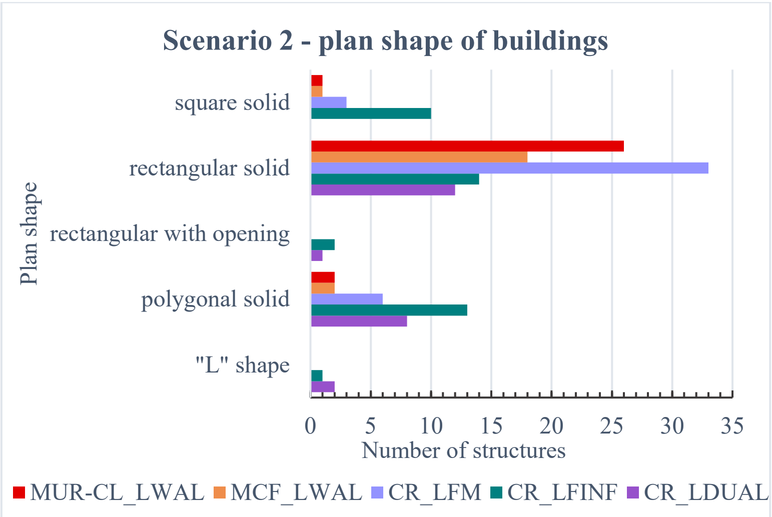

Figure 13. Taxonomy and plan shape in scenario 2.

While in scenario 1 most dominant are the rectangular solid and polygonal solid shapes with all taxonomy types, in scenario 2 the number of polygonal solid plan shape for masonry structures (MUR and MCF) is decreased. The rectangular solid and square solid plan shapes are more preferable for the seismic stability of the structures; however, the plan shape should be considered together with the taxonomy of the exposed entity.

3.2.2. PLACEMENT OF BUILDINGS IN URBAN BLOCK

In the case study area buildings are mainly placed adjacent with one building, adjacent with two buildings and there are alone standing buildings. The number of buildings adjacent on one side in scenario 1 is 45.8% and increases to 53.5% in scenario 2. The number of detached buildings decreases from 41.9% (scenario 1) to 32.9% (scenario 2). There are a few buildings which are adjacent on both sides and their percentage in scenario 1 and 2 are 7.1% and 13.5% respectively.

In scenario 1, dominant is unreinforced masonry structures (MUR) adjacent on one side with other structures (figure 14). Having this kind of seismically vulnerable structures adjacent to other structures represents a threat for the seismic safety of the urban block. Considering this aspect, in scenario 2 the number of adjacent standing MUR structures is decreased (figure 15). Though the number of adjacent on one side and adjacent on both sides in scenario 2 increases compared to scenario 1, having structures with better taxonomy can help increase the seismic safety at urban scale.

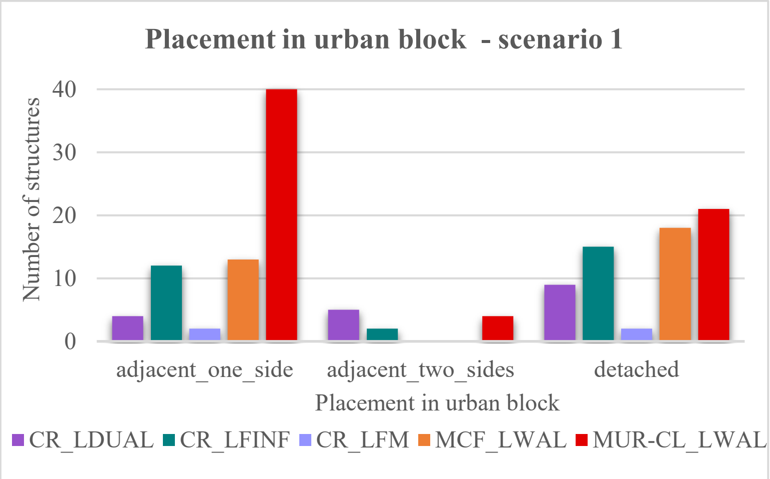

Figure 14. Placement in urban block and structural system in scenario 1

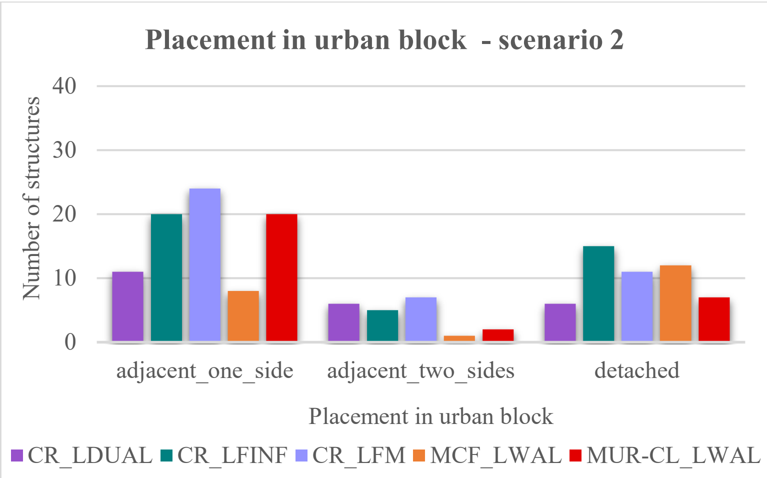

Figure 15. Placement in urban block and structural system in scenario 2.

3.2.3. OCCUPANCY TYPE OF BUILDINGS AND NUMBER OF OCCUPANTS

The case study location is mainly residential urban area consisting of multilevel apartment buildings and houses. In scenario 1 the percentage of residential occupancy type is 82.3 % and increases to 85% in scenario 2. There are also buildings with mixed occupancy type usually consisting of residential areas at upper floors and commercial use in ground floor. The presence of mixed occupancy buildings is very similar in both scenarios, approximately 11%. As standalone buildings with commercial occupancy type there are just a few in scenario 1 (6.1%), while in scenario 2 their number decreases to 3.9%.

In order to determine the number of occupants in different scenarios of case study the following steps were taken. First, the total residential area in m^2 of the buildings was calculated for both scenarios. The overall residential area in scenario 1 is equal to 181.687m^2 and in scenario 2 is 256.462m^2.

Second, to define the average living space of flats was calculated according to census data from 2021 [20]. In the Municipality of Karposh the average size of a flat is 80m^2. According to this data there are 2.271 flats in scenario 1 and 3.205 flats in scenario 2. Third, the average number of occupants per flat was defined based on data in General Urban Plan (GUP) of City of Skopje [21]. Referring to GUP the required standard living area for one occupant should be between 20 to 25m^2 [21].

Based on this data the average number of occupants per flat is equal to 3 persons. Calculated in line with the described steps, the total number of occupants in scenario 1 is equal to 6.816 while in scenario 2 is 9678. The distribution of number of occupants in taxonomies present in exposure models of scenario 1 and 2 is shown in figure 16.

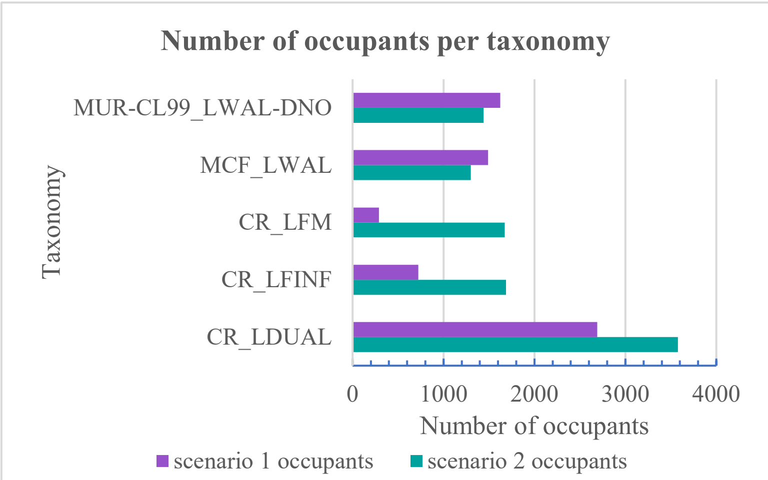

Figure 16. Number of occupants per taxonomy in scenario 1 and 2.

3.3. REPLACEMENT COST OF BUILDINGS

Defining the replacement cost of the buildings for the case study Karposh was based on the ESRM20 data [18]. In ESRM20 the average replacement cost of the buildings, which covers the structural system, non-structural elements and contents, was defined according to the following criteria:

- The country of interest
- The positioning of the building in urban context, i.e. big city, urban or rural areas
- The occupancy type of the building
- The structural material of the building

Based on the stated criteria the average replacement cost of buildings in case study area equals to 520€/m2 and it is multiplied with different indices according to the structural material. Namely, buildings with reinforced concrete structure (CR) and confined masonry structure (MCF) have the average replacement cost of 546€/m2, while the unreinforced masonry (MUR) costs 494€/m2. The average replacement costs per taxonomy in scenario 1 and 2 are shown in figure 17.

The replacement costs of buildings calculated and presented in this research are of approximate relevance. To define relevant replacement costs of the buildings in N. Macedonia additional comprehensive researches should be pursued to obtain all the required information.

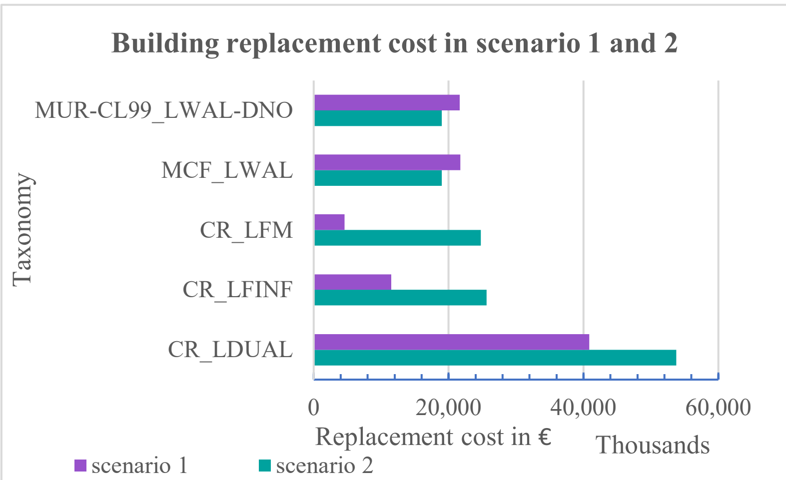

Figure 17. Replacement cost per taxonomy in scenario 1 and 2.

4. CONCLUSION

For a comprehensive seismic risk assessment, it is crucially important to have reliable data about the components of risk; hazard, exposure and vulnerability. The components of exposure and vulnerability can be influenced and can be altered in order to have less damage and losses when an earthquake hits.

In this paper the focus is on defining the exposure model. The taxonomy defined in exposure model can serve for development of site specific fragility and vulnerability functions. However, in the case study Karposh the fragility and vulnerability functions were selected from existing data base of ESRM20 created for the European building stock [18]. Consequently, the taxonomy of the exposure model for scenario 1 and 2 was defined in a way to be correlated with these fragility and vulnerability functions of ESRM20.

Beside the taxonomy, attention was paid also to urban planning parameters such as: plan shape of buildings, position in urban block, occupancy type and number of occupants. In order to calculate the economic losses, the average replacement cost was defined for each taxonomy based on data for structural losses available in ESRM20.

The defined exposure models for both scenarios were used in the seismic risk assessment of the case study area with use of Open Quake Engine and the results from two scenarios were compared in order to define the role and importance of urban planning in reducing seismic risk [1].

The exposure component in urban environments has a very dynamic character, usually more emphasized when pressurized by urbanization. Due to its dynamic character the exposure model requires to be established in a system which will continuously keep track of the changes that happen in urban environment and update the exposure model attribute information.

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68
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FLASH FLOODS VULNERABILITY ASSESSMENT OF THE MUNICIPALITY OF ČELINAC, BOSNIA AND HERZEGOVINA

Abstract

This paper analyses the susceptibility of territory of municipality Čelinac to flash floods using the Flash Flood Potential Index (FFPI). All operations related to calculating the FFPI were conducted in a GIS environment. The research results showed that 38.42% of the territory belongs to the category of low susceptibility to flash floods. The category of moderate susceptibility includes 36.86% of the territory, while 18.77% of the territory is classified as highly susceptible to flash floods. The very high susceptibility to flash floods applies to the area occupying 5.95% of the total territory of the Čelinac municipality. This research can be useful to all subjects involved in natural disaster protection, local government, insurance companies, and the general population.

Keywords: FFPI, flash floods, GIS, Čelinac

ПРОЦЈЕНА УГРОЖЕНОСТИ ОПШТИНЕ ЧЕЛИНАЦ БУЈИЧНИМ ПОПЛАВАМА

Сажетак

У овом раду анализирана је угроженост територије општине Челинац од бујичних поплава примјеном индекса потенцијала бујичних поплава (FFPI). Све операције које су се односиле на израчунавање FFPI, урађене су у ГИС окружењу. Резултати истраживања показали су да 38,42% општине припада категорији ниске угрожености бујичним поплавама. Категорија средње угрожености обухвата 36,86% територије, док се 18,77% територије налази у категорији високе угрожености. Веома висока угроженост бујичним поплавама односи се на простор који заузима 5,95% од укупне територије. Ово истраживање може бити од користи свим субјектима који се баве заштитом од природних несрећа, локалној самоуправи и слично.

Кључне ријечи: FFPI, бујичне поплаве, ГИС, Челинац

1. INTRODUCTION

One of the most significant and prevalent natural hazards are flash floods, which cause significant economic damage and in some cases, loss of life [1, 2, 3]. Based on research conducted in Europe during the period from 1950 to 2006, 40% of all flood events were flash floods [4]. What is concerning is the fact that the number of flash floods has increased when observing the period from 1950 to the beginning of the 21st century [5]. However, despite flash floods being one of the most significant natural hazards, occurring in many regions of Europe, the degree of their investigation and documentation is not at a satisfactory level [4, 5, 6, 7]. The level of investigation of flash floods in Republika Srpska, i.e., Bosnia and Herzegovina, is low and not proportional to their significance, especially when considering the economic and other damages caused by flash floods [8]. Flash floods are classified as natural hydrological disasters characterized by the sudden appearance of maximum water flows and the significant transport of suspended and bedload sediment in the beds of flash flood streams. Flash floods can be described as a hydrological phenomenon characteristic of watersheds with steep slopes and relatively small surface areas. Flash floods occur in response to extreme rainfall episodes, which are usually short in duration and high in intensity [9]. In differentiating flash floods, the key determinant relates to the speed of occurrence, which, in the case of intense rainfall episodes, is analogous to the watershed concentration time, typically averaging around 6 to 7 hours [10, 11]. Flash flood streams are defined as natural streams with large and extreme fluctuations in water flow and sediment transport during a hydrological year. The specific and variable characteristics of climate, relief, terrain geology, soil and vegetation cover, as well as changes in socioeconomic conditions such as population migration or land use, represent a wide range of conditions and factors contributing to the occurrence of flash floods. The frequency of flash floods depends on the dominance of those factors and conditions that favor their occurrence. The genesis of flash floods is linked to mountainous areas, while lower areas within the same watersheds, usually inhabited, often become even more vulnerable to flood waves. Natural disasters cannot be prevented, but a better understanding of the processes and clearly defined methodologies can help mitigate their impacts. The Floods Directive 2007/60/EC highlighted the need for preparing flood hazard maps and flood risk maps. However, all activities related to the creation of these maps focused only on larger river channels, while flash flood streams and their watersheds were completely neglected [12]. Given that flash floods in Republika Srpska, i.e., Bosnia and Herzegovina, are one of the most frequent natural disasters, mapping the hazard and risk of flash floods is of particular scientific and societal interest. It should be emphasized that flash floods pose a real challenge when it comes to their detection and forecasting. On one hand, the methodologies used for analyzing flash floods can be very simple, for example, methodologies that only consider precipitation data. On the other hand, there are complex methodologies that utilize sophisticated software, spatial data management, modeling, and forecasting to support them [13]. Observing globally, many countries have developed specific tools used to assess the potential occurrence of flash floods, but the United States, relatively speaking, leads in this regard. In the USA, as part of efforts to enhance flash flood management, a tool has been developed with the aim of better understanding local physical-geographical characteristics that influence the occurrence and development of flash floods [14, 15, 16, 17]. One of the tools commonly used in identifying areas with a high potential for flash floods is the Flash Flood Potential Index (FFPI), first applied by Greg Smith in 2003. This index takes into account numerous factors directly influencing the runoff process, all aimed at identifying areas with a high potential for flash flood development [18]. However, in order to enhance Smith's original methodology, several authors have contributed to modifying the existing methodology to avoid subjective approaches when defining the weighting factors for individual criteria included in the analysis [19, 20, 21, 22, 23, 24, 8, 25].

This paper analyzes the FFPI for the territory of the Čelinac municipality to gain insight into the spatial distribution of areas vulnerable to flash floods. Geospatial data processing and necessary analyses were conducted using the open-source QGIS 3.17 software package. The analysis results, in the form of a flash flood hazard map, were overlaid with data related to populated areas, all aimed at identifying the most vulnerable inhabited places. Research of this type can be significant for local government units because the local level is a crucial instance in reducing the risk of natural disasters. Additionally, the research results can be beneficial to various sectors such as water management, forestry, agriculture, spatial planning, transportation, environmental protection, and similar fields. Moreover, they can serve as a basis for further in-depth research on this issue.

2. STUDY AREA

The municipality of Čelinac is located in the northwestern, hilly-flat region of the Republika Srpska, within Bosnia and Herzegovina. The municipality covers an area of 362 km2 and shares borders with the city of Banja Luka and the municipalities of Laktaši, Prnjavor, Kotor Varoš, Teslić, and Kneževo. The municipality has a population of 16,974 inhabitants [26]. The municipality of Čelinac comprises 30 inhabited places organized into 17 local communities. It's important to emphasize that Čelinac is situated in the central part of the Banja Luka region, with major arterial roads, regional routes, and railway lines traversing its territory, connecting the entire region. The southern and southwestern parts of the municipality reach elevations up to 760 meters, while the northern part, which is the largest in terms of area, ranges from 300 to 600 meters above sea level. The lowest point in Čelinac is at the confluence of the Jošavka River and the Vrbanja River, at an altitude of 196 meters. The climate in the Čelinac municipality is moderately continental, influenced by the continental climate of the Pannonian Plain and the mountain climate from the Manjača, Vlašić, and Čemernica massifs. The average annual temperature is 10.4°C, with December being the coldest month and July the warmest. The pronounced annual temperature fluctuations, along with high amplitude of absolute extreme temperatures, reflect a high degree of continental climate. The average annual precipitation in Čelinac is around 1000 mm, with the highest rainfall occurring in July and November, and the lowest in February. There are approximately 130 rainy days per year. The northern, central, and western parts of the municipality belong to the Vrbas River basin, while the eastern and southern parts belong to the Ukrina River basin. The most significant watercourse in the municipality is the Vrbanja River, with other major watercourses including the Jošavka, Ukrina, Turjanica, and Švrakava rivers. Looking at the network of permanent and intermittent watercourses, it can be concluded that the hydrographic network is well developed. Forests and forest land dominate the overall land use structure, covering 23,761 hectares or 61.45% of the total area of the municipality. The second most prevalent land use category is agricultural land, spanning 9,791 hectares or 27.12% of the municipality's territory. Within the agricultural land category, arable land is the most prevalent (7,102 hectares), while meadows and pastures cover 2,588 hectares. Other areas in the observed territory include built-up land, water bodies, and other land use categories.

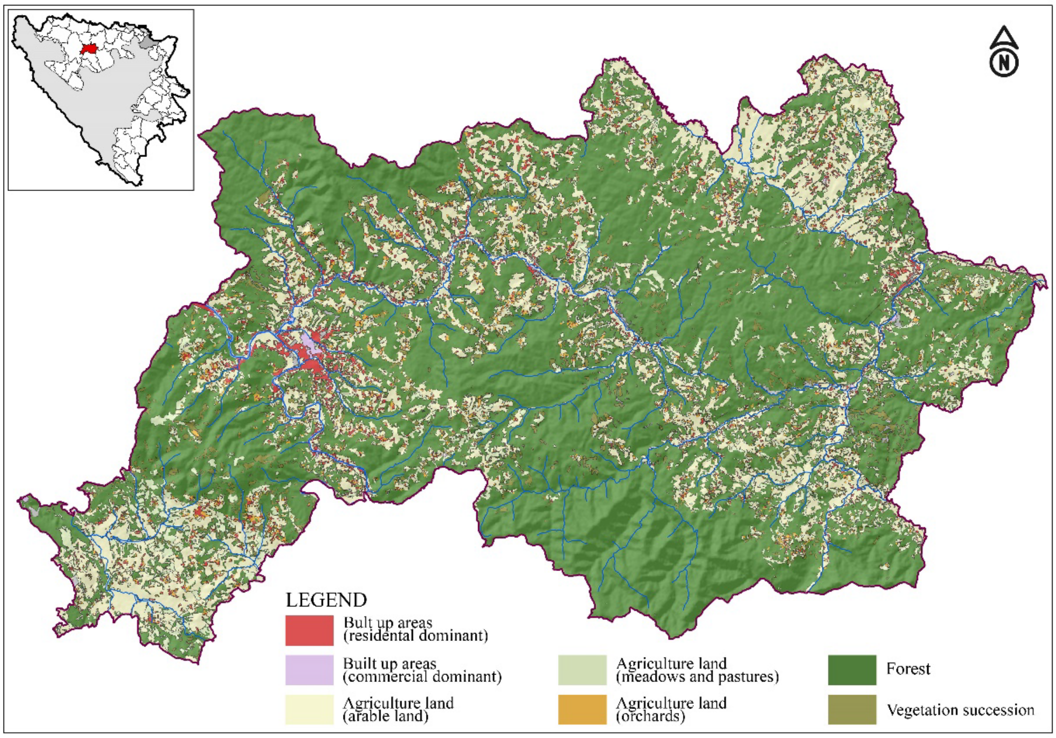

Figure 1. The territory of the Čelinac municipality

3. MATERIALS AND METHODS

The method used in this study to determine the susceptibility to flash floods involves calculating the Flash Flood Potential Index (FFPI). The original Flash Flood Potential Index (FFPI), developed within the framework of the National Weather Service for the Colorado River basin, utilized variables related to terrain slope, vegetation cover, soil texture, and land use [18]. Due to the absence and unavailability of certain data, this study analyzed variables related to terrain slope, geological substrate, land cover, and vegetation index. The coefficient values for each variable range from 1 to 10, where the lowest value (1) represents areas least vulnerable to flash floods. Standardization of the coefficients is performed for each specified variable based on predefined values. The Flash Flood Potential Index is calculated based on the formula:

$$FFPI = (S + L + G + V) / 4 \tag{1}$$

where S represents terrain slope, L represents land cover, G represents geological characteristics, and V represents vegetation cover.

Terrain slope data were obtained based on the analysis of a digital terrain model generated from the digitization of topographic maps at a scale of 1:25,000. This digital terrain model has a spatial resolution of 25 meters. Terrain slopes were initially calculated in percentages, after which the following formula was applied [27]:

$$S = 10^{n/30} \tag{2}$$

where "n" represents the slope in %. If "n" is greater than or equal to 30%, then the value of S is always 10. Slopes ranging from 0-30% are assigned values from 1-9 using a simple classification method of equal intervals. Geological substrate data were obtained through the digitization of basic geological maps at a scale of 1:100,000. Specific types of geological substrates were assigned corresponding coefficients based on the characteristics of the rocks themselves (e.g., strength, permeability). Land cover data relate to the Corine Land Cover and were obtained from the European Environment Agency portal. The FFPI values assigned to each land cover class depend on the influence of that class on the occurrence of floods [28, 24]. The highest FFPI values (10, 8, 7) are assigned to built-up areas and areas used for agricultural production. On the other hand, areas covered by forests or pastures have lower values due to their infiltration capabilities, which affect the runoff rate.

The vegetation index is calculated based on the NDVI in the QGIS environment, for the period from May to October, using Landsat 8 satellite imagery with a spatial resolution of 30 meters. The calculation of NDVI (Normalized Difference Vegetation Index) is based on the following formula:

$$NDVI = \frac{NIR-R}{NIR+R} \tag{1}$$

where NIR represents the value of the near-infrared band and R represents the value of the red band. The NDVI values for the Čelinac municipality range from 0.02 to 0.66. Values closer to zero represent built-up areas and usually have low vegetation presence (0-0.2). Moderate NDVI values (0.2-0.5) indicate the presence of sparse vegetation (pastures, shrub vegetation, etc.). High NDVI values (above 0.5) indicate the presence of forests and other dense vegetation.

Table 1. Coefficient Values for Different Variables and Their Categorization According to FFPI

Slope (%)	Land cover (CLC)	Vegetation index	Geology	FFPI
≤ 3	-	0,55 – 0,66	Carbonate rocks	1
6	131, 311, 312	0,52 – 0,55	Alluvial sediments	2
9	313	0,49 – 0,52	Dykes, peridotites, hornfels	3
12	-	0,46 – 0,49	Flysch, lapor,bBreccia	4
15	231	0,43 – 0,46		5
18	324	0,39 – 0,43	Metamorphic rocks	6
21	243	0,35 – 0,39	Proluvium	7
24	242	0,30 – 0,35	-	8
27	-	0,22 – 0,30	-	9
≥ 30	112	0,02 – 0,22	-	10

After standardizing the coefficients for each individual variable and calculating the Flash Flood Potential Index, the classification process is undertaken to identify areas based on their susceptibility to flash floods. In this study, four classes of susceptibility to flash floods have been identified: low, moderate, high, and very high susceptibility to flash floods. The susceptibility class may indicate the possibility of flash floods occurring under appropriate conditions. However, whether flash floods will occur and at what intensity depends on numerous factors.

4. RESULTS AND DISCUSSION

Flash floods represent one of the most prevalent natural hazards across much of the territory of Bosnia and Herzegovina, including the Republika Srpska. The increase in rainfall due to climate change, particularly the rise in extreme rainfall events and the increase in the number of days with rainfall exceeding 20 mm [29], has resulted in an increase in the frequency of flash floods of varying intensities. Hydrological and meteorological data, as well as flood data, are often available for large rivers and basins, while such data usually do not exist for small basins. Small basins have their own characteristics and play a role in runoff formation, making it very important for them to be the subject of hydrological analyses [30]. Intense rainfall is an important but not decisive factor influencing the formation of flash floods. Some of the factors essential for flash flood formation were analyzed in this study, and the Flash Flood Potential Index was calculated to identify areas with different characteristics related to flash flood susceptibility. The variables analyzed include terrain slope, geological substrate, land cover, and vegetation index. Appropriate coefficient values were assigned to each individual variable to standardize them. All analyzed layers were converted into raster data models, and layers related to terrain slopes and NDVI were subsequently reclassified according to defined values.

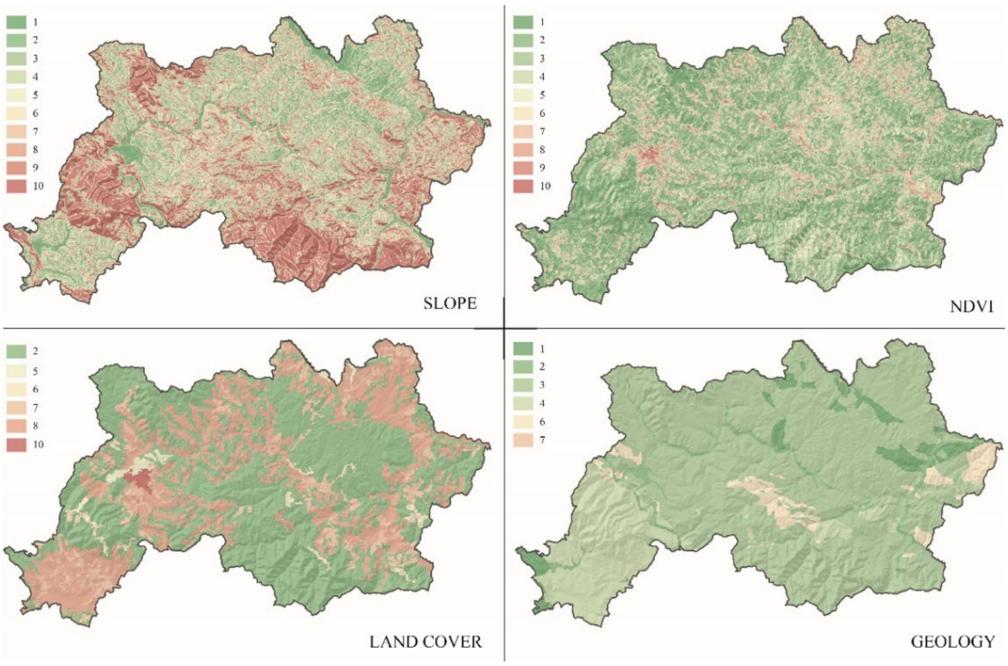

Figure 2. Analyzed variables with standardized values

After standardizing the analyzed variables, a final layer was created using the raster calculator. On the final layer, or the synthesis map, values were grouped into four categories: low, moderate, high, and very high susceptibility to flash floods. Based on the FFPI values, the most prevalent category is low susceptibility to flash floods, covering 137.4 km2 or 38.42% of the Čelinac municipality's territory. Following the low susceptibility category, large areas are covered by the moderate susceptibility category, extending over 131.8 km2 or 36.86% of the Čelinac municipality's territory. The high susceptibility category to flash floods covers 67.1 km2 or 18.77% of the total municipality's territory, while the very high susceptibility category is recorded on 21.3 km2 or 5.95% of the Čelinac municipality's territory. The values related to the high and very high susceptibility categories are closely related to the physical-geographical characteristics of the observed area.

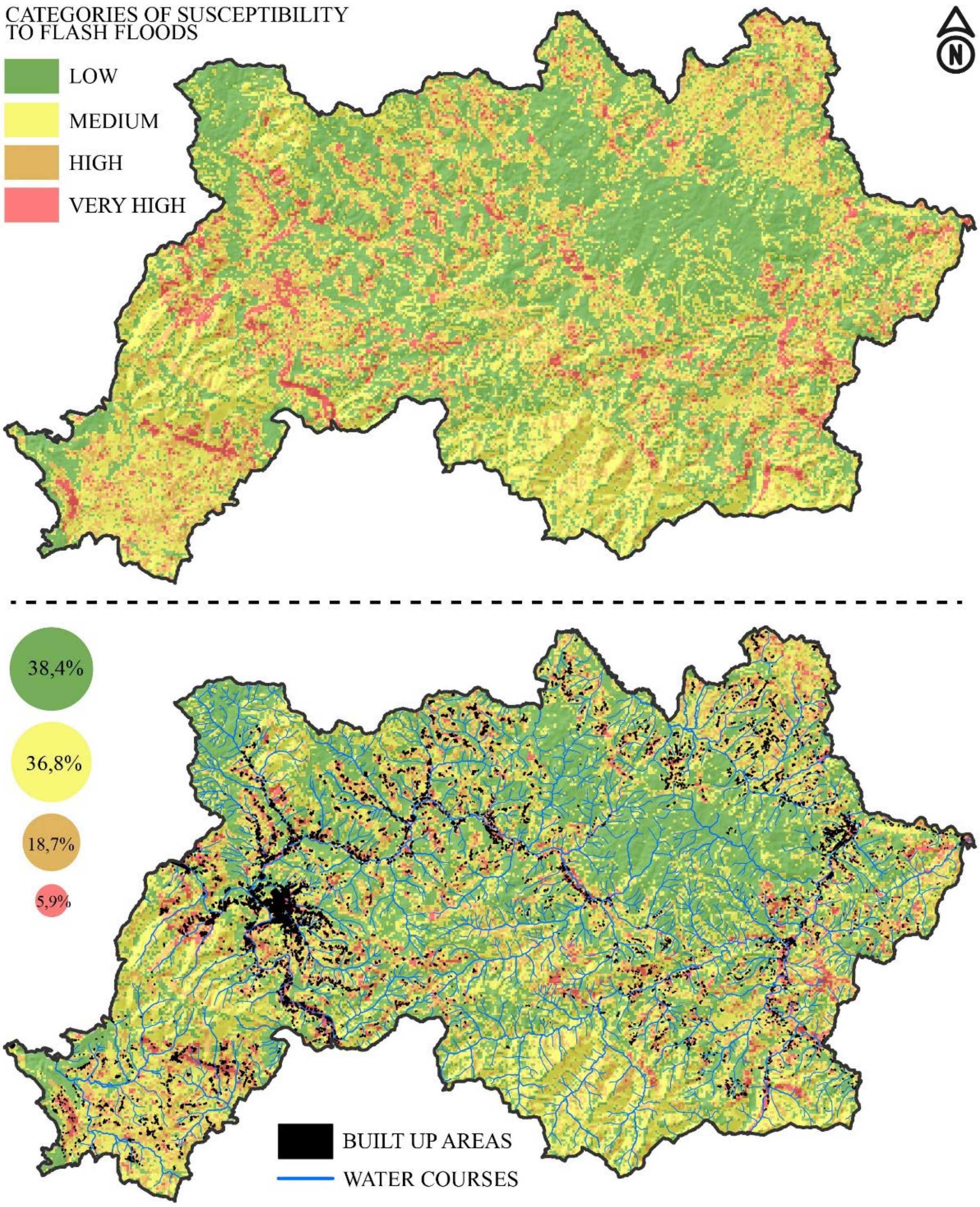

Figure 3. Categories of susceptibility to flash floods calculated based on FFPI

When it comes to geological characteristics, the territory of the Čelinac municipality is mostly characterized by rocks that are, conditionally speaking, resistant to erosion. However, due to a combination of different factors, areas with moderate and strong erosive processes have been identified in the observed area. Moderate erosive processes are identified in the southwest, central, and northeast parts of the municipality, while strong erosive processes are identified in several locations in the wider surroundings of the municipal center, as well as in the north and east of the observed area. On the other hand, forest complexes located in the northwest, central, and southern parts of the municipality are partially degraded. It is important to note that pure deciduous forests are the most prevalent in the forest structure, occupying about 80% of the total forested area. Looking at the vertical breakdown of the relief, higher values are recorded in the northwest, west, south, and east parts of the municipality. These characteristics, combined with other physical-geographical characteristics, have influenced the formation of flash flood catchments in the observed area. A larger number of flash streams in the observed area belong to the mixed category of flash streams, with an emphasis on surface erosion type. Previous research in the Ukrina River basin also identified the mixed category of flash streams as the most dominant type in the basin [30]. In the southern, western, and eastern parts of the observed area, characterized by hilly-mountainous terrain, flash streams with large longitudinal slopes and pronounced linear erosion have been identified. In these areas, erosion is concentrated only in the beds of flash streams. Due to their location, these flash streams do not currently pose a threat to settlements or infrastructure, so they are not the focus of activities related to protection from the harmful effects of flash floods. Using zonal statistics, the mean FFPI values were calculated for each individual inhabited place. Five classes were identified in total to observe differences in FFPI values at the level of inhabited places.

Figure 4. Average FFPI values per inhabited places

The most vulnerable inhabited places to flash floods are Čelinac, Miloševo, Popovac, Lipovac, Kablovi, and Basići. Inhabited places with slightly lower average FFPI values include Šahinovići, Balte, Mehovci, Čelinac Gornji, Ospječko, Branešci Gornji, Vijačanji Gornji, Šnjegotina Velika, Šnjegotina Srednja, and Šnjegotina Donja. Approximately 67% of the total population of the municipality resides in these inhabited places. However, when comparing the average FFPI values for inhabited places with the values defined for susceptibility categories to flash floods, it is observed that, on average, all inhabited places in the Čelinac municipality fall into the moderate susceptibility category to flash floods.

5. CONCLUSION

More significant and systematic research on flash floods in Republika Srpska, i.e., Bosnia and Herzegovina, is not adequately represented in numbers. In order to predict flash floods, it is not sufficient to analyze only meteorological data; it is necessary to include in the analysis multiple physico-geographical characteristics that influence the occurrence and development of flash floods. In practice, the influence of geological substrate, relief, density of the hydrographic network, land use, density of vegetation cover, erosive processes, and other factors affecting runoff and the creation of conditions for the occurrence of flash floods is often analyzed. Identifying areas at risk of flash floods, i.e., producing a hazard map, is crucial for preventive flood protection activities. If the local community, or any other administrative level of governance, has developed preventive measures related to protection from flash floods, there is a greater chance of avoiding material damages, disruptions in economic activities, or, in the worst case, loss of human lives. There are many different original and modified methodological approaches aimed at identifying areas vulnerable to flash floods. One of the simpler methodologies that yields solid results is the Flash Flood Potential Index (FFPI). This study applied a methodology for calculating the FFPI for the territory of the municipality of Čelinac. The research results showed that 38.42% of the municipality belongs to the category of low susceptibility to flash floods. The category of moderate susceptibility to flash floods encompasses 36.86% of the municipality's territory, while 18.77% of the municipality's territory is classified as highly susceptible to flash floods. Very high susceptibility to flash floods refers to an area occupying 5.95% of the total territory of the Čelinac municipality. Furthermore, in order to gain insight into the vulnerability of individual settlements to flash floods, overlays were created between the layers representing the FFPI values and the layers representing the boundaries of populated areas with population figures. Average FFPI values indicate that Čelinac, Miloševo, Popovac, Lipovac, Kablovi, and Basići have a higher susceptibility to flash floods than other populated areas in the municipality. Considering both natural and anthropogenic factors influencing the occurrence and development of flash floods, there is a need to establish a system for periodic or continuous monitoring and control of flash floods. With the help of new technologies, it is possible to gather detailed field data that can be analyzed and incorporated into predictive models. These activities may not be able to eliminate the occurrence of flash floods, but they can provide timely information regarding the onset of danger, thereby helping to avoid more serious damages to people and property. The concept of FFPI has certain limitations, but its application in conditions where analysts are constrained by the quantity and quality of data still yields usable results. Of course, efforts should be made to use the most relevant data for analysis in terms of accuracy and detail, and to continuously improve and adapt the methodology to the specific characteristics of the areas under investigation. Additionally, if possible, it is desirable to validate the results of the analysis to determine whether the applied model is adequate for the given task. The results of this research can serve relevant institutions involved in natural disaster protection as well as local communities. Furthermore, this research can serve as a starting point for further and more detailed investigations into this issue.

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69
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MATHEMATICAL SUBJECTS AND THE ENTRANCE EXAM AS PREDICTORS OF THE ACADEMIC SUCCESS OF GEODESY STUDENTS

Abstract

All the neighboring countries are facing rapid depopulation, and thus decreasing number of high school graduates. On the other hand, it is needed to select the best quality candidates to enroll colleges/universities in order to be trained for future profession in shortest study time and solid passing rate. The most effective forecast for success in studying (graduation) is during candidate testing (entry exam) and during their first year of studies.

This paper shows analysis of factors that determine enrolment of candidates to geodesy study program; marks and passing mathematics (during the first year of study); status of enrolled students and completion of studies, as well as connection between the length of studying and academic results in the secondary school and results of entry exam and possibility of foreseeing successfulness of studying – graduation.

Keywords: Predicting of Academic success, entry exam, mathematical subjects, decision trees

МАТЕМАТИЧКИ ПРЕДМЕТИ И ПРИЈЕМНИ ИСПИТ КАО ПРЕДИКТОРИ АКАДЕМСКОГ УСПЈЕХА СТУДЕНАТА ГЕОДЕЗИЈЕ

Сажетак

Све земље ближег и ширег окружења суочавају се с брзим смањењем становништа, па и свршеним средњошколцима. С друге стране неопходно је спровести одабир што квалитенијих кандидата за успис на факултете / универзитете, како би били оспособљени за будуће занимање уз што краће вријеме студирања и солидну пролазност. Најефектније предвиђање за успјешност завршетка студија (дипломирање) је већ при тестирању (избору) кандидата при упису и током прве године студија.

У раду је приказана анализа фактора који одређују упис кандидата на студиј геодезије; оцјене и период полагања математичких предмета (које студенти слушају у првој години студија); статус уписаних студената и завршетак студија, као и повезаност дужине студирања и успјеха у средњој школи и резултата квалификационог испита и могућност предвиђања успјешности дипломирања.

Кључне ријечи: предвиђање академског успјеха, пријемни испит, математички предмети, стабла одлучивања

1. INTRODUCTION

In the course of the first year of study of the first cycle at study program Geodesy at Faculty of architecture, civil engineering and geodesy of the University of Banja Luka, the mathematical subjects are: Analytical geometry and linear algebra (AGLA), Differential and Integral calculus 1 (DIC 1) and Differential and Integral Calculus 2 (DIC 2). Majority of students enrolled to this study program come from gymnasium and secondary/vocational civil engineering school. The significance of entry (qualifying) exam for enrollment into the Faculty of architecture, civil engineering and geodesy (FACEG), as well as the correlation between the result on entry exam and success in mathematical subjects exam is analyzed in paper [1]-[3], while the impact of passing mathematical subjects in forecasting academic success of students is analyzed in papers [4]-[8].

The paper analyses: three factors that determine enrolment of students (secondary school success, entry exam results, total score); marks and period of taking math exams (the ones students have in the first year of study) during studying; status of enrolled students and completion of the first cycle, as well as correlation between the length of studying and success in secondary school and results of entry exam.

We used advanced techniques (decision trees) that enable students' graduation forecasting.

Looking into the passing of mathematical exams it appeared that for the successful completion of the first cycle of studies, a more important predictor was the period of passing (when was the exam taken and passed) rather than the mark obtained at the exam.

Taking and passing particular mathematical exams during the current year of studying shows that prediction of successful graduation is from 82,1% to 91,5%.

The improvement of prediction for successful graduation of geodesy students is achieved by generating rules form the data.

2. ORGANIZATION OF THE RESEARCH

Over the course of 12 years (since 2012 /the first generation/ till 2023) the Study program Geodesy (SP G) enrolled, or transferred from other faculties, 348 students.

The secondary school score and the entry exam are both valued with 50 points each, while for entry exam of mathematics, the minimum passing threshold is 15 points. At the start of academic 2023/24 year, there were 163 active students, while 122 students have completed (graduated) the first cycle of studies.

For the analysis and graphical presentation of data, application of adequate statistical tests (Anova, Independent t test and $\chi 2$ test) and classification trees, we used analytical-statistical tool IBM SPSS Statistics, version 27 [9],[10]. For the improvement of prediction of completion of the first cycle, we used classification trees that are most frequently used statistical techniques in the field of generating rules from the data [11],[12].

3. RESULTS OF RESEARCH

The secondary school success was in the range from 23,75 to 50, while the average score during the secondary education was 41,14.

The points that the candidates realized during the entry exam were in the range from 15 to 50, while the average score in the entry exam of enrolled students was 25,94.

Total scores were in the range from 42,25 to 99,02 and the average total score at entry exam was 67,08.

Figure 1 shows average success in secondary school, during the entry exam, and a total score of SP G students over the 12 years.

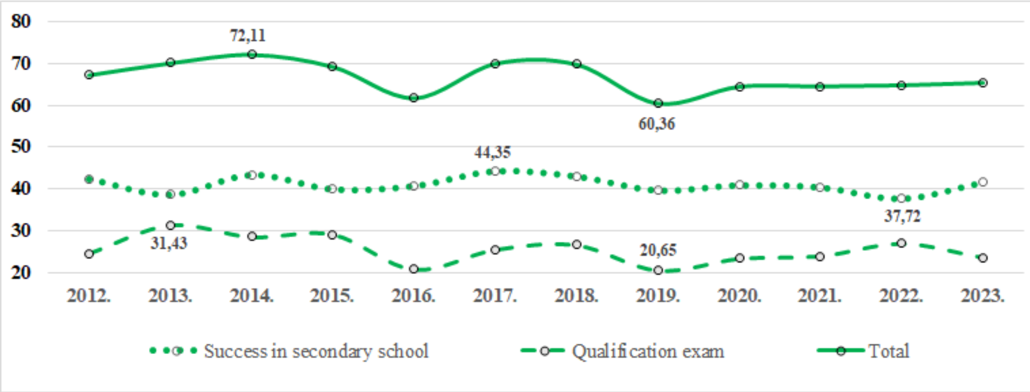

Figure 1. Average success in secondary school, during the entry exam, and a total score of SP G students over the 12 years

Applying the Anova test, we got statistically highly significant difference (p = 0,000) of achieved success during the secondary education of SP G students over the 12 years. Additional application of Multiple Comparisons Post Hoc test gave statistically highly significant difference (p = 0,0097; 0,0087) of achieve discusses during the secondary education of SP G students enrolled in 2013 and 2014, i.e. 2017 respectively, and statistically significant difference (p = 0,017; 0,011) of achieved secondary education success of SP G students enrolled in 2022 and 2014, i.e. 2017 respectively.

We also got statistically highly significant difference (p = 0,000) by applying Anova test on entry exam for SP G students over the course of 12 years. Additional application of Multiple Comparisons Post Hoc test gave statistically highly significant difference (p = 0,000 and 0,001) of achieved success on SP G entry exam of 2013 and 2016, i.e. 2019 respectively, and statistically significant difference (p = 0,043; 0,025; 0,013 and 0,030) of SP G students enrolled 2013 and 2023; 2014 and 2016; 2015 and 2016; 2016 and 2019 respectively.

Completed secondary schools were classified into three groups: Gymnasium, Vocational Civil Engineering secondary school (Civ. Eng. school) and other secondary schools.

Processing the candidates who enrolled SP G by applying Anova test we did not get statistically significant difference of achieved success in secondary education (p = 0,113) and during the entry exam (p = 0,152) of students were classified into three groups over the course of 12 years.

Status of students enrolled until academic year 2019/20 (they could have graduated) is shown in Table 1. 257 students were enrolled by 2019/20 (for three students transferred from other faculties second. school was not specified).

Table 1. Status students enrolled by 2019/20.

Students' status	Secondary schools (groups)			Total
	Gymnasium	Civ. Eng. school	Other secondary schools	
active	54	75	34	163
dropped out	14	27	13	54
no status	8	17	5	30
transfer – after 1st year	2	5	3	10
Total	78	124	55	257

Applying the $\chi 2$ test did not produce statistically significant difference ($\chi 2$ = 2,763, p = 0,838) of students' status in relation with completed secondary school.

Applying the Anova test, we got statistically highly significant difference (p= 0,000) of achieved success during the secondary education and during the entry exam of SP G students in relation to the status of studying. Additional application of Multiple Comparisons Post Hoc test gave statistically highly significant difference (p = 0,000) of achieved success during the secondary education of students who are active and who transferred after the first year, and statistically significant difference (p = 0,018) of student who are active and who dropped out, and (p = 0,041) students who dropped out and those who transferred after the first year.

We also got statistically highly significant difference (p = 0,006) during the entry exam of students who were active and who dropped out, i.e. who were active and without status (p = 0,002).
Passed mathematical subjects of students enrolled by 2019/20 are shown in Table 2.

Table 2. Achieved marks of mathematical subjects taken till 2019/20.

Subject	Mark					Total
	6	7	8	9	10	
AGLA	76	63	21	10	5	175
DIC 1	76	49	23	15	6	169
DIC 2	84	36	17	15	7	159

The time period of taking the passed mathematical exams for students enrolled by 2019/20 are shown in Table 3.

Table 3. Time of taking the Math exams in the period until 2019/20.

	Exam passed				Total
	In current year	In next year	After two or more years	Not passed	
AGLA	143 (73%)	28 (14,3%)	4 (2%)	21 (10,7%)	196
DIC 1	118 (61,5%)	35 (18,2%)	16 (8,3%)	23 (12%)	192
DIC 2	50 (29,2%)	53 (31%)	56 (32,7%)	12 (7%)	171

Graduated students enrolled until 2019/20 in relation to completed secondary school is shown in Table 4.

Table 4. Graduated students enrolled until 2019/20 and completed secondary school

Sec. school /groups/	Graduated		Total
	Yes	No	
Gymnasium	42	12	54
Civ. Eng. school	50	25	75
Other secondary schools	30	4	34
Total	122	41	163

Applying the $\chi 2$ test we got statistically significant difference ($\chi 2$ = 6,149, p = 0,046) of a number of students who did(not) graduate in relation to previously completed secondary school.
Table 5 shows lasting of studying (days) for students who completed the first cycle.

Table 5. Lasting of studying (days)

Study program	N	Min.	Max.	Median	Mean	Std. Dev.
Geodesy	122	1424	3797	1829,50	1983,97	483,491

We discovered statistically highly significant correlation between negative prefix of the length of studying and success in secondary school (r = - 0,381) and between the length of studying and entry exam (r = - 0,319), while there was statistically highly significant correlation between positive prefix of success in secondary schools and entry exam (r = 0,243).
By monitoring the correlation of passing two or all three mathematical subjects that students study during the first year, the results show that students successfully complete the studies if they pass at least two subjects during the current year, or at least one in the current year and the second, or the second and third, in the next year or the following year (Table 6).

Table 6. Correlation of passing of particular subjects and completion of the first cycle (graduation)

Subject(s)	During the current year	Graduated	During the next year	Graduated	After two years or later	Graduated
AGLA	123	101 (82,1%)	26	20 (76,9%)	2	1 (50%)
DIC1	105	93 (88,6%)	31	20 (64,5%)	13	9 (69,2%)
DIC2	47	43 (91,5%)	50	46 (92%)	49	33 (67,3%)
AGLA & DIC1	96	87 (90,6%)	40*	26 (65%)	13**	9 (69,2%)
AGLA & DIC2	47	43 (91,5%)	50*	46 (92%)	49**	33 (67,3%)
DIC1 & DIC2	47	43 (91,5%)	50*	46 (92%)	49**	33 (67,3%)
AGLA, DIC1 & DIC2	47	43 (91,5%)	50*	46 (92%)	49**	33 (67,3%)

* at least one of subjects passed in the following year
** at least one of subjects passed after two years

Additional correlation of monitored variables is possible to find using advanced techniques. As an example we give the application of the decision tree (Figure 2).

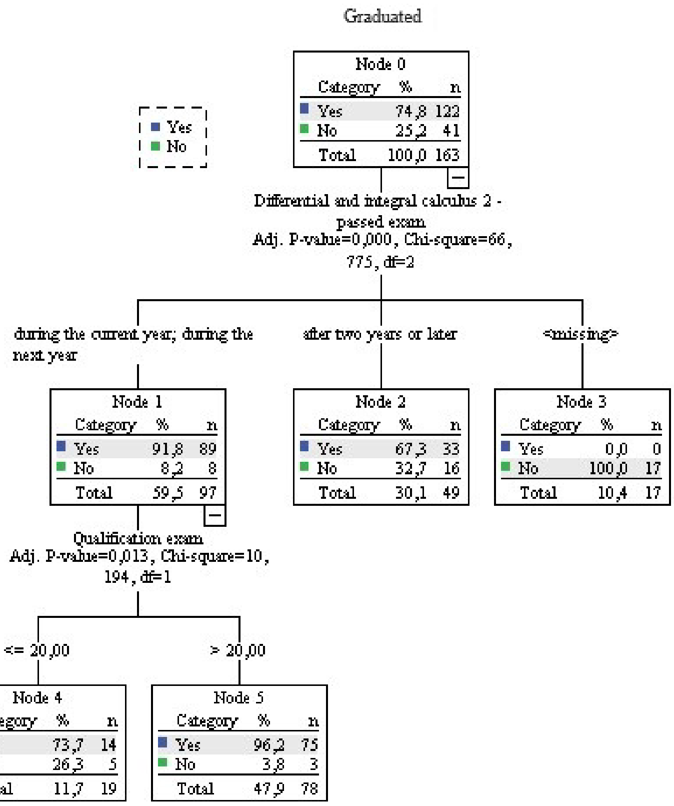

Figure 2. Example of the decision tree

Generated rules for three nodes are given as an example:

/ Node 4 */.*
IF (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year") AND (Qualification exam NOT MISSING AND (Qualification exam <= 20))
THEN

Node = 4
Prediction = 1
Probability = 0.736842

/ Node 5 */.*
IF (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year") AND (Qualification exam IS MISSING OR (Qualification exam > 20))
THEN
Node = 5
Prediction = 1
Probability = 0.961538

/ Node 2 */.*
IF (Differential and integral calculus 2 - passed exam = "after two years or later")
THEN
Node = 2
Prediction = 1
Probability = 0.673469
By forcing the variable „Entry exam“ we generated the tree (Figure 3) and rules.

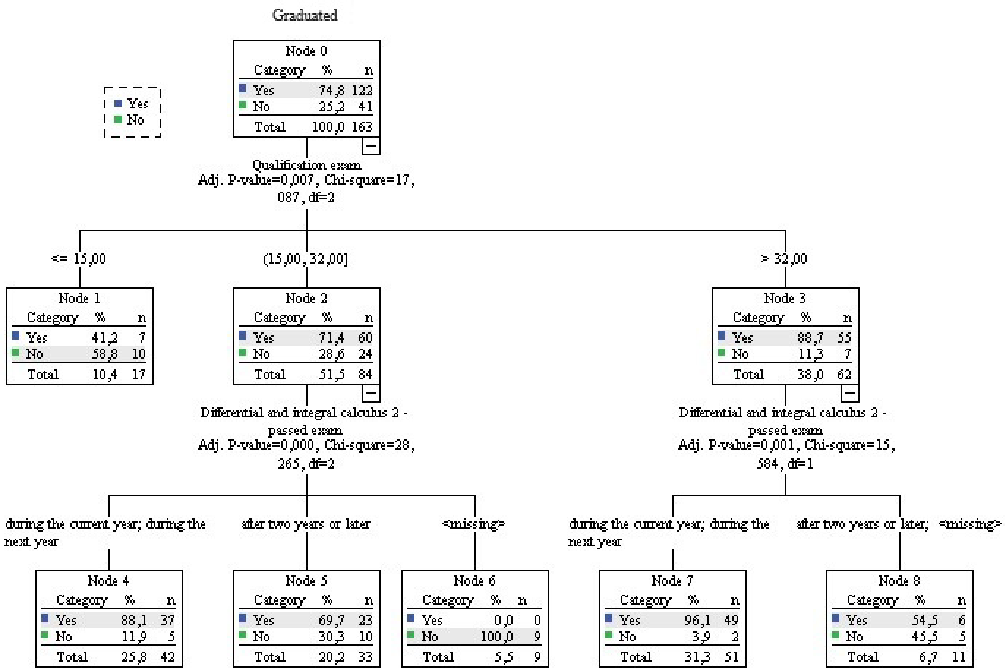

Figure 3. Generated tree by forcing the variable „Entry exam“

Generated rules:

/ Node 1 */.*
IF (Qualification exam NOT MISSING AND (Qualification exam <= 15))
THEN
Node = 1
Prediction = 2
Probability = 0.588235

/ Node 4 */.*
IF (Qualification exam IS MISSING OR (Qualification exam > 15 AND Qualification exam <= 32)) AND (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year")

THEN
Node = 4
Prediction = 1
Probability = 0.880952

/ Node 5 */.*
IF (Qualification exam IS MISSING OR (Qualification exam > 15 AND Qualification exam <= 32)) AND (Differential and integral calculus 2 - passed exam = "after two years or later")
THEN
Node = 5
Prediction = 1
Probability = 0.696970

/ Node 7 */.*
IF (Qualification exam NOT MISSING AND (Qualification exam > 32)) AND (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year")
THEN
Node = 7
Prediction = 1
Probability = 0.960784
/ Node 8 */.*
IF (Qualification exam NOT MISSING AND (Qualification exam > 32)) AND (Differential and integral calculus 2 - passed exam != "during the current year" AND Differential and integral calculus 2 - passed exam != "during the next year")
THEN
Node = 8
Prediction = 1
Probability = 0.545455

4. DISCUSSION

All the countries of Southeast Europe are faced with the problem of low birth rate, which is reflected on a number of secondary school students and their further education (studying). High education institutions implement a lot of activities to interest and select the best quality candidates for the continuation of education. Selection of candidates for enrollment is very complex and demands intense and permanent work with potential candidates during their secondary education.

FACEG initiated research in regards the passing of entry exams in 2012 [6] and has been implementing the workshops in secondary schools that educate the civil engineering and geodesy profiles and in gymnasiums, for the past 10 years, and also organizes preparation classes. Preparatory classes consist of 20 hours and, prior to the coronavirus period, were conducted in the classroom for two weeks in June. However, since the onset of the coronavirus period (in 2020) untill now, they have been held online for five weeks using Google Meet and Google Classroom applications [13]. The importance of preparation classes has been recognized among the faculties in the region that organize preparatory classes and/or enable candidates to use the solved tasks from mathematics entry exam [13]-[17]. The criteria for enrollment to undergraduate studies in Croatia is based on: achieved success in secondary school (400 points) and passed exams at the state prom test (Croatian language – 50, mathematics up to 450 and physics /not a condition for enrollment, but yields points/ up to 100 points); achievements at competitions – direct enrollment (1000 points)/participation in state-level competitions in mathematics and physics or winning one of the top three places in civil engineering technology/ [18].

Some faculties organize preparation of students also after the enrollment, to prepare the students for the future profession before the start of academic classes [19].

After a good selection of candidates at enrollment, it is necessary to research the influence of passing particular exams already in the first year of studying, to the successful completion of studies. For the prediction of results, it is necessary to use techniques that are more advanced. The paper [20] describes creation of a prediction model for students' success by means of Data mining and analyzing the factors that influence the achieved level of successfulness. We tested three methods of data mining: logistical regression, decision tree and neuron nets. The Study [21] aims to provide step-by-step guidance set for teachers who are ready to apply the data mining techniques in order to predict students' success. Successful creation of a model that has 92% correctness in predicting the students' final outcome point to the potential of artificial neural nets [22]. The paper [23] analyzes data on studying success and exam passing rate on the first year of undergraduate studies for eight generations of students. Goals of research were: to make a predictive model that would enable identification of students with high probability of not making 30 ECTS points during the academic year, and offer students an information on probability for passing particular exams, i.e. achieving the targeted number of ECTS points at the end of the academic year.

5. CONCLUSION

The candidates yielded solid success during secondary education (during the whole 12 years period of enrollment the average score was 41,14), while the result of entry exam was worse (average score was 25,94). The total average score was 67,08.

Looking into the passing of mathematical exams it appeared that for the successful completion of the first cycle of studies, a more important predictor was the period of passing (when was the exam taken and passed) rather than the mark obtained at the exam.

Taking and passing particular mathematical exams during the current year of studying shows that prediction of successful graduation is from 82,1% to 91,5%.

The improvement of prediction for successful graduation of geodesy students is achieved by generating rules form the data.

Predicting factors influencing students' academic success is significant due to the organization and structure of the entrance exam itself, as well as the importance of certain academic subjects for successful completion of studies. This research can further be applied to other study programs at the Universities.

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70

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NESTED POLYNOMIALS TRIGONOMETRIC AND HYPERBOLIC TYPE WITH APPLICATIONS

Abstract

In this paper we introduce nested trigonometric and hyperbolic polynomials of rank n by employing nested trigonometric and hyperbolic functions, respectively. Our investigation delves into some interesting properties of nested polynomials, establishing some recurrence formulas and deriving some useful summation formulas. Additionally, we establish a connection between nested trigonometric polynomials and one specific class of special polynomials that satisfy a second-order Sturm-Liouville differential equation. Finally, we outline several applications of nested polynomials. Among others, it is shown that nested trigonometric polynomials can be used for the linear static analysis of curved Bernoulli–Euler beam.

Keywords: Nested functions, Nested polynomials, Mittag-Leffler functions, Sturm-Liouville differential equation

ТРИГОНОМЕТРИЈСКИ И ХИПЕРБОЛИЧКИ УГЊЕЖДЕНИ ПОЛИНОМИ СА ПРИМЈЕНАМА

Сажетак

У раду уводимо угњеждене тригонометријске и хиперболичне полиноме ранга н користећи угњеждене тригонометријске и хиперболичке функције, редом. Истражујемо нека њихова занимљива својства, успостављајући неколико рекурзивних формула и изводећи неке корисне сумацијске формуле. Додатно, успостављамо везу између угњеждених тригонометријских полинома и једне специфичне класе специјалних полинома који задовољавају Штурм-Лиувилову диференцијалну једначину другог реда. На крају, наводимо неколико примјена уведених полинома. Између осталог, показано је да се тригонометријски полиноми могу користито за линеарну статичку анализи закривљене Ојлер-Бернулијеве греде.

Кључне ријечи: угњеждене функције, угњеждени полиноми, Митаг-Лефлерове функције, Штурм-Лиувилова диференцијална једначина

1. INTRODUCTION

The Mittag-Leffler function, introduced by Swedish mathematician Gösta Magnus Mittag-Lefler in [1,2], is a special function of a particular form

$$E_\alpha(z)=\sum_{n=0}^{\infty}\frac{z^n}{\Gamma(\alpha n+1)},\alpha,z\in C,Re(\alpha)>0,$$

where Γ is the gamma function. This function is presented in relation to his approach for summing certain divergent series. During the first half of the twentieth century, the Mittag-Leffler function remained almost unknown to the majority of scientists. Since then, Mittag-Leffler functions have been studied extensively, and they play a crucial role in understanding complex systems with memory effects and fractional-order dynamics. So, with the development of fractional calculus, scientists' interest in Mittag-Leffler functions has surged [3-6]. Solutions to certain linear fractional differential equations can be expressed using Mittag-Leffler functions [7, 8]. Over the past two decades, the appeal of Mittag-Leffler functions and Mittag-Leffler type functions has notably increased, particularly among engineers and scientists, owing to their extensive application in various practical problems, including fluid flow, diffusion-like transport, electrical networks, probability and statistical distribution theory [9-11]. Of particular interest are the trigonometric and hyperbolic type functions based on the Mittag-Leffler function introduced in [12]. Also, these functions are called „nested", because with the finite derivative they become functions in the same class.

This paper introduces nested trigonometric and hyperbolic type polynomials by employing nested trigonometric and hyperbolic functions. In Section 3 of the paper, we explored several properties of nested polynomials, established recurrence and summation formulas. The subsequent part of the paper, Section 4, focuses on applying these introduced polynomials.

2. PRELIMINARIES AND NOTATATION

In this section we recall some definitions and assertions from [12-14].

2.1. TRIGONOMETRIC AND HYPERPOBLIC TYPE FUNCTIONS

In [12] functions of trigonometric type with p elements $T_{pj}: R\to R, j=0,1,\dots,p-1, p\in N$, are defined as

$$T_{pj}(x)=\sum_{n=0}^{\infty}\frac{(-1)^n x^{pn+j}}{(pn+j)!}.$$

They can be named *p tuple nested function of trigonometric type* because after some step derivatives return to itself, that is

$$T'_{p0}(x)=-T_{pp-1}(x),\quad T'_{p1}(x)=T_{p0}(x),\quad \dots,\quad T'_{pp-1}(x)=T_{pp-2}(x).$$

For example,

$$T_{10}(x)=e^{-x},\qquad T_{20}(x)=\cos x,\qquad T_{21}(x)=\sin x.$$

Functions of hyperbolic type with p elements $H_{pj}: R\to R, j=0,1,\dots,p-1, p\in N$, are defined as [12]

$$H_{pj}(x)=\sum_{n=0}^{\infty}\frac{x^{pn+j}}{(pn+j)!}.$$

They can be named *p tuple nested function of hyperbolic type* because after some step derivatives return to itself, that is

$$H'_{p0}(x)=H_{pp-1}(x),\qquad H'_{p1}(x)=H_{p0}(x),\qquad \dots,\quad H'_{pp-1}(x)=H_{pp-2}(x).$$

For example,

$$H_{10}(x)=e^{x},\quad H_{20}(x)=\cosh x,\qquad H_{21}(x)=\sinh x.$$

Functions T_{pj} and H_{pj} find extensive applications across various domains as they serve as solutions to certain classes of differential equations and fractional differential equations [15, 16]. For example, the solution of the differential equation [15]

$$y'''(x) - y(x) - 1 = 0, \qquad y(0) = 1, \qquad y'(0) = 2, \qquad y''(0) = 4$$

is

$$y(x) = 2H_{30}(x) + 2H_{31}(x) + 4H_{32}(x) - 1.$$

Also, nested functions are solutions of some classes of partial differential equations which in the boundary and initial conditions contain triple nested functions of trigonometric and of hyperbolic type [17].

2.2. SPECIAL POLYNOMIALS AND SPECIAL FUNCTIONS

In [13] are studied the special polynomials of the form

$$F_0(x) = 1, F_{2n}(x) = \sum_{k=0}^{n} (-1)^{n+k} \binom{2n}{2k} x^{2k}, F_{2n-1}(x) = \sum_{k=1}^{n} (-1)^{n+k+1} \binom{2n}{2k-1} x^{2k-1} \tag{1}$$

Although they are non-orthogonal, they play important role because are enumerators of rational functions of the form

$$f_0(x) = 1, \qquad f_{2n}(x) = \frac{(-1)^n F_{2n}(x)}{(x^2+1)^n}, \quad f_{2n-1}(x) = \frac{(-1)^{n-1} F_{2n-1}(x)}{(x^2+1)^n}, n \in N, \tag{2}$$

which have several applications. For example, these functions can be used for the arc-length parameterized curves of the form [14]

$$r_{2n}(s) = \langle \int_0^s f_{2n}(x)dx, \int_0^s f_{2n-1}(x)dx \rangle, \tag{3}$$

where $s > 0$ is the length of the curve. The arc-length curves are useful in engineering applications, especially for the analysis of beam-like structures. Curves (3) are employed in the linear static analysis of curved Bernoulli-Euler beams because the beam equations possess analytical solutions, which is a rarity in this field [14].

Theorem 1.1. [13] For special polynomials $F_n(x)$, the following summation formulas hold

$$e^x = \frac{1}{\cos 1} \sum_{n=0}^{\infty} \frac{F_{2n}(x)}{(2n)!} - \frac{1}{\sin 1} \sum_{n=1}^{\infty} \frac{F_{2n-1}(x)}{(2n)!},$$

$$\cos(x) = \frac{1}{\cosh 1} \sum_{n=0}^{\infty} (-1)^n \frac{F_{2n}(x)}{(2n)!}, \qquad \sin(x) = \frac{1}{\sinh 1} \sum_{n=1}^{\infty} (-1)^n \frac{F_{2n-1}(x)}{(2n)!},$$

$$\cosh(x) = \frac{1}{\cos 1} \sum_{n=0}^{\infty} \frac{F_{2n}(x)}{(2n)!}, \qquad \sinh(x) = -\frac{1}{\sinh 1} \sum_{n=1}^{\infty} \frac{F_{2n-1}(x)}{(2n)!}.$$

Theorem 1.2.[18] For special polynomials $F_n(x)$, the following recurrence formulas hold

$$F_{2n+2}'(x) = 2(n+1)\big(xF_{2n}(x) + F_{2n-1}(x)\big),$$

$$F_{2n+2}(x) = (x^2-1)F_{2n}(x) + 2xF_{2n-1}(x),$$

$$xF_{2n}'(x) = n((x^2+1)F_{2n-2}(x) + F_{2n}(x)).$$

Theorem 1.3. [14] For polynomials $F_n(x), n \in N$, the following hold

$$F_{2n-1}^2(x) + F_{2n}^2(x) = (x^2+1)^{2n}.$$

Theorem 1.4. [14] Polynomials $F_n(x), n \in N_0$, are solutions of the Sturm-Liouvile differential equation

$$(x^2+1)y''(x) - 2(2n-1)xy'(x) + 2n(2n-1)y(x) = 0. \tag{4}$$

Moreover, $y_n(x) = C_1F_{2n}(x) + C_2F_{2n-1}(x)$ are the only solutions of (4).

3. NESTED TRIGONOMETRIC AND HYPERBOLIC POLINOMIALS

In this section we introduce nested trigonometric and hyperbolic polynomials of rank n.

Definition 2.1. Let $T_{pnj}: R \to R,\ j = 0,1,\dots,p-1,\ p,n \in N_0$. We say that T_{pnj} is a polynomial of trigonometric type of rank n, with p element, if

$$T_{p00}(x) = 1, T_{pn0}(x) = \sum_{k=0}^{n} (-1)^k \binom{pn}{pk} x^{pk},$$

$$T_{pnj}(x) = \sum_{k=0}^{n-1} (-1)^k \binom{pn}{pk+j} x^{pk+j}, j = 1,\dots,p-1.$$

For p=2, we have

$$T_{200}(x) = 1, T_{2n0}(x) = \sum_{k=0}^{n} (-1)^k \binom{2n}{2k} x^{2k}, T_{2n1}(x) = \sum_{k=0}^{n-1} (-1)^k \binom{2n}{2k+1} x^{2k+1}, n \in N.$$

Theorem 2.1. If $\lambda^3 = -1, \lambda \in R, \lambda \neq -1$, then for trigonometric polynomials $T_{3nj}(x)$, $j = 0,1,2, n \in N$,

$$T_{3n0}(x) + \lambda T_{3n1}(x) + \lambda^2 T_{3n2}(x) = (\lambda x + 1)^{3n}$$

hold.

Proof. From the binomial formula, we obtain

$$(\lambda x + 1)^{3n} = \sum_{i=0}^{3n} \binom{3n}{i} (\lambda x)^i$$

$$= \sum_{k=0}^{n} \binom{3n}{3k} x^{3k}\lambda^{3k} + \sum_{k=0}^{n-1} \binom{3n}{3k+1} x^{3k+1}\lambda^{3k+1} + \sum_{k=0}^{n-1} \binom{3n}{3k+2} x^{3k+2}\lambda^{3k+2}.$$

Since $\lambda^3 = -1$, we have

$$(\lambda x + 1)^{3n} = \sum_{k=0}^{n} (-1)^k \binom{3n}{3k} x^{3k} + \lambda \sum_{k=0}^{n-1} (-1)^k \binom{3n}{3k+1} x^{3k+1} + \lambda^2 \sum_{k=0}^{n-1} (-1)^k \binom{3n}{3k+2} x^{3k+2},$$

which proves the assertion.

From Theorem 2.1 we immediately obtain the next assertion.

Theorem 2.2. If $\lambda^p = -1, \lambda \in R, \lambda \neq -1$, then for trigonometric polynomials $T_{pnj}(x)$, $j = 0,1,\dots,p-1, p > 3, n \in N$,

$$\sum_{j=0}^{p-1} \lambda^j T_{pnj}(x) = (\lambda x + 1)^{pn}$$

hold.

Theorem 2.3. If $\lambda^p = -1, \lambda \in R, \lambda \neq -1$, then for hyperbolic polynomials $T_{pnj}(x)$, $j = 0,1,\dots,p-1, p > 3, n \in N$,

$$(-1)^n \left(T_{pn0}(x) - \sum_{j=1}^{p-1} \lambda^{p-j} T_{pnj}(x)\right) = (x + \lambda)^{pn}$$

hold.

Proof. From the binomial formula and $\lambda^p = -1$ we have

$$(x + \lambda)^{pn} = \sum_{k=0}^{pn} \binom{pn}{k} x^k \lambda^{pn-k}$$

$$= \sum_{k=0}^{n} \binom{pn}{pk} x^{pk} \lambda^{p(n-k)} + \sum_{k=0}^{n-1} \binom{pn}{pk+1} x^{pk+1} \lambda^{p(n-k-1)+p-1} + \cdots$$
$$+ \sum_{k=0}^{n-1} \binom{pn}{pk+p-1} x^{pk+p-1} \lambda^{p(n-k-1)+1}$$
$$= \sum_{k=0}^{n} (-1)^{n-k} \binom{pn}{pk} x^{pk} + \lambda^{p-1} \sum_{k=0}^{n-1} (-1)^{n-k-1} \binom{pn}{pk+1} x^{pk+1} + \cdots$$
$$+ \lambda \sum_{k=0}^{n-1} (-1)^{n-k-1} \binom{pn}{pk+p-1} x^{pk+p-1}.$$

So, we obtain the assertion.

Definition 2.2. Let $H_{pnj}: R \to R,\ j = 0,1,\dots,p-1, p, n \in N_0$. We say that H_{pnj} is a polynomial hyperbolic type of rank n, with p element, if

$$H_{p00}(x) = 1, H_{pn0}(x) = \sum_{k=0}^{n} \binom{pn}{pk} x^{pk}, \quad H_{pnj}(x) = \sum_{k=0}^{n-1} \binom{pn}{pk+j} x^{pk+j}, j = 1,..,p-1.$$

For p=2, we have

$$H_{200}(x) = 1, H_{2n0}(x) = \sum_{k=0}^{n} \binom{2n}{2k} x^{2k}, H_{2n1}(x) = \sum_{k=0}^{n-1} \binom{2n}{2k+1} x^{2k+1}, n \in N.$$

From the binomial formula, we obtain

$$H_{2n0}(x) + H_{2n1}(x) = \sum_{k=0}^{n} \binom{2n}{k} x^{2n-k} = (x+1)^{2n}.$$

So, in general case we have

$$H_{pn0}(x) + H_{pn1}(x) + \cdots + H_{pnp-1}(x) = (x+1)^{pn}.$$

Theorem 2.4. If $\omega^3 = 1, \omega \in R, \omega \neq 1$, then for hyperbolic polynomials $H_{3nj}(x),\ j = 0,1,2, n \in N$,

$$H_{3n0}(x) + \lambda H_{3n1}(x) + \lambda^2 H_{3n2}(x) = (\omega x + 1)^{3n}$$

hold.

From Theorem 2.4 we immediately obtain the next assertion.

Theorem 2.5. If $\omega^p = 1, \omega \in R, \omega \neq 1$, then for hyperbolic polynomials $H_{pnj}(x),\ j = 0,1,\dots,p-1, p > 3, n \in N$,

$$\sum_{j=0}^{p-1} \omega^j H_{pnj}(x) = (\omega x + 1)^{pn}$$

hold.

Theorem 2.6. If $\omega^p = 1, \omega \in R, \omega \neq 1$, then for hyperbolic polynomials $H_{pnj}(x),\ j = 0,1,\dots,p-1, p > 3, n \in N$,

$$\sum_{j=0}^{p-1} \omega^{p-j} H_{pnj}(x) = (x + \omega)^{pn}$$

hold.

Proof. Using the binomial formula, we have

$$(x+\omega)^{pn} = \sum_{i=0}^{pn} \binom{pn}{i} x^i \omega^{pn-i}$$

$$= \sum_{k=0}^{n} \binom{pn}{pk} x^{pk} \omega^{p(n-k)} + \sum_{k=0}^{n-1} \binom{pn}{pk+1} x^{pk+1} \omega^{p(n-k-1)+p-1} + \cdots$$
$$+ \sum_{k=0}^{n-1} \binom{pn}{pk+p-1} x^{pk+p-1} \omega^{p(n-k-1)+1}.$$

Since $\omega^p = 1$, we have

$$(x+\omega)^{pn} = \sum_{k=0}^{n} \binom{pn}{pk} x^{pk} + \omega^{p-1} \sum_{k=0}^{n-1} \binom{pn}{pk+1} x^{pk+1} + \cdots + \omega \sum_{k=0}^{n-1} \binom{pn}{pk+p-1} x^{pk+p-1},$$

which proves the assertion.

3.1. CONNECTION BETWEEN SPECIAL POLYNOMIALS AND TRIGONOMETRIC POLYNOMIALS

Using Definition 2.1 and (1) we obtain the connection between special polynomials $F_n(x)$ and polynomials $T_{2nj}(x), j = 0,1$:

$$F_0(x) = T_{200}(x), \quad F_{2n}(x) = (-1)^n T_{2n0}(x), \quad F_{2n-1}(x) = (-1)^n T_{2n1}(x), \quad n \in N. \tag{5}$$

Theorem 2.7. Polynomials $T_{2nj}(x), j = 0,1, n \in N$, satisfy

$$T_{2n0}^2(x) + T_{2n1}^2(x) = (x^2+1)^{2n}.$$

Proof. Using (5) and Theorem 1.3 we obtain the proof.

Theorem 2.8. For polynomials $T_{2nj}(x), j = 0,1, n \in N$, it holds that

$$T'_{2(n+1)0}(x) = -2(n+1)(xT_{2n0}(x) + T_{2n1}(x)),$$
$$xT'_{2(n+1)0}(x) = (n+1)(T_{2(n+1)0}(x) - (x^2+1)T_{2n0}(x)),$$
$$T_{2(n+1)0}(x) = (1-x^2)T_{2n0}(x) - 2xT_{2n1}(x).$$

Proof. Using Theorem 1.2 and (5) we obtain the assertion.

Theorem 2.9. For nested functions and nested polynomials, the following summation formulas

$$H_{10}(x) = \frac{1}{\cos 1} \sum_{n=0}^{\infty} (-1)^n \frac{T_{2n0}(x)}{(2n)!} - \frac{1}{\sin 1} \sum_{n=1}^{\infty} (-1)^n \frac{T_{2n1}(x)}{(2n)!}$$
$$T_{20}(x) = \frac{1}{\cosh 1} \sum_{n=0}^{\infty} \frac{T_{2n0}(x)}{(2n)!}, T_{21}(x) = \frac{1}{\sinh 1} \sum_{n=1}^{\infty} \frac{T_{2n1}(x)}{(2n)!}$$
$$H_{20}(x) = \frac{1}{\cos 1} \sum_{n=0}^{\infty} (-1)^n \frac{T_{2n0}(x)}{n!}, H_{21}(x) = -\frac{1}{\sin 1} \sum_{n=1}^{\infty} (-1)^n \frac{T_{2n1}(x)}{n!}$$

hold.

Proof. Follows from Theorem 1.1.

4. APPLICATIONS

Theorem 3.1. Polynomials $T_{2nj}(x), j = 0,1, n \in N$, are solutions of the Sturm-Liouville differential equation (4). Moreover, only $y_n(x) = CT_{2n0}(x) + DT_{2n1}(x)$ are the solutions of (4).

Proof. The proof follows from Theorem 1.4.

Using (2) and (5) we obtain

$$f_0(x) = 1, f_{2n}(x) = \frac{T_{2n0}(x)}{(x^2+1)^n} = \cos(2n\, arctan(x)),$$
$$f_{2n-1}(x) = -\frac{T_{2n1}(x)}{(x^2+1)^n} = \sin(2n\, arctan(x)), n \in N.$$

It is proved in [14] that functions (2) can be used for the linear static analysis of curved Bernoulli–Euler beam, where the beam axis is described with

$$x(s) = \ln(1+s^2), y(s) = 2\arctan(s) - s, s \in [0, s_L],$$

where s_L is the solution of the equation $y(s_L) = 0$. So, trigonometric polynomials $T_{2nj}(x), j = 0,1, n \in N$, can be used for the linear static analysis of curved Bernoulli–Euler beam.
The equilibrium differential equations for a curved Bernoulli–Euler beam seldom possess analytical solutions. Nonetheless, employing arc-length parameterized curves (3) enables the discovery of precise solutions for linear static analysis of curved beams. The availability of analytical solutions in computational mechanics is greatly advantageous, serving as crucial reference benchmarks for evaluating new mechanical models and numerical techniques.

5. CONCLUSION

The Mittag-Leffler function, as a generalization of the exponential function plays a significant role in fractional calculus and has applications in various areas of mathematics and physics. This function arises naturally in problems involving fractional calculus, fractional differential equations, and in the context of anomalous diffusion and relaxation phenomena.
In this paper, we focused on two classes of Mittag-Leffler functions, called nested trigonometric and hyperbolic. Utilizing these functions, we formed nested polynomials of type trigonometric and type hyperbolic that we connected with special polynomials introduced in [13]. We have examined certain properties of these polynomials, obtained recursive relations and summation formulas. Using the connection (5) between nested trigonometric polynomials and the polynomials introduced in [13], we have shown that these polynomials are solutions to the Sturm-Liouville differential equation. Additionally, their application has been demonstrated, since trigonometric polynomials can be used for the linear static analysis of curved Bernoulli–Euler beam.

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71
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SKAFFOLDING TECHNIQUE IN GRAPHING ELEMENTARY FUNCTIONS – A CASE STUDY

Abstract

In this paper, the authors present the application of the scaffolding technique in drawing graphs of some elementary functions. First-year students of the Faculty of Architecture, Civil Engineering, and Geodesy were tested using two exams: an entrance test and an exit test. The obtained results show whether students are more successful in drawing graphs of elementary functions after using the scaffolding technique in math teaching. Based on the research results, scaffolding can indeed help students in graphing elementary functions.

Keywords: scaffolding, elementary functions, math teaching

СКАФОЛДИНГ ТЕХНИКА У ЦРТАЊУ ГРАФИКА ЕЛЕМЕНТАРНИХ ФУНКЦИЈА – СТУДИЈА СЛУЧАЈА

Сажетак:

У овом раду аутори су приказали примјену скафолдинг технике у цртању графова неких елементарних функција. Студенти прве године Архитектонско-грађевинско- геодетског факултета тестирани су помоћу два теста – улазног и излазног. Добијени резултати нам показују да ли су ученици успјешнији у цртању графика елементарних функција након примјене скафолдинг технике у настави математике. На основу резултата истраживања, скафолдинг техника може помоћи ученицима у цртању графика елементарних функција.

Кључне ријечи: скафолдинг, елементарне функције, настава математике

1. INTRODUCTION

The concept of scaffolding, which falls within the domain of Mathematical Education research, was introduced by Wood, Bruner, and Ross [1] and is based on the developmental theories of Vygotsky [2]. Significant changes are needed in relation to traditional approaches to teaching because the teacher's role is shifting from 'showing and telling' to providing responsible guidance in the development of a student’s own thinking. This orientation necessitates a variety of support for students' thought constructions, fostering individual thinking and leading to the creation of mathematically valid understandings. The term "scaffolding" has been used to reflect the way in which adult support is adjusted as the child learns and is eventually removed when the student can "stand on his own" [1]. According to Wood, Bruner, Ross, and Vygotsky [1], [2], key aspects of scaffolding in mathematical education include:

Gradual Release of Responsibility: The teacher begins by providing substantial support and guidance, gradually reducing this support as students gain confidence and competence. This gradual release allows students to take on increasing levels of responsibility for their learning.

Tailored Support: Scaffolding is personalized to the individual student's needs, abilities, and prior knowledge. Teachers must be attuned to students' levels of understanding and provide appropriate support accordingly.

Promotion of Critical Thinking: Scaffolding encourages students to engage in higher-order thinking skills such as problem-solving, analysis, and synthesis. Rather than simply memorizing facts or procedures, students are challenged to actively construct their own mathematical understanding.

Creation of Valid Understandings: The ultimate goal of scaffolding is to foster the development of mathematically valid understandings. This involves not only arriving at correct answers but also understanding the underlying concepts and principles.

Flexibility and Adaptability: Scaffolding should be flexible and adaptable, allowing for modifications based on students' progress, feedback, and changing needs. Teachers must be prepared to adjust their support strategies as necessary to ensure optimal learning outcomes.

Scaffolding provides a structure that helps students construct knowledge by building upon their existing abilities. Commonly used in problem-solving, it is usually provided in the following three forms: 1) breaking the task down into smaller tasks, 2) keeping the task constant but increasing the weight of the material, or 3) creating scaffolding within a single task [3]. Linder et al. used scaffolding in redesigning an introductory computer science course to engage students in their chosen subject majors and better prepare them for higher-level teaching. Their scaffolding structure included classroom activities and short one-week assignments targeting skills needed for the final classwork, resulting in weaker students building skills earlier in the course and students displaying more confidence in their programming and problem-solving skills [3], [4].

Although the scaffolding technique is used in many areas of education, it is particularly interesting and applicable in learning mathematics. In this paper, the authors deal with drawing graphs of elementary functions using the scaffolding technique in the first year of technical studies. Graphing elementary functions is important for first-year technical students to understand the functions themselves. Graphs of functions have been studied in several papers. For example, in paper [5], the author deals with drawing graphs of logarithmic functions based on scaffolding implementation. The authors concluded the following: 1) In the step of understanding the problem, students experienced limitations in understanding logarithmic symbols. The students did not recognize the symbols in the question, 2) in the step of designing the plan, the students decided to create tables for drawing logarithmic graphs. They chose a number that corresponds to 2^x. This shows that they knew the correlation between logarithmic and exponential functions, 3) In the step of making the plan, the students accurately drew the points based on the table previously made in the plan development phase. They connected the dots to make a graph. In this step, scaffolding was not carried out, 4) in the step of looking back, students did not check the answers they had already received. The students realized that the answers they received did not correspond to the instructions on the questions. Students who are accustomed to looking back will have better reasoning than students who do not check back. In paper [6], the authors obtained their results based on the realized obligations of the students (homework) as well as two oral protocols with first-year students of the Faculty of Mechanical Engineering and second-year students of the Faculty of Architecture and Civil Engineering of the University in Banja Luka who completed five tasks related to sketching graphs of linear functions and functions $f(|x|)$ and $|f(|x|)|$. By analyzing the feedback, they found that abstraction and generalization are in many cases difficult activities that may be beyond the students' ability. In these cases, teacher intervention through means of helping understand mathematical concepts, within the appropriate placement of mathematical construction of objects, significantly helped students understand and achieve their generalization goals and abstractions.

Paper [7] presents reflections on using a scaffolding approach to engage civil engineering students in learning Structural Analysis subjects. In this approach, after listening to lectures on theory, students are provided with a series of practice problems, each accompanied by the steps, formulas, hints, and tables needed to solve the problem. Gradually, with increasing confidence in the application of the method as a tool for structural analysis, the amount of help provided is reduced until eventually, no help is provided at all. The author concluded that the scaffolding approach is a suitable practice for involving students in their learning. Every student participates actively, whereby stronger students are given the opportunity to advance faster. Weaker students receive more attention along with the ability to advance at a slower pace. Students are assisted in learning alone or in a group through properly designed guided tasks, which are gradually removed with increasing student competence. The students' answers through evaluation show their very high level of satisfaction with this unit and the teaching adopted style.

Problem-solving is the most important ability. When solving problems, students not only utilize existing mathematical knowledge but also engage all high-level thinking skills. However, students still face many difficulties when solving problems. Students' difficulty with problems that cannot be solved by one routine procedure requires critical analysis and an understanding of a concept and application of mathematical skills [8]. One strategy used for solving problems is scaffolding.

This study provides empirical research in the area of drawing graphs of elementary functions before and after applying the scaffolding technique in teaching with first-year students of the Faculty of Architecture, Civil Engineering and Geodesy.

2. METODOLOGY AND RESEARCH

2.1. METODOLOGY OF THE RESEARCH

Students of the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka in their first year of study, enrolled in the academic year 2023/24, were observed for the use of the scaffolding technique in learning mathematics. Students enrolled in civil engineering and geodesy study programs took a mathematics test during the entrance exam, while architecture students took a test of their own choice - a mathematics test or a spatial ability test. In the first year of the academic year 2023/24, a total of 149 students were enrolled, with 85 students enrolled in the Architecture department, 39 students enrolled in the Civil Engineering department, and 25 students enrolled in the Geodesy department. In the research, a total of 111 first-year students from the Faculty of Architecture, Civil Engineering, and Geodesy participated.

For the purposes of this research, we conducted two tests, an entrance test and an exit test, that consisted of 4 types of tasks. In the given tests, knowledge of the following elementary functions was required: quadratic function, exponential function, logarithmic function, and trigonometric functions sin x and cos x. Each test is scored with a total of 20 points.

The first test - the entrance test was solved by students at the beginning of the second semester of their first year of study, before the lectures on elementary functions. We note that elementary functions are studied during secondary education and were also an integral part of the Mathematics entrance exam at the Faculty of Architecture, Civil Engineering, and Geodesy.

The second test - the exit test was solved by the students after attending the teaching units on elementary functions. The authors of this paper used the scaffolding technique during the lectures for a total of three weeks (three hours per week). Tasks from book [9], [10] were used for lectures and test construction.

Students solved each test within one school class, or 45 minutes.

For the statistical study, the IBM SPSS was used as the analytical-statistical software package. Descriptive statistics were used for presenting and summarizing data. Also, the Paired Samples t-Test, non-parametric Mann-Whitney U test, The Wilcoxon signed-rank test, The Kruskal-Wallis test and the Spearman’s rank correlation coefficient were used. No normal distribution was noticed by the variables that were observed [11].

2.2. RESEARCH QUESTIONS

This paper aims to answer the following research questions (RQs):
RQ1: How successful are students in drawing graphs of elementary functions before using the scaffolding technique in mathematics teaching, i.e., with only prior knowledge from high school and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of elementary functions based on the study program profile?
RQ2: How successful are students in drawing graphs of quadratic functions before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of quadratic functions based on the study program profile?
RQ3: How successful are students in drawing graphs of exponential functions before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of exponential functions based on the study program profile?
RQ4: How successful are students in drawing graphs of logarithmic functions before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of logarithmic functions based on the study program profile?
RQ5: How successful are students in drawing graphs of trigonometric functions sin x and cos x before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of trigonometric functions based on the study program profile?

3. RESULTS AND DISCUSSION

With the label U1, U2, U3 and U4 we marked the tasks on the entrance test, and with I1, I2, I3 and I4 the tasks on the exit test.

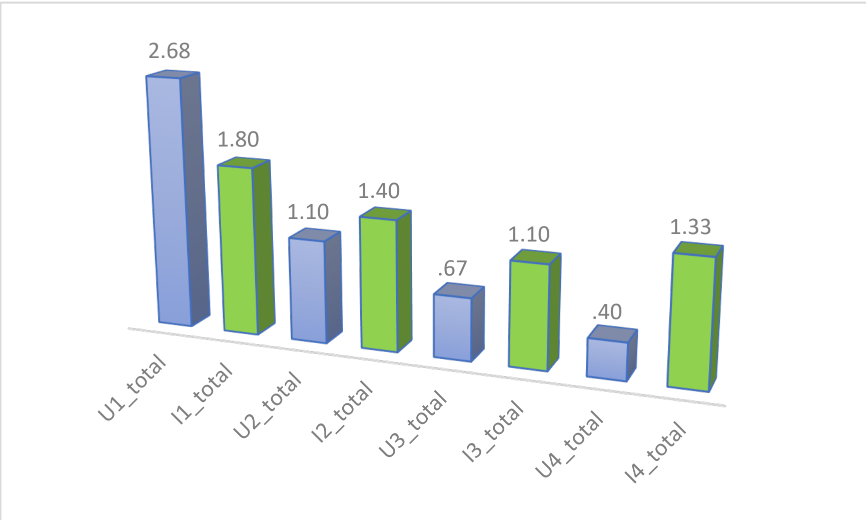

Figure 1. Success by tasks on the entrance and exit tests (arithmetic means).

From Figure 1, it can be seen that students achieved better performance on all tasks in the exit test, except the first one.
We will analyze and statistically process the data obtained from the entrance and the exit tests, in accordance with the research questions.

RQ1: How successful are students in drawing graphs of elementary functions before using the scaffolding technique in mathematics teaching, i.e., with only prior knowledge from high school and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of elementary functions based on the study program profile?
Table 1 shows the final success of students on the entrance and exit tests, according to the department. Looking at the arithmetic mean, it is clear that the students of geodesy achieved the greatest progress, and the students of architecture the weakest.

Table 1. Success on the entrance and exit test - according to the department

		N	Mean	Std. Deviation	Minimum	Maximum
Entrance_total	CE	39	6.18	4.762	0	19
	ARCH	46	4.26	3.511	0	16
	GEO	26	3.88	3.882	0	16
	Total	111	4.85	4.159	0	19
Exit_total	CE	39	6.59	6.129	0	20
	ARCH	46	4.52	5.876	0	20
	GEO	26	6.15	5.801	0	18
	Total	111	5.63	5.971	0	20

The Paired Samples t-Test showed there is not a statistically significant difference in success between the entrance and the exit test for all tested students (t=-1.378, df=110, p=0.171). The Wilcoxon signed-rank test showed a statistically significant difference in success between the entrance and the exit test for geodesy students (Z=-2.100, p=0.036). However, it can be seen from table 1 that students of geodesy did not achieve the maximum number of points neither on the entrance nor on the exit test.

The Kruskal-Wallis test at a significance level of 0.05 showed a statistically significant difference between groups (study programs) in the entrance test (χ2=6.748, df=2, p=0.034), while the Mann-Whitney U test revealed this difference between civil engineering and geodesy students, as well as between civil engineering and architecture students. In the exit test, there was no statistically significant difference in success between groups (χ2=4.810, df=2, p=0.090), but the Mann-Whitney U test determined that there is a statistically significant difference in success between civil engineering and architecture students. Civil engineering students were more successful in solving tasks in the exit test (table 1).

A positive correlation with the significance at the 0.01 level of success was obtained between success in the entrance exit tests (rs=0.249).

RQ2. How successful are students in drawing graphs of quadratic functions before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of quadratic functions based on the study program profile?

Task 1 (entrance test). Draw graphs of quadratic functions: (a) $f(x) = x^2$ (1 point) (b) $f(x) = -x^2$ (1 point) (c) $f(x) = 4 - x^2$ (2 points) (d) $f(x) = |4 - x^2|$ (2 points).

Task 1 (exit test). Draw graphs of quadratic functions: (a) $f(x) = (x+1)^2$ (1 point) (b) $f(x) = -(x+1)^2$ (1 point) (c) $f(x) = x^2 - 4x + 5$ (2 points) (d) $f(x) = |x^2 - 4x + 5|$ (2 points).

The Paired Samples t-Test showed a statistically significant difference in the success of solving the first task between the entrance and exit tests (t=4.540, df=120, p=0.000). Specifically, students exhibited poorer performance in drawing graphs of quadratic functions in the exit test (table 2).

The Kruskal-Wallis test indicated that there was no statistically significant difference between groups (study programs) in the success of solving the first task, neither in the entrance test (χ2=0.767, df=2, p=0.681) nor in the exit test (χ2=5.298, df=2, p=0.071).

Table 2. Success on the entrance and exit test - drawing graphs of quadratic functions

		N	*Mean*	*Std. Deviation*	*Minimum*	*Maximum*
U1_total	*CE*	*39*	*2.67*	*1.691*	*0*	*6*
	ARCH	*46*	*2.85*	*1.577*	*0*	*6*
	GEO	*26*	*2.42*	*2.212*	*0*	*6*
	Total	*111*	*2.68*	*1.773*	*0*	*6*
I1_total	*CE*	*39*	*1.87*	*1.989*	*0*	*6*
	ARCH	*46*	*1.65*	*2.273*	*0*	*6*
	GEO	*26*	*1.96*	*1.928*	*0*	*6*
	Total	*111*	*1.80*	*2.084*	*0*	*6*

RQ3: How successful are students in drawing graphs of exponential functions before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of quadratic functions based on the study program profile?

Task 2 (entrance test). Draw graphs of exponential functions: (a) $f(x) = 2^x$ (1 point) (b) $f(x) = -2^x$ (1 point) (c) $f(x) = 1 - 2^x$ (2 points).

Task 2 (exit test). Draw graphs of exponential functions: (a) $f(x) = 2^{x+1}$ (1 point) (b) $f(x) = -2^{x+1}$ (1 point) (c) $f(x) = 2 - 2^{x+1}$ (2 points).

The Paired Samples t-Test showed a statistically significant difference in the success of solving the second task between the entrance and exit tests (t=-3.038, df=110, p=0.003). The students showed better performance in solving the second task in the exit test (table 3).

Table 3. Success on the entrance and exit test - drawing graphs of exponential functions

		N	*Mean*	*Std. Deviation*	*Minimum*	*Maximum*
U2_total	*CE*	*39*	*1.67*	*1.528*	*0*	*4*
	ARCH	*46*	*.63*	*1.218*	*0*	*4*
	GEO	*26*	*1.08*	*1.383*	*0*	*4*
	Total	*111*	*1.10*	*1.433*	*0*	*4*
I2_total	*CE*	*39*	*1.59*	*1.482*	*0*	*4*
	ARCH	*46*	*1.17*	*1.582*	*0*	*4*
	GEO	*26*	*1.50*	*1.449*	*0*	*4*
	Total	*111*	*1.40*	*1.515*	*0*	*4*

The Kruskal-Wallis test at a significance level of 0.05 showed a statistically significant difference between groups (study programs) in the success of solving the second task in the entrance test (χ^2=15.139, df=2, p=0.001), while the Mann-Whitney U test revealed this difference between civil engineering and architecture students (U=487.500, Z=-3.906, p=0.000). Civil engineering students were more successful than architecture students (table 3). The Kruskal-Wallis test indicated that there was no statistically significant difference between groups (study programs) in the success of solving the second task in the exit test (χ^2=2.776, df=2, p=0.250).

It is evident that civil engineering students were the most successful, while architecture students were the least successful in drawing graphs of exponential functions (table 3).
However, the obtained results are not satisfactory.

RQ4: How successful are students in drawing graphs of logarithmic functions before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of logarithmic functions based on the study program profile?

Task 3 (entrance test). Draw graphs of logarithmic functions: (a) $f(x) = log_3 x$ (1 point) (b) $f(x) = log_3(x+1)$ (2 points) (c) $f(x) = log_3 x$ +1 (2 points).

Task 3 (exit test). Draw graphs of logarithmic functions: (a) $f(x) = log_{1/2} x$ (1 point) (b) $f(x) = log_{\frac{1}{2}}(x-1)$ (2 points) (c) $f(x) = log_{1/2} x$ - 1 (2 points).

The Paired Samples t-Test showed a statistically significant difference in the success of solving the third task between the entrance and exit tests (t=-2.368, df=110, p=0.02). The students showed better performance in solving the third task in the exit test (table 4).

Table 4. Success on the entrance and exit test - drawing graphs of logarithmic functions

		N	*Mean*	*Std. Deviation*	*Minimum*	*Maximum*
U3_total	*CE*	*39*	*1.13*	*1.704*	*0*	*5*
	ARCH	*46*	*.48*	*1.243*	*0*	*5*
	GEO	*26*	*.31*	*1.050*	*0*	*5*
	Total	*111*	*.67*	*1.416*	*0*	*5*
I3_total	*CE*	*39*	*1.18*	*1.918*	*0*	*5*
	ARCH	*46*	*.89*	*1.479*	*0*	*5*
	GEO	*26*	*1.35*	*2.077*	*0*	*5*
	Total	*111*	*1.10*	*1.784*	*0*	*5*

The Kruskal-Wallis test at a significance level of 0.05 showed a statistically significant difference between groups (study programs) in the success of solving the third task in the entrance test (χ^2=9.184, df=2, p=0.01), while the Mann-Whitney U test revealed this difference between civil engineering and architecture students (U=356.500, Z=-2.513, p=0.012), as well as civil engineering and geodesy students (U=685.000, Z=-2.360, p=0.018). Civil engineering students were more successful in solving the third task in the entrance test (table 4). The Kruskal-Wallis test indicated that there was no statistically significant difference between groups (study programs) in the success of solving the third task in the exit test (χ^2=0.544, df=2, p=0.762).

RQ5: How successful are students in drawing graphs of trigonometric functions sin x and cos x before and after applying the scaffolding technique? Is there a statistically significant difference in drawing graphs of trigonometric functions based on the study program profile?

Task 4 (entrance test). Draw graphs of exponential functions: (a) $f(x) = \sin x$ (1 point) (b) $f(x) = 2\sin x$ (2 points) (c) $f(x) = \sin 2x$ (2 points).

Task 4 (exit test). Draw graphs of exponential functions: (a) $f(x) = \cos x$ (1 point) (b) $f(x) = \frac{1}{2}\cos x$ (2 points) (c) $f(x) = \cos\frac{x}{2}$ (2 points).

The Paired Samples t-Test showed a statistically significant difference in the success of solving the third task between the entrance and exit tests (t=-5.110, df=110, p=0.000). The students showed better performance in solving the fourth task in the exit test (table 5).

Table 5. Success on the entrance and exit test - drawing graphs of trigonometric functions

		N	Mean	Std. Deviation	Minimum	Maximum
U4_total	CE	39	.72	1.621	0	5
	ARCH	46	.30	1.113	0	5
	GEO	26	.08	.272	0	1
	Total	111	.40	1.223	0	5
I4_total	CE	39	1.95	2.200	0	5
	ARCH	46	.80	1.529	0	5
	GEO	26	1.35	1.672	0	5
	Total	111	1.33	1.875	0	5

The Kruskal-Wallis test at a significance level of 0.05 showed no statistically significant difference between groups (study programs) in the success of solving the fourth task in the entrance test (χ^2=3.641, df=2, p=0.162) nor in the exit test (χ^2=5.799, df=2, p=0.055). The Mann-Whitney U test determined that there is a statistically significant difference in success between civil engineering and architecture students in the exit test, for task 4 (U=665.000, Z=-2.303, p=0.021), table 5.

CONCLUSION

In mathematics, just like in all cognitive abilities or academic subjects, there is a ladder. You cannot understand multiplication if you don't understand addition. We call this a developmental ladder. Each step relies on the previous one. If you skip to the top of the ladder, your foundation is not stable. It is necessary to build skills from the ground up. We achieve this through the use of the scaffolding technique during learning [12].

According [13] teachers found that benefits of Scaffolding in Education are: improves the likelihood that students will retain new information, helps connect foundational knowledge to new concepts , engages students with their learning and tracking their own progress, gives students more autonomy and independence in the classroom, bridges student learning gaps in traditionally difficult course content, reduces students' feelings of frustration, improves communication between students and teachers , encourages students asking for help, keeps classes organized and on schedule.

Based on the obtained results, we can conclude that students performed better on the exit test after the implementation of the scaffolding technique in lessons on elementary functions. However, the results obtained are not satisfactory, and we believe that students achieved a low average number of points in both tests and in all tasks. This can be justified by the fact that the students were attending high school from 2019 to 2023, and were affected by the COVID-19 pandemic and online learning. Additionally, no "rewards" were offered for successfully completing the tests, so some students did not make much effort.

From Figure 1, it can be seen that students performed best on the first task, quadratic functions, on both the entrance and exit tests, while they performed worst on the fourth task, trigonometric functions. A similar result was obtained in paper [14], the students achieved the lowest success in the entrance exam for enrolled to the faculty in solving problems in trigonometry.

Based on the results obtained, we conclude that the greatest progress was made by geodesy students, while architecture students showed the weakest performance, even though geodesy students did not achieve the maximum number of points on either the first or second test. In almost all tasks, civil engineering students achieved the best results.

Based on the research cited in the introduction and the results obtained in this study, we believe that the scaffolding technique is very useful in teaching mathematics, especially in lessons on elementary functions. Elementary functions and drawing their graphs are fundamental topics in mathematics and should be given more class time in universities, during which the scaffolding technique should be used. Additionally, research could be conducted in secondary schools as bases of future students [15]. Such research should be extended to future generations in order to obtain more relevant results.

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72
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USING NATURAL LANGUAGE PROCESSING (NLP) FOR CATEGORIZING PAPER TITLES FROM GOOGLE FORMS

Abstract

Modern data collection, storage, and processing rely on diverse techniques to handle various types of information, ranging from structured tables to free-form text. This paper explores the captivating application of Natural Language Processing (NLP) for categorizing titles from Google Forms or any other textual data. The process of training an NLP model will be demonstrated through a specific example. Just as we learn from our past experiences, NLP models need to be fed with relevant data and labels. This ensures accurate and efficient processing even when new titles are introduced. We will conclude with a fascinating demonstration of how NLP algorithms analyze the structure and meaning of titles. By identifying keywords and understanding the context, they can automatically classify titles into relevant categories. This dramatically simplifies data organization and analysis, empowering us to extract valuable insights faster.

Keywords: Data Mining, Classification, Natural Language Processing, Multi-Layer Perceptron

КОРИШЋЕЊЕ ОБРАДЕ ПРИРОДНОГ ЈЕЗИКА (NLP) ЗА КАТЕГОРИЗАЦИЈУ НАСЛОВА РАДОВА СА ГУГЛ ФОРМСА

Сажетак

Модерне методе прикупљања, чувања и обраде података ослањају се на разнолике технике како би се носиле са различитим типовима информација, од структурираних табела до слободног текста. Овај рад се бави примјеном обраде природног језика (NLP) за категоризацију наслова из Google Формс или било којих других текстуалних података. Кроз конкретан примјер, илустроват ћемо процес обучавања NLP модела. Баш као што и ми учимо из претходних искустава, тако и NLP моделе треба хранити релевантним подацима и ознакама. Тако осигуравамо прецизну и ефикасну обраду чак и када се унесу нови наслови.Завршит ћемо приказом како NLP алгоритми анализирају структуру и значење наслова. Идентификујући кључне ријечи и разумијевајући контекст, они могу аутоматски сврстати наслове у релевантне категорије. Ово драстично поједностављује организацију и анализу података, омогућавајући нам брже добијање драгоцијених увида.

Кључне ријечи: рударање података, класификација, обрада природног језика, вишеслојни перцептрон

1. INTRODUCTION

When it comes to the categorization and sorting of textual data collected through various forms, the main criterion is often cited as selecting one of the specified category options. Analyzing and categorizing textual data is a rather time-consuming task, susceptible to errors.

It has been observed that, during the textual registration of participants in numerous events in Bosnia and Herzegovina, the benefits of algorithms from the field of artificial intelligence (AI) [1] and machine learning (ML) [2] are minimally utilized.

AI, ML, and NLP work together to tailor systems for text processing to specific tasks. This involves adjusting models, optimizing performance, and continuous learning to adapt models to changes in language and data.

Progress in NLP often stems from innovations within machine learning, including new model architectures, pattern recognition algorithms, and improved data learning techniques.

NLP algorithms can understand the meaning and context of words and phrases, enabling subtle categorization. This is crucial when titles may have subtle differences in meaning that need to be accurately captured.

In this paper, we will analyze methods of using natural language to achieve a high degree of accuracy in the textual processing of data required for classifying areas of innovation based on the textual title submitted through Google Forms at the International Innovation Fair for Youth "Inost mladih" [3].

2. LITERATURE REVIEW AND RESULTS OBTAINED FROM SIMILAR RESEARCH STUDIES

Text analysis is a crucial component in numerous fields, including document classification and information mining. Automatic text classification offers an efficient way to organize and understand large amounts of data. Several authors have tackled similar topics and demonstrated the significance of applying NLP in numerous studies.

In a study conducted by Pang et al. (2002), the authors investigated the use of various feature extraction methods, such as tokenization, stemming, and TF-IDF (Term Frequency-Inverse Document Frequency), for sentiment classification of movie reviews [4].

In their study, Liu et al. (2010) provided an overview of feature extraction methods for text analysis, including n-grams, which are sequences of n consecutive words. These methods have proven effective in capturing local dependencies in [5].

Wang et al. (2023) compared the performance of various deep learning algorithms, such as Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNNs), for classifying short texts on social media. They found that LSTM networks achieved the best results due to their ability to capture sequential information in [6].

The study by Kim (2014) demonstrates promising results in the field of sentiment analysis of Twitter data. The combination of TF-IDF weighting and SVM classifier achieved an accuracy of 89%[7]. Accuracy [8] is defined as the ratio of correctly classified items to the total number of classified items. In this case, out of 100 tweets classified by Kim's model, 89 were classified correctly (positive, negative, or neutral).

Although an accuracy of 89% is impressive, it does not provide a complete picture of the model's performance. It is important to consider other performance metrics, such as recall and F1-score. The F1-score [9] combines precision and recall into a single metric. Recall [10] measures the proportion of relevant items that were correctly classified. It is possible that Kim's model missed some relevant tweets (e.g., classifying negative tweets as neutral).

For a complete picture, additional information is needed such as:

1. What was the ratio of positive, negative, and neutral tweets in Kim's dataset?
2. What values were achieved for recall and F1-score?
3. How does Kim's model compare to other models for sentiment analysis of Twitter data?

While the 89% accuracy suggests that Kim's model was successful in accurately classifying the majority of Twitter data, for a comprehensive evaluation of its performance, additional information on other metrics and comparison with alternative models is necessary.

Xu et al. (2018) achieved promising results using an LSTM (Long Short-Term Memory) network for automatic classification of news categories. Their model reached an F1-score of 92%, indicating high precision and recall during classification.

The F1-score is the harmonic mean between precision and recall. A high F1-score means that the model is effective in both accurately identifying relevant categories (precision) and finding the majority of relevant articles (recall) [11].

LSTM networks are a type of recurrent neural networks that excel in learning sequential dependencies in data. In text, the order of words and their context can be crucial for determining the category of news. LSTM networks can learn these long-term dependencies and utilize them for improved classification.

For a better understanding of the study, it is necessary to further investigate:

- How many different news categories did the model classify?
- What was the format of news articles in the dataset (text, title, abstract, etc.)?
- How does the performance of the LSTM network compare to other models for news category classification?

The study by Xu et al. (2018) demonstrates that LSTM networks can be an effective tool for automatic news category classification. A high F1-score of 92% indicates the model's robustness. However, for a comprehensive understanding of the research, it would be useful to know more about the specifics of the study and comparisons with other models.

3. MATERIAL METHODS AND RESEARCH ORGANIZATION

During the data collection process, the Data Meaning process [12] was utilized. As a foundational basis for analysis, we used participant data from the International Exhibition of Ideas, Innovations, and Creativity "Inost mladi" spanning from 2015 to 2022. The dataset includes the following information:

1. Category Name
   - Automation
   - Informatics
   - Free Topic (business models, architecture, medicine, design...)
2. Paper Title

When using the MLP (Multiple Layer Perceptron) classifier for Natural Language Processing (NLP), it is typically employed as part of a broader system that involves multiple data processing steps.

When implementing the MLP classifier for NLP, libraries such as TensorFlow, PyTorch, or scikit-learn can be helpful as they provide ready-made implementations of these algorithms and functions for working with data. It is important to emphasize that the efficiency of the model is often linked to the quality of training data, the selection of relevant features, and the proper tuning of hyperparameters.

The MLP (Multiple Layer Perceptron) [13] is a classifier whose operation is based on the functioning of a multilayer perceptron. The multilayer perceptron is a model of artificial neural networks that maps input datasets to a set of corresponding outputs. Artificial Neural Networks (ANN) [14], in particular, attempt to mimic the functioning of the human brain by representing a set of interconnected neurons. In this study, we analyzed a total of 7,000 paper titles. This large sample size allows us to draw relevant conclusions with a high degree of confidence.

The independent variables include paper categories (such as Automation, Informatics, and Free Topic), while the dependent variables focus on the analysis of textual content within the papers, such as themes, writing styles, and structure.

For data processing and analysis, we utilized the Python programming language, which provides a rich ecosystem of libraries and tools for text processing, machine learning, and data analytics. Specifically, we employed popular libraries like TensorFlow, PyTorch, and scikit-learn for implementing machine learning models.

The data is organized into three main categories: training, validation, and testing. Training data was used for model training, validation data for parameter tuning and performance evaluation during training, while testing data was used for final model performance evaluation after training. This organization allows us to objectively assess the model's performance on new, unseen data.

4. RESEARCH RESULTS

The following sections will present the steps through which we arrived at the results, using the MLP classifier.

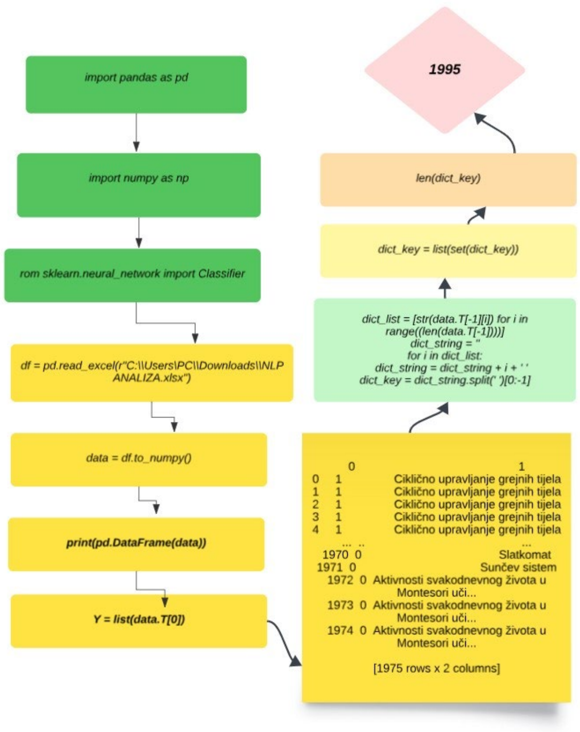


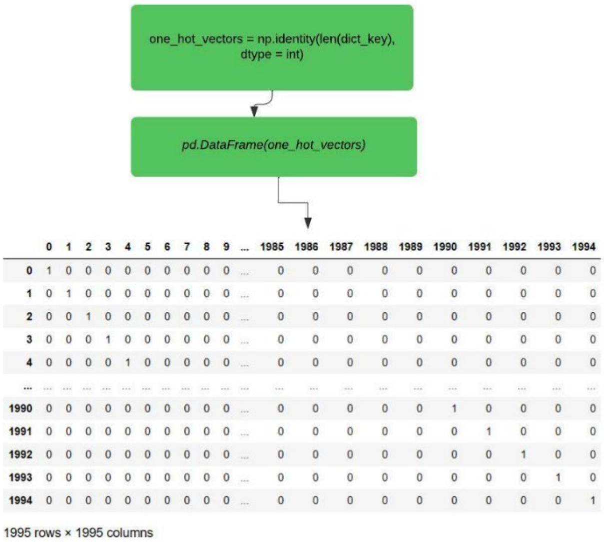
Figure 1. Flowchart 1: Procedure for Creating Input Parameters Using an Excel Database and Text Preparation

In the continuation of the paper, we will illustrate the process of text vectorization.

We generate a unit matrix using the NumPy package, whose dimensions are equal to the size of the set of unique words in the database.

The algorithm we apply for vectorization is 'one-hot encoding', meaning that each unique word is associated with a unit vector (unit, in this context, means that it contains only one unit, and everything else is zeros, analogous to vectors i, j, k in a 3D Gaussian coordinate system).

Afterwards, we create a dictionary containing all unique words as keys and the corresponding vectors as their values. All of this will be presented in Step 2.



	0	1	2	3	4	5	6	7	8	9	...	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0	1	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
1	0	1	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1990	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	1	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	1	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	1	0	0
1993	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	1	0
1994	0	0	0	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	1

Figure 2. Flowchart 2: Text Vectorization Process

In Step 3, we will use the 'dictionary' as a reference to create a list X, which is a list of aggregated unit vectors corresponding to each title in the Excel database.

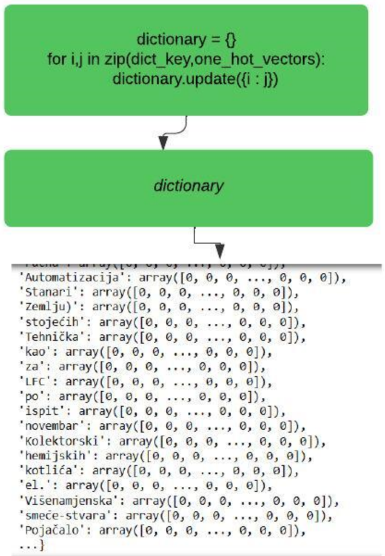


Figure 3. Flowchart 3: Process of Creating a Vector List

In Step 4, efforts will be directed towards checking the model's performance on the validation set during training to prevent overfitting. It can be observed at the end that the number of elements in the X list is equal to the number of titles in the Excel database, which is 1975 entries.

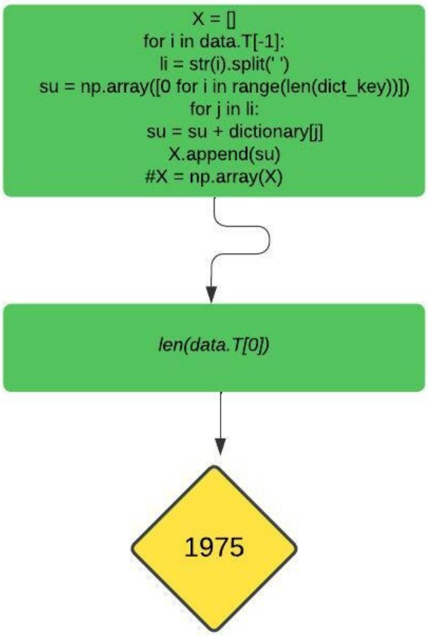


Figure 4. Flowchart 4: Procedure for Testing the Number of Entries

In Step 5, using the MLP classifier, we will calculate the percentage of classification accuracy based on the data. By using the MLPClassifier object from the SciPy package, we create a Multilayer Perceptron Neural Network with the 'Adam' optimizer and logistic (sigmoidal) activation function. The network has 15 hidden layers, trained for 1000 generations, and the algorithm is allowed to stop training before the 1000th iteration if it reaches an appropriate tolerance level.

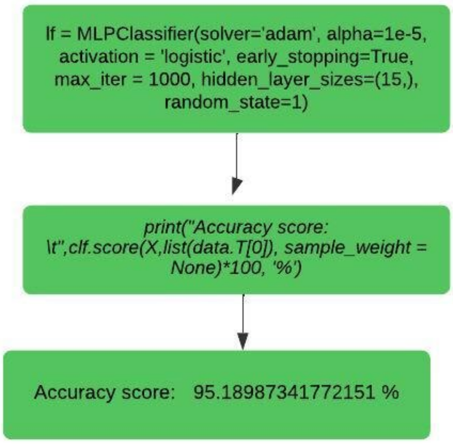


Figure 5. Flowchart 5: Accuracy Calculation

In the following sections, on Figure 1, we will visually present the Loss and Validation Scores Chart during Training Iterations.

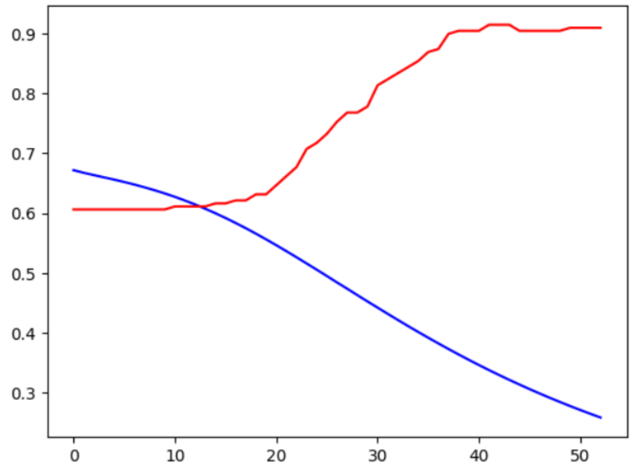


Figure 6. Loss and Validation Scores Chart during Training Iterations

This Fig. 6 illustrates the changes in model loss and validation scores throughout the neural network training process. The x-axis represents the training iterations, while the y-axis displays the model loss (blue line) and validation scores (red line).

Model loss indicates the amount of error the model has during predicting the target variable on the training dataset. A lower loss value signifies a better model prediction. Validation scores provide insight into the model's performance on an independent dataset not used for training. This line represents the accuracy or another performance metric of the model on a dataset it hasn't seen during training.

Analyzing this chart allows us to track how the model's loss decreases over iterations, indicating that the model is improving its prediction. Additionally, we monitor how validation scores increase or stabilize, suggesting that the model generalizes well to new, unseen data.

This chart helps us understand the model learning process and evaluate its ability to generalize to new, unseen data. The analysis of the graph was performed using data visualization tools through Python, utilizing the Matplotlib library. Data on model loss and validation results were collected during the neural network training process, then organized and prepared for visualization. The graph illustrates changes in model loss and validation results throughout the training iterations, enabling tracking of model prediction improvement and its ability to generalize to new data.

5. DISCUSSION

The demonstrated accuracy rate of 95.19% in title classification underscores the proficiency of the natural language processing (NLP) methodologies employed in this study. By leveraging NLP techniques, we were able to discern patterns and extract meaningful insights from textual data, thereby facilitating effective title classification.

It's crucial to acknowledge the limitations posed by the relatively small dataset utilized in this study. While our results are promising, they should be interpreted with caution, considering the constraints imposed by the dataset size. Moreover, the applicability of our findings may vary across different datasets with distinct characteristics and complexities.

In light of these considerations, future research endeavors will focus on enhancing the robustness and generalizability of our approach. This includes evaluating the performance of the model using additional performance metrics such as precision, recall, F1-score, and others. Such comprehensive evaluation metrics are particularly pertinent in scenarios involving multiple classes or imbalanced class distributions.

Furthermore, the significance of our findings extends beyond the realm of title classification. The methodologies and insights derived from this study hold implications for various NLP applications, including sentiment analysis, document classification, and information retrieval. By elucidating effective strategies for processing textual data, our research contributes to the advancement of NLP methodologies and their practical applications across diverse domains.

6. CONCLUSION

This experiment focused on analyzing the significance of applying NLP for categorizing submitted papers for the International Innovation Fair Inost Mladih.

The mentioned natural language processing method enabled the automation of the title categorization process, contributing to time savings and resources that would otherwise be required for manual review and labeling of titles.

Furthermore, a quick and secure analysis of a large amount of data was generated, resulting in faster data retrieval at a specific moment.

Applying NLP for categorizing paper titles from Google Forms aids in automating this task, making the organization of information collected through surveys or forms more efficient.

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73

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INVESTIGATION OF THE PURPOSE OF THE TRAVEL IN THE AREA OF UNA – SANA CANTON FOR THE NEEDS OF EXPRESSWAY CONSTRUCTION

Abstract

In this paper, research data on the purpose of the trip, the origin and destination of the trip, and the occupancy of vehicles for the construction of the expressway were analyzed. All published data are given in tables with percentages, and graphical representation in a GIS environment is used. The research included nine locations in the area of the Una-Sana Canton, which are also displayed in a GIS environment. Research results showed that the preliminary expressway route should go along the Bihać - Cazin - Velika Kladuša section. This research can be useful to all subjects involved in the preparation of expressway feasibility studies, local self-government and the like.

Keywords: trafic research, traffic counting, GIS, survey

ИСТРАЖИВАЊЕ СВРХЕ ПУТОВАЊА НА ПОДРУЧЈУ УНСКО - САНСКОГ КАНТОНА ЗА ПОТРЕБЕ ИЗГРАДЊЕ БРЗЕ ЦЕСТЕ

Сажетак

У овом раду анализирани су подаци истраживања о сврси путовања, поријеклу и циљу путовања, и попуњености возила за изградњу брзе цесте. Сви подаци који су обрађени дати су у табелама са процентима, и искориштени су за графички приказ у ГИС окружењу. Истраживањем је обухваћено девет локација на простору Унско – санског кантона које су такође приказане у ГИС окружењу. Резултати истраживања су показали да би идејна траса брзе цесте требала ићи дионицом Бихаћ – Цазин – Велика Кладуша. Ово истраживање може бити од користи свим субјектима који се баве израдама студија оправданостих брзих цеста , локалној самоуправи и слично.

Кључне ријечи: саобраћајно истраживање, бројање саобраћаја, ГИС, анкета

1. INTRODUCTION

Throughout history, human lives and obligations have always been unimaginable without a quality and rationally built traffic infrastructure throughout the territory of a country as an indispensable part of a global and dynamic economic system [1]. Traffic research implies defining the problems and goals of research, determining data origins and types of research, method of data collection, data analysis and report on obtained research results. With the right approach and survey methodology, relevant and useful data with high value can be collected. One of the goals of the work is to clearly present the methodology of the survey as well as other information that affects the final research result [2]. Considering the high population density and a large number of settlements, as well as the significant traffic-geographical importance of this area, the road network is relatively well-developed (it is connected to the rest of the Federation by arterial roads, and the connectivity of the Canton centers is achieved via regional roads without the existence of higher-order highways), although there are certain issues such as the obsolescence and deterioration of certain parts of the transportation infrastructure. [3,9]. In the research part of the paper, questionnaires were used: origin and destination of the trip, average vehicle occupancy, purpose of the trip. Due to the global development of traffic and traffic demand, the existing traffic infrastructure does not meet the existing requirements. The planned expressway Bihać-Cazin-Velika Kladuša expressway route is located in the western part of Bosnia and Herzegovina, in the Una-Sana canton. It passes through the municipality of Velika Kladuša, starting from the Maljevac border crossing, then continues through the city of Cazin towards Bihać, up to the junction of the expressway route with the planned Bihać bypass, shown in Figure 2. of this paper (see Figure 2.).The Una-Sana Canton has a network of road infrastructure consisting of a network of local and regional roads, via main roads, and European road routes that connect the Una-Sana Canton with Corridor Vc and further to the south and north with the Republic of Croatia. Main connection with Corridor Vc is the European route E-761, which runs through Bihać - Bosanski Petrovac - the inter-entity demarcation line, while the connection of the southern part of the Una-Sana Canton with the Republic of Croatia is made via road E-59, which runs through Izaćić-Bihać - Ripač-Užljebić. The development of the international transport axis in BiH in the northwest-southeast direction, along with the already established north-south axis of development, is a prerequisite for polycentric sustainable development at the regional level, which is a generally accepted modern approach to the country development and one of the basic principles of the country development in the EU. The implementation of the Bihać-Velika Kladuš expressway construction project would complete the strategically important project of adequate road connection of the Una-Sana Canton with other areas in Bosnia and Herzegovina and the Republic of Croatia. The construction of a new road implies a road with four traffic lanes, two lanes on both sides. The purpose of building a new road is to shorten the travel time to the destination. In addition to shortening the travel time, the construction of the new road also improves the area where it is located, thereby encouraging the investors and the development of the industrial zone. The planned expressway will reduce and relieve traffic on the existing roads, thereby achieving greater traffic safety and security for other road users [4]. The authors propose the aforementioned general statement as a hypothesis, which will be either refuted or confirmed during the preparation of planning and study documentation (traffic studies, multi-criteria analysis, and feasibility study). This documentation represents one of the input data for the financial-economic analysis of the mentioned documentation, in which the profitability of the proposed expressway will be elaborately justified. The adopted methodology for the analysis and forecast of traffic needs, relevant for traffic infrastructure development studies, will be based on the research of the mentioned needs between individual zones within the narrower and wider gravitational area of the treated roadway.

The narrower gravitational area includes primarily populated places through which the mentioned route passes. The narrower gravitational area includes populated areas of the following municipalities/cities:

- In the City of Bihać: Bihać, Bajrići, Jankovac, Brekovica, Vrsta, Velika Gata, Donja Gata;
- In the City of Cazin: Vrelo, Mutnik, Pjanići, Ćoralići, Donja Barska, Kovačevići, Čajići, Gornja Barska, Pećigrad, Rošići, Mujakići;
- In the municipality of Velika Kladuša: Šabići, Šumatac, Mala Kladuša, Miljkovići, Glavica, Grahovo, Trn, Polje, Nepeke, Velika Kladuša, Trnovi.

The municipalities/cities through which the Bihać-Cazin-Velika Kladuša expressway section passes are taken as the wider gravitational area. The expressway route passes through the cities of Bihać and Cazin and the municipality of Velika Kladuša. As a broader area, the region of Slovenia and

Croatia can also be considered, with an emphasis on Croatia. The latter is justified by the fact that the construction of the proposed expressway would result in a shorter (higher quality) route connecting parts of the Sisak-Moslavina and Karlovac counties with the Lika-Senj County (see Figure 1.).

Figure 1. The area of the expressway
Source: Civil Engineering Institute IG

The following sections will present the methodology employed, the obtained results at the study site, as well as the objectives of this research.

2. STUDY AREA

The Una-Sana Canton consists of the cities of Bihać, Bosanska Krupa and Cazin and five other municipalities. The Una-Sana canton borders Croatia in the north, west and northeast, Republika Srpska in the east and southeast, and Canton 10 in the southwest. The city of Bihać is located in the northwestern part of BiH, belongs to the entity of the Federation of BiH and is the seat of USC. According to the population census, the city of Bihać has 61,564 inhabitants. The city has an area of 900 km², which is 21.8% of the USC territory, and it is composed of 35 local communities. Its relief is to a greater extent diverse, mainly consisting of fields, hills and mid-mountain land. The average altitude is 224.7 meters, the greater part of the area is located on terrains 600 meters above sea level, while a part is located in the mountain and hill-mountain belt and over 900 meters. The city of Cazin is also located in the northwestern part of Bosnia and Herzegovina at the intersection of the roads leading from Bihać to Velika Kladuša. Cazin has about 66,149 inhabitants distributed into 23 local communities and spreading over an area of 356 km2. The terrain is predominantly low-lying between 200 and 400 meters above sea level. This area has a temperate-continental climate with rather harsh winters and hot summers. The municipality of Velika Kladuša is located in the far northwest of Bosnia and Herzegovina. In the south it borders the municipalities of Bužim and Cazin, while in the west, north and east it borders Croatia and the municipalities of Centingrad, Vojnić, Topusko, Glina and Dvor. The municipality has about 40,419 inhabitants, and it covers an area of 331.73 km². Velika Kladuša is one of the most densely populated places in Bosnia and Herzegovina, it is divided into 14 local communities.

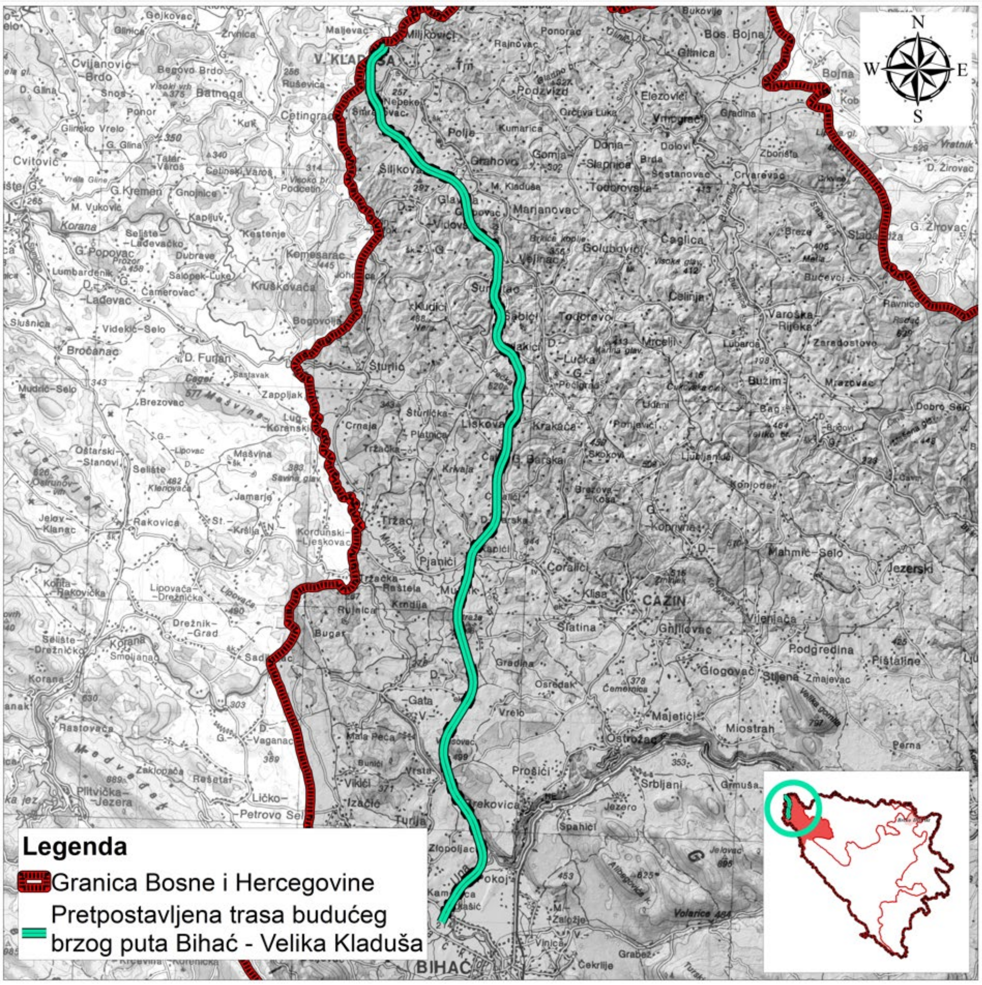

Figure 2. Figure 2. The assumed route of the expressway
Source: Civil Engineering Institute IG

3. MATERIALS AND METHODS

Given that the length data, i.e. distribution of transport infrastructure, are not sufficient to draw relevant conclusions about the transport development of the country, but essentially represent a good foundation for further research, the following parameters were also calculated.

Traffic network density

$$a = \frac{\mathrm{D} \times 100}{\mathrm{P}} \quad (1)$$

Where D is the length of communication, and P is the area in km^2

Table 1. Calculation of the traffic network density in a wider gravitational scope

D ***(length of main and regional roads in a wider gravitational area)*** **km**	***P (area of inhabited places through which the planned expressway route passes) km²***	***Traffic network density (a)***
326.43 km	*1,632.15 km²*	20

The traffic network density in the wider gravitational area (city of Cazin, municipality of Velika Kladuša and the city of Bihać), through which the planned route of the expressway passes, amounts to 20.

Table 2. Calculation of the traffic network density in the narrower gravitational scope

D (length of main and regional roads in a narrow gravitational area) km	***P (area of inhabited places through which the planned expressway route passes) km²***	***Traffic network density (a)***
80.8 km	258.74 *km²*	31.22

The traffic network density in the narrower gravitational area, which includes all populated places through which the expressway route passes, amounts to 31.22.

Length of communications per 10,000 inhabitants

$$a' = \frac{D \times 10000}{L} \quad (2)$$

Where D is the length of communication, and L is the number of inhabitants:

Table 3. Calculation of the length of communications per 10,000 inhabitants in the wider gravitational area

D (length of main and regional roads in the wider gravitational area) km	***L (number of inhabitants in the wider gravitational area)***	***Length of communications per 10,000 inhabitants (a')***
326.43 km	*162,829*	20.05 km

The length of communications covering the wider gravitational area per 10,000 inhabitants amounts to 20.05 km.

Table 4. Calculation of the length of communications per 10,000 inhabitants in the narrower gravitational area coverage

D (length of main and regional roads in the narrower gravitational area) km	***L (number of inhabitants in the narrower gravitational range)***	***Length of communications per 10,000 inhabitants (a')***
80.8 km	71.653	11,27 km

The length of communications per 10,000 inhabitants is 11.27 km.

Network density in relation to the area and number of inhabitants, the so-called Engel coefficient

$$A = \sqrt{\frac{D \times 100}{P} = \frac{D \times 10000}{L}} = \frac{D \times 1000}{\sqrt{P \times L}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$A = \sqrt{a \times a'}$

Table 5. Calculation of the Engel coefficient in the narrower gravitational area

Traffic network density	***Length of communication per 10,000 inhabitants (a')***	***Engel coefficient***
31,22	11,27 km	18,75

Table 6. Calculation of the Engel coefficient in the wider gravitational area

Traffic network density	***Length of communication per 10,000 inhabitants (a')***	***Engel coefficient***
20	20,05	20,24

In this paper, in addition to the mentioned calculations, the survey method was also utilized. The survey method is an organized and pre-prepared examination, research, that is, the poll of views, opinions and data on a topic or phenomenon by means of a survey questionnaire as a series of questions, which are addressed to a high number of people." [3]. For the purposes of this research, a survey questionnaire was created which, among other things, investigated the trip: type of vehicle, origin – destination of trip, purpose of the trip, vehicle occupancy and average annual mileage of the vehicle. The survey was conducted in the period of May to June 2023, as shown in Figures 4 and 5 in the continuation of the paper. The applied method involves one of the research or additional research methods used in the preparation of multi-criteria analyses, traffic studies, and feasibility studies. It also constitutes one of the basic input data for analyses that involve presenting potential benefits after the construction of the planned roadway in socio-economic or multi-criteria analysis and aim to illustrate calculations of time savings, vehicle operation, travel motivations, and reducing the number of traffic accidents. This analysis serves as supplementary research to gather as precise data as possible using AADT (Average Annual Daily Traffic) to create detailed study documentation.

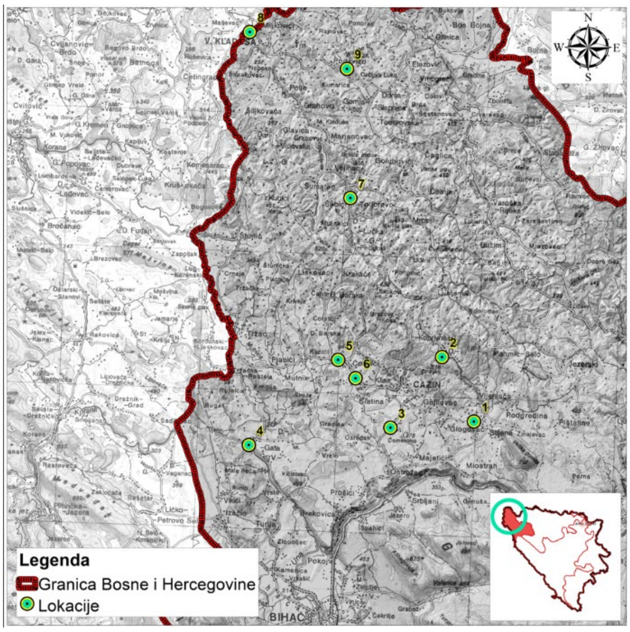

Figure 3. Locations of polling stations
Source: Civil Engineering Institute IG

4. RESULTS AND DISCUSSION

An expressway represents one of the main elements of traffic infrastructure of a country and contributes to the development of the territory where it is located. One of the solutions to increase the intensity of traffic and the density of traffic flow is precisely the realisation of the expressway.

Figure 4. Survey of road users1

Figure 5. Survey of road users 2

After processing the data obtained by surveying all nine locations shown in Figure 3, the results are shown in the following table:

Table 7. Percentage analysis of respondents by polling places

	PC	**HDV + LDV**	**BUS**
NO.	1860	838	314
% Of those surveyed	61.76	27.82	10.42

Table 8. Length of trip

Length of trip (km)				
0-10 km	**10-20 km**	**20-50 km**	**50-100 km**	**>100 km**
9	15.4	44.2	5.6	25.8
%	%	%	%	%

Table 9. Purpose of trip

PRIVATE	57.3
BUSINESS	42.7

Table 10. Type of trip

TRANSIT	21
ORIGINAL - TARGET	24,5
LOCAL	54,5

According to the results of the survey conducted among 3,012 traffic participants, the majority of vehicles, 1,860 of them, were passenger vehicles. It was also found that the most common travel distance was between 20 and 50 kilometers, accounting for 44.2% of the total number of respondents, while the least common was on routes between 50 – 100 kilometers, at 5.6% (Table No. 8). Out of the total number of respondents, 57.3% stated that they had undertaken private trips, while 54.5% were local trips (Table No. 10). Furthermore, the analysis showed that the highest percentage of respondents had local trips, accounting for 54.5%, while 21% of respondents had transit-type trips (Table No. 10).

5. CONCLUSION

Based on the results of a survey of 3,012 road users, it was determined that the largest number of passenger vehicles was 1,860. Also, the trip length was determined, where the highest number of respondents used a section of 20-50 km, then 57.3% were private trips and 54.5% local travel. The mentioned expressway is connected to the Vc corridor and road routes in the Republic of Croatia via the road infrastructure network of the Una-Sana Canton and the Federation of Bosnia and Herzegovina. The beginning of the road in question is at its junction with the planned Bihać bypass, and the end is in the area of the Maljevac border crossing. These studies are of paramount importance for identifying deficiencies in the current traffic infrastructure and determining areas that require improvement to increase efficiency and safety on roads. Data collected through travel purpose surveys and vehicle surveys provide input information necessary for the preparation of traffic studies, feasibility studies, and other analyses required for the planning and implementation of the expressway. Without accurate information about the needs and demands of road users, there is a risk of building infrastructure that does not meet the actual needs of the community. This can result in inefficient use of resources, unnecessary costs, or insufficient road capacity. Therefore, conducting in-depth research on travel purposes and vehicle surveys is crucial as an initial step in planning the expressway to ensure that the new infrastructure adequately meets traffic demands and enhances the quality of life in the community.

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74
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NATURE PROTECTION REGIMES AND CONSTRUCTION REGULATIONS IN SPATIAL PLANS OF AREAS OF SPECIAL PURPOSE IN THE REPUBLIC OF SRPSKA

Abstract

According to the Law on Spatial Development and Construction of the Republic of Srpska, the spatial plan of the Special Purpose Area of the Republic of Srpska is adopted mandatory for national parks and other areas if this is determined by documents of a higher order or wider area. The Spatial Plan of the Special Purpose Area of the Republic of Srpska defines priority objectives in the categories of space and time, based on the completed harmonization of precisely identified conflicting and potentially conflicting goals. According to the Law on Nature Conservation of the Republic of Srpska, the following protection regimes are implemented in the protected area: Ia, Ib, II and III level of protection. In this paper, an analysis of the protection regime and building rules in the spatial plans of the special purpose area of the Kozara National Park and the Sutjeska National Park was carried out.

Keywords: Special purpose area plan, protected areas, Republic of Srpska

РЕЖИМ ЗАШТИТЕ ПРИРОДЕ И ПРАВИЛА ГРАЂЕЊА И УРЕЂЕЊА У ПРОСТОРНИМ ПЛАНОВИМА ПОДРУЧЈА ПОСЕБНЕ НАМЈЕНЕ У РЕПУБЛИЦИ СРПСКОЈ

Сажетак

Према Закону о уређењу простора и грађењу Републике Српске, просторни план подручја посебне намјене Републике Српске доноси се обавезно за националне паркове и друга подручја уколико је то одређено документима вишег реда или ширег подручја. Просторним планом подручја посебне намјене Републике Српске одређују се приоритетни циљеви у категоријама простора и времена, а на основу извршеног усаглашавања прецизно идентификованих сукобљених и потенцијално сукобљених циљева. Према Закону о заштити природе Републике Српске, на заштићеном подручју спроводе се сљедећи режими заштите: Ia, Iб, II и III степен заштите. У овом раду извршена је анализа режима заштите и правила грађења у просторним плановима подручја посебне намјене Националног парка Козара и Националног парка Сутјеска.

*Кључне ријечи**:** план подручја посебне намјене, заштићена подручја, Република Српска*

1. INTRODUCTION

The analysis of the application of legal regulations in the domain of protected area of exceptional or great importance determined the subject matter and the goals of work research. The work aims to prove the importance of spatial planning documentation for nature protection. We are witnessing the gradual degradation of nature in national parks, and the reason for this is precisely the lack of spatial planning documentation, which is the basis for nature conservation and protection. "Kozara" National Park is one of the 34 protected areas on the territory of Republika Srpska, and only it has an approved Spatial Plan for Special Purpose Areas, which is a devastating but also worrying fact.

The spatial unit represents a complex with multiple functions and purposes that are of existential importance for the survival of the area [1]. Interpolating different purposes within protected areas, if not viewed integrally, can lead to a series of undesirable consequences such as uncontrolled spatial urbanization [2]. In the desire to meet the needs of its users, the design process often neglects the broader environment, potentially endangering the protected area [3].

In many cases, the management of protected areas at the beginning of the 20th century endangered already vulnerable traditional rights and habits of local population [4]. Today, protected areas are used not only for preserving biodiversity but also for safeguarding natural and cultural assets [5]. Protected areas are even promoted as solutions for certain social problems [6], hence the need for not only protecting the area but also planning its organization, use, development, and construction. It is recommended and necessary for protected areas to have developed and adopted spatial plans of special purpose that will be implemented and respected [7].

Bosnia and Herzegovina was an integral part of the former Socialist Federal Republic of Yugoslavia. In the period from 1945–1963, under the name of the People's Republic of Bosnia and Herzegovina, and from 1963 until 1992, as the Socialist Republic of Bosnia and Herzegovina, From 1992 until today, the state was Bosnia and Herzegovina (https://sh.wikipedia.org/wiki/Socijalisti%C4%8Dka_Republika_Bosna_i_Hercegovina) [8]. Bosnia and Herzegovina is a country that is divided into two entities, Republika Srpska and Bosnia and Herzegovina, as well as the independent territory of Brčko District. Due to the complex territorial-administrative division of the country, there is also a complex planning system. In the Republic of Srpska, spatial planning is done at the level of local self-government units, while in the Federation of Bosnia and Herzegovina, spatial planning is at the canton level. In the Republic of Srpska, spatial planning documents are divided into strategic and executive documents. The strategic documents are: the spatial plan of the Republic of Srpska; the spatial plan of special purpose areas of the Republic of Srpska; the common spatial plan for the territories of two or more local self-government units; the spatial plan of a local self-government unit; and the urban plan. Implementation documents of spatial planning are: zoning plan, zoning plan of special purpose areas, regulatory plan, urban project, and subdivision plan ("Official Gazette of the Republic of Srpska", number: 40/13) [9].

In this paper, special attention will be paid to the spatial plans of the special-purpose areas that were made for the national parks located in the territory of the Republic of Srpska. In question are two of the three national parks on the territory of the Republic of Srpska: the "Kozara" National Park and the "Sutjeska" National Park. The spatial plan of the special purpose area of NP "Kozara" has been adopted by the competent institutions, while the spatial plan of the special purpose area of NP "Sutjeska" has not yet been adopted. Third, the "Drina" National Park has not adopted or completed the spatial plan of the special purpose area, which is why it is not an integral part of this scientific work.

Spatial plans of special purpose areas are made for areas that are of natural and cultural-historical value, for areas that have tourist or hydro potential, as well as for the construction of buildings for which a building permit is issued by the competent ministry or department that is responsible for the construction in the territory of the local self-government unit, exploitation of mineral resources [10]. The spatial plan of the special purpose area is also prepared for areas that require a special regime of organization, organization, use and protection of space or if they are defined as such in the Spatial Plan of the Republic of Srpska [11].

Spatial plans of areas of special purpose have existed as an integral part of the spatial planning and development system in these areas since the 1970s, specifically, the obligation to prepare them was first defined with the enactment of the Spatial Planning Law in 1974 ("Official Gazette of SR BiH", No. 13/74) [12]. At that time, the mentioned Law introduced the spatial plan of a special area as a subcategory of spatial development plans. In 1986, the first spatial plan for a protected natural area in Bosnia and Herzegovina and today's Republic of Srpska was adopted - the Spatial Plan of the

Special Area, the Sutjeska National Park. Through the mentioned plan, the ranking of the areas of the national park and the surrounding area planned for expansion was conducted based on their overall value by defining precise protection regimes (I, II, III) and their limitations. The first protection regime is defined as the strictest regime for areas of exceptional value, while the third protection regime implies the least restrictions and full use of the area without pollution and degradation of natural resources and their reproduction.

In the period that followed, despite frequent changes in laws, their role in the spatial planning system did not diminish. Their names differed, as did the methodology applied during their preparation and the authority responsible for issuing the document. The content of spatial planning documentation was determined by appropriate sublegal acts - regulations on the method of preparation, content, and formation of spatial planning documents. After the wartime events in the period from 1992 to 1995, the Republic of Srpska initiated the adoption of its own regulations in the field of nature protection and spatial planning. According to the Law on Spatial Planning from 1996 ("Official Gazette of the Republic of Srpska", No. 19/96) [13], spatial plans for areas are adopted, among other things, for national parks and other protected areas.

The first Republic of Srpska Law on Nature Protection was enacted in 2002 ("Official Gazette of the Republic of Srpska", No. 50/02) [14] and it contained a different categorization of protected areas compared to legal solutions before 1992. The Law on National Parks from 1996 ("Official Gazette of the Republic of Srpska", No. 21/96) [15] regulated the protection, development, and management of these categories of protected areas, as well as the boundaries of the designated national parks Sutjeska and Kozara, with the obligation to harmonize spatial plans of the national park areas within two years.

According to the current Law on Spatial Planning and Construction of the Republic of Srpska ("Official Gazette of the Republic of Srpska", No. 40/13) [16], spatial plans for areas of special purpose are mandatory for national parks and other areas if specified by a higher-level document or a wider area. The spatial plans for areas of special purpose in the Republic of Srpska determine priority objectives in spatial and temporal categories, based on the achieved harmonization of precisely identified conflicting and potentially conflicting objectives. Additionally, this Plan establishes protective belts and zones, special areas and objects, locations for monitoring the environmental condition, protected objects, general spatial development concepts, spatial organization (settlement system, necessary infrastructure system, etc.), measures for environmental improvement and protection, and other provisions.

In order to obtain a comparative analysis of the situation in the field of protection of protected areas and the creation of spatial plans for special purpose areas, we analyzed the situation in the field of nature protection in the neighboring Republic of Serbia, where we can conclude that the legislative framework is identical to the legislation in the Republic of Srpska.When analyzing the situation in the field of nature protection, in the neighboring Republic of Serbia, we can conclude that the legislative framework is similar to that in the Republic of Srpska. The field of nature protection in Serbia is regulated by the Law on Environmental Protection, the Law on Nature Protection, and other laws or regulations directly or indirectly related to nature and natural value [17]. When it comes to the national parks of Serbia, particularly important laws are the Law on National Parks and the Law on Planning and Construction [18]. In Serbia, there has been a balanced ratio of spatial plans by types from 1960 to 2010. The predominance of using spatial plans for areas of special purpose practically began in 2010 and continues to this day. After 50 years of spatial planning practice in Serbia, there has been a kind of deformation of the system for the first time, leading to its practical reduction to one type of plan. Such simplification is not good for the system, but it has its reasons [19].

Spatial plans for protected natural areas as a subcategory of spatial plans for areas of special purpose have not been prepared in the territory of the Republic of Srpska in the last 10 years, i.e., since 2014. In 2017, another national park - Drina - was declared by adopting a special law, but the spatial plan for the area of this newly established national park was not developed during the previous period, and a decision to start the preparation of this document has not been made either [20].

In addition to the Law on Spatial Planning and Construction of the Republic of Srpska and the Regulation on the Method of Preparation, Content, and Formation of Spatial Planning Documents ("Official Gazette of the Republic of Srpska", No. 69/13) [21] , there are also numerous other sectoral laws that condition the preparation of spatial plans for areas of special purpose, as well as segments related to protection regimes, such as the Law on Nature Protection of the Republic of Srpska [22], the Law on Waters of the Republic of Srpska ("Official Gazette of the Republic of Srpska", No. 50/06) [23], and others.

The research for the purposes of this paper is based on a review of the legal regulations regarding protection regimes of protected areas and regulations for planning and construction in spatial plans for areas of special purpose. Additionally, for the purposes of this paper, special focus is placed on the analysis of spatial plans for areas of special purpose for the National Parks "Kozara" and "Sutjeska".

2. METODOLOGY

When writing this scientific work, the following were used: The spatial plan of the special purpose area for the "Kozara" National Park and the spatial plan for the "Sutjeska" National Park, the Law on Spatial Planning and Construction of the Republic of Srpska, the Law on Nature Protection, and the Law on National Parks. On the basis of the mentioned documents, a comparative analysis of the plans as well as the protection regime and regulation of the arrangement and construction in the protected areas, National Park "Kozara" and National Park "Sutjeska," was performed. The two mentioned national parks were chosen for consideration because they are the only ones that have developed special purpose area plans. Although the plan for NP "Sutjeska" was not adopted, it served as a basis for obtaining information and data on the state of park protection and the defined conditions of construction and arrangement. The paper also presents a comparative analysis of the state of nature protection in the Republic of Srpska, the Federation of Bosnia and Herzegovina, Serbia, and Montenegro. The analysis refers to protection regimes that are used in the Republic of Srpska and which are used in neighboring countries.

2.1. PROTECTED AREAS AND SPECIAL PURPOSE AREAS IN APPLICABLE LAWS

The protection zones or protection regimes are an integral part of spatial plans for areas of special purpose in the segment of land use, spatial organization, built-up areas, and spatial functionality. The legal basis for protection regimes is provided through sectoral laws, depending on the nature of the special purpose of the area for which the plan is being developed.

The protection regimes for spatial plans of areas of special purpose for protected areas are defined by the Law on Nature Protection of the Republic of Srpska ("Official Gazette of the Republic of Srpska", No. 20/14) [24] **.** The concept of nature protection under this law is based on the following basic elements: protected areas, protected species, protected minerals and fossils, protection zones, protection regimes, and others.

Protected areas are areas with pronounced geological, biological, ecosystem, or landscape diversity and are significant as habitats for bird species and other migratory species in accordance with international regulations. They can be designated as protected areas of general interest. Protected areas include: strict nature reserve, special nature reserve, national park, natural monument, protected habitat, protected landscapes (protected natural landscape, protected cultural landscape, and nature park), protected area with sustainable use of natural resources (forest park, objects of shaped nature).

The protection regime is defined as a set of measures and conditions determining the manner and degree of protection, use, development, and improvement of the protected natural asset. The protection concept is based on a three-level protection regime: I, II, and III levels. In order to obtain a comparative analysis and assessment of the situation in the countries in the region and their practices when it comes to the protection of space, we analyzed the protection regimes implemented in the territory of the Republic of Serbia, Montenegro, and the Federation of Bosnia and Herzegovina. After the analysis, we came to the conclusion that Republika Srpska and countries from the region have the same or similar protection regimes. The above can be used for cross-border cooperation, for harmonizing spatial documents with those of the countries of the region, or for rewriting the management of protected areas in order to obtain good, functional, and sustainable protected areas. In the territory of the Federation of Bosnia and Herzegovina, there is one protected area in the category of a national park, the Una National Park ("Official Gazette of the Federation of BiH", No. 44/08) [25]**.** In the Una National Park (Federation of Bosnia and Herzegovina), the protection regime is established as follows: a) an area of strict and directed protection, and b) an area of directed development which includes the area within the boundaries of the National Park that is not covered by the zone of strict and directed protection. In the territory of Serbia, the protection concept is based on a three-level protection regime: I, II, and III levels, as is the case in the Republic of Srpska [26]. When it comes to the territory of Montenegro, the protection concept in protected areas is the same as in the Republic of Srpska and Serbia. In protected areas in Montenegro, protection zones are designated where the following protection regimes are implemented: a) protection zone I - strict protection regime, b) protection zone II - active protection regime, and c) sustainable use regime [27].

The first-level protection regime is presented in two sub-levels: Ia is the strict protection regime, while Ib is the strict protection regime with the possibility of population management. The Ia level protection regime is implemented in the part of the protected area with original, unaltered, or slightly altered ecosystems of exceptional scientific and practical significance, allowing exclusively natural succession. Furthermore, the Ia level protection regime excludes all forms of land use and activities, except for scientific research, controlled education, and intervention activities in emergency situations, which are carried out with the expert opinion of the Republic Institute for the Protection of the Cultural, Historical, Natural Heritage. The Ib level protection regime is implemented in the part of the protected area with original, unalterable, or slightly altered ecosystems of great scientific and practical significance. Ib level protection allows exclusively for research, controlled education, and activities aimed at preserving and improving the existing ecosystem conditions. The II level protection regime is implemented in the part of the protected area with partially altered ecosystems of great scientific or practical significance. The II level protection allows for management interventions aimed at the restoration, revitalization, and overall improvement of the natural asset without affecting the primary values of their natural habitats, populations, and ecosystems. It also allows for controlled traditional activities that have not compromised the primary values of the area during their operation. The III level protection regime is implemented in the part of the protected area with partially altered ecosystems of scientific or practical significance. The III level protection allows for selective and limited use of natural resources, management interventions aimed at restoration, revitalization, and overall improvement of the natural asset, sustainable use, development, and improvement of rural households, arrangement of cultural heritage and traditional construction objects, preservation of traditional activities of the local population, development of infrastructure in line with the values, potentials, and capacities of the protected area intended for the development of ecological, rural, health, sports and recreational tourism, and other forms of tourism in accordance with the concept of sustainable development.

2.2. ANALIYSIS OF THE PROTECTION REGIME IN THE SPATIAL PLANS OF THE SPECIAL PURPOSE AREAS FOR THE NATIONAL PARKS „KOZARA“ AND „SUTJESKA“

The protection regimes prescribed by laws and legislative acts are an integral part of spatial plans for areas of special purpose. Some are directly incorporated into the spatial planning document itself, while others need to be adjusted depending on the development concept and specific characteristics of the area of special purpose.

Spatial plans for areas of special purpose in protected areas represent the fundamental instrument for the protection and development of such areas. The spatial plan envisages full protection of all objects, sites, and complexes. When it comes to protection regimes, protected areas designate protection zones proposed by the Republic Institute for the Protection of the Cultural, Historical Natural Heritage n the Expert Basis - Study of the Protection of the Protected Area. The protection study determines the values of the area that need to be protected, as well as the forms of management over it [28]. The Ministry, upon the proposal of the Institute, may designate protection zones around the boundaries of the protected area, ecologically significant area, or ecological corridor, which may be determined when establishing the area or subsequently, in order to prevent or mitigate impacts. Protection regimes implemented in the spatial plan for areas of special purpose are prescribed by the Declaration Act of the protected area, based on the aforementioned Protection Study.

The Kozara National Park was first declared in 1967 and has since been continuously protected. Within the Kozara National Park is the Kozara Memorial Complex on Mrakovica, which was declared a Cultural Heritage of Outstanding Importance in 2011 ("Official Gazette of the Republic of Srpska" no: 125/11) [29] **.** The memorial complex consists of a central monument with a memorial wall and a museum. The surface area of the narrower protection zone is 11.38 hectares, and the wider one is 15.68 hectares [30]. The Law on the Kozara National Park was enacted in 2012 ("Official Gazette of the Republic of Srpska" no: 121/12) [31]**.** The Kozara National Park covers an area of 3907.54 hectares, of which 161.74 hectares are under the protection regime of the first level, 492.56 hectares under the protection regime of the second level, and 3253.23 hectares under the protection regime of the third level (Picture 1.). In the spatial plan for areas of special purpose, protection regimes are considered in a broader context. All segments that can influence the appearance and development of the protected area are taken into account, whereas the legal regulations in prescribing protection regimes did not consider any development segment. In the spatial plan, the rules for development and construction are more specifically defined compared to the legal regulations. The rules for development and construction are particularly detailed when it comes to the zone where the protection regime of the third level is established, which plans the construction of certain facilities for tourism purposes (sports and recreation schools, new toll booths, catering facilities, accommodation capacities, infrastructure development and expansion for the ski resort on Mrakovica, camping sites, picnic areas, and others). Tourism is often planned in special-purpose plans as a complementary activity [32]. In accordance with the defined zones for the protection of natural and cultural-historical values, the basic functions of the National Park are also defined: protective, scientific-research, tourist-recreational, and educational. The basic functions of the National Park are carried out in the following spatial units: forests and forest land, agricultural land, zones of intensive use and visitation, and areas of infrastructure systems. In the spatial plan of the special-purpose area, zoning of the Kozara National Park has been carried out according to the purpose of space use: zone of intensive visitation, zone with existing facilities, zone of planned construction, ski resort zone on Mrakovica, Mrakovica memorial complex, and individual natural sites for tourism purposes [33]. This spatial plan of the special-purpose area does not include a section specifically addressing rules for development and construction.

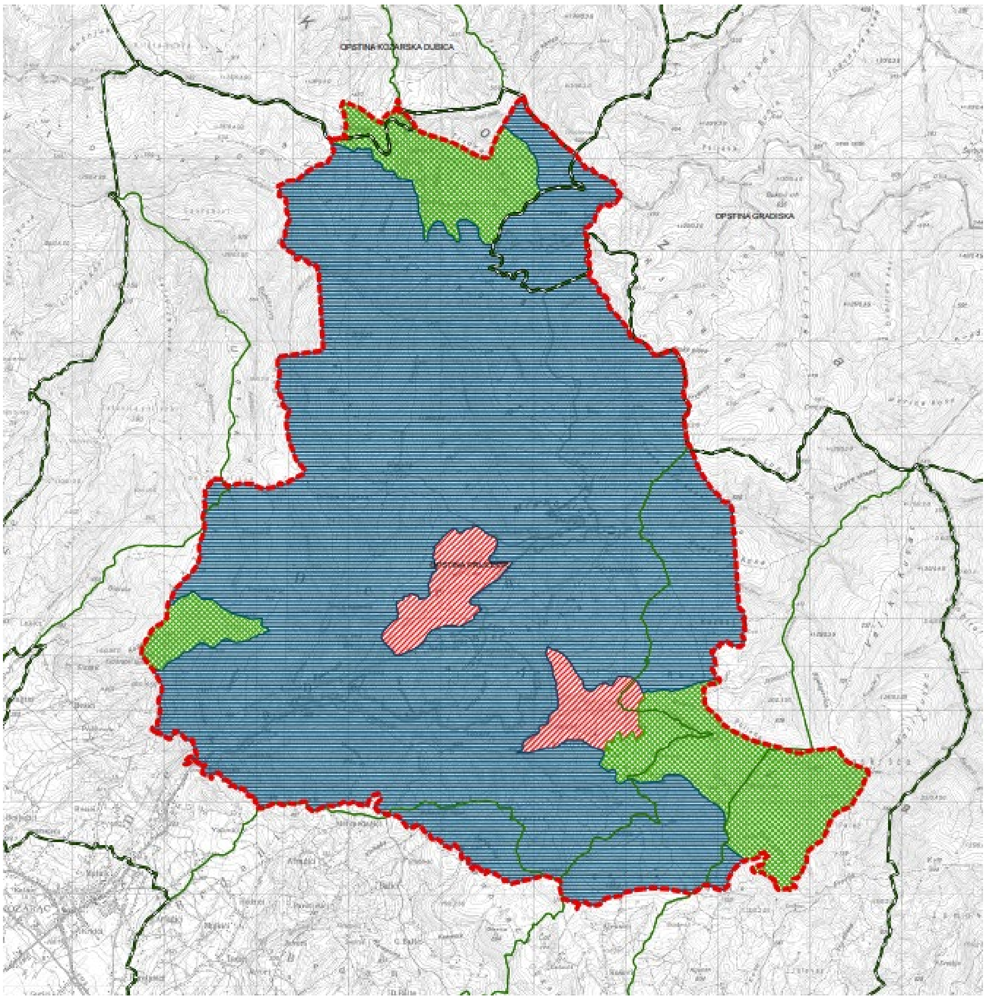

Figure 1. Zonation map of the Kozara National Park- the blue color indicates the third-level protection mode, the second-level protection mode is green, and the first-level protection mode is red (Spatial plan of the special purpose area for the National Park Kozara)

Nacionalni park "Sutjeska" is the oldest national park in the territory of present-day Republika Srpska. The area was first declared protected in 1962 and has since had a continuous protection status [34]. The Law on the Sutjeska National Park was enacted in 2012, alongside the Law on the Kozara National Park (Official Gazette of Republika Srpska, No. 121/12) [35]. Within the Sutjeska National Park is the Tjentište Memorial Complex, which was declared a Cultural Heritage of Outstanding Importance in 2009 (Official Gazette of Republika Srpska, No. 90/09) [36]**.** The memorial complex includes the Monument to the Battle of Sutjeska, the Memorial House, the Memorial Ossuary, and individual commemorative monuments. The area of the narrower protection zone is 70.5 hectares, and the wider one is 49.5 hectares [37]. The Sutjeska National Park covers an area of 16,051.34 hectares, of which 2,375.82 hectares are under first-degree protection, 2,549.62 hectares under second-degree protection, and 11,126.17 hectares under third-degree protection (Picture 2). A spatial plan for the special-purpose area has been prepared for the Sutjeska National Park since 2015, but it has not yet been adopted by the relevant institutions. Just like in the previously mentioned spatial plan for special-purpose areas, in this plan for the Sutjeska National Park, protection regimes are considered in a broader context. In the spatial plan for the special-purpose area of the Sutjeska National Park, the rules of organization and construction are more detailed compared to the legal regulations [38]. The rules of organization and construction are significantly more detailed in areas where the third-degree protection regime is established, where the construction of facilities for tourism purposes is planned. In accordance with the defined zones of protection of natural and cultural-historical values, the basic functions of the National Park are also defined: protective, scientific-research, tourist-recreational, and educational. The basic functions of the National Park are carried out in the following spatial units: forests and forest land, Perućica, agricultural land, zones of intensive use and visitation, and areas of infrastructure systems. In this spatial plan, the rules of organization and construction are specified in the Zone with the protection regime of the third degree, which relate to: construction of facilities, organization and use of space in tourist-recreational sites, conditions for construction, shaping, and arrangement of facilities at rest areas and open spaces; conditions for construction, arrangement, and use of land on micro-dams and reservoirs; conditions for the reconstruction of existing zones of vacation houses and recreational facilities within the boundaries of the National Park.

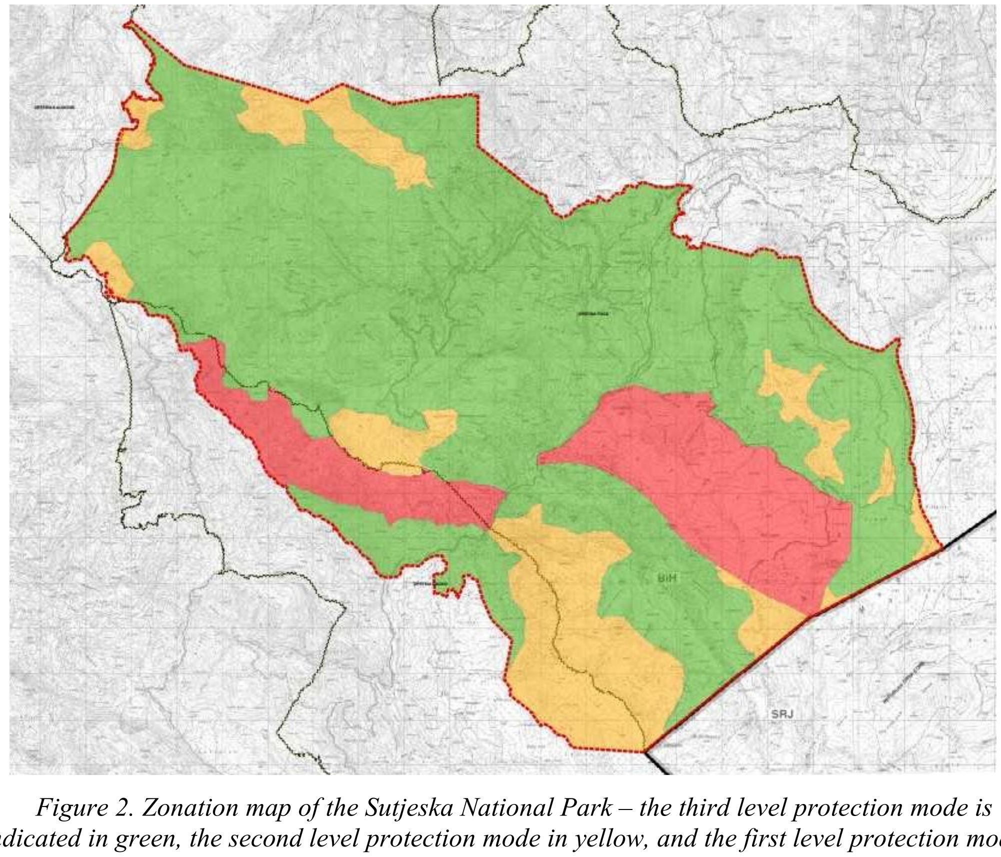

Figure 2. Zonation map of the Sutjeska National Park – the third level protection mode is indicated in green, the second level protection mode in yellow, and the first level protection mode in red (Spatial plan of the special purpose area for the National Park Sutjeska)

When analyzing both spatial plans of special purpose areas for the "Kozara" National Park and the "Sutjska" National Park, it was observed that the plans met the legally prescribed form of the plan. The planning and construction rules are specified in the plans, which serve as the basis and guidelines for the preparation of implementing documents. By implementation documents, we mean zoning plans, regulation plans, urban projects, and subdivision plans. The spatial plan of the special purpose area for the "Kozara" National Park served as the basis for defining the further development

of the park, its organization, and its arrangement, as well as for the adoption of a document in the field of spatial planning. The priorities for creating spatial planning documents for NP "Kozara" are:
• zoning plan of the special purpose area of the Republic of Srpska;

- development of regulatory plans for the picnic area Benkovac and Duge njive;
- preparation of the regulation plan of the Mrakovica ski resort, if there is a new construction and a change in regulation;
- development of regulatory plans for eco-lodge settlements in Grabovac, Kustaic-stanovi, and Razboj locations;
- creation of regulatory plans or plans for the subdivision of camps in the localities Pasini Konaci, Stara Planina, Planiste, and Glavusa.

Spatial planning documents, which are listed as priorities for adoption according to the Spatial Plan of the special purpose area for the "Kozara" National Park, have been prepared and adopted, which makes it easier for the Park to control construction within its borders. The spatial plan of the special purpose area for the "Sutjeska" National Park was prepared in 2014 but was not adopted, which represents a huge problem for the management, development, and protection of the park. "Sutjeska" National Park is the oldest national park in Bosnia and Herzegovina, but due to the lack of spatial planning documentation, it is the most endangered. It is primarily endangered due to the construction of small hydroelectric power plants that are planned within the boundaries of the park but also in the immediate vicinity of the borders. In addition to small hydroelectric power plants, wild, illegal construction on the territory of the park poses a threat to the park. From all of the above, we see how important it is to establish protection regimes in the protected area, but also how important it is to have spatial planning documents that will enable guidelines for the arrangement and construction of the space to be adopted. Only with strategic planning will we be able to preserve protected areas that we will pass on to the next generation.

3. CONCLUSION

The plans for the special purpose areas of the Kozara and Sutjeska National Parks provide a framework for implementing the provisions prescribed by the Law on Nature Protection, the Law on National Parks, and the Law on Spatial Planning and Construction of the Republika Srpska. Further elaboration of the provisions of the laws, prescribing rules for the organization and construction of tourist facilities and accompanying infrastructure, helps to resolve conflicts that may arise in the area due to the existence of other spatial purposes besides the dominant one. Through protection regimes in spatial plans for special-purpose areas, the impact of the dominant special purpose on other spatial purposes is considered, and the prescribed rules of organization reduce the possibility of negative environmental impact, thus providing opportunities for sustainable use of space by users. Protected areas in the territory of Republika Srpska cannot boast of the timeliness of spatial planning documents. Only a few protected areas have adopted any spatial planning documents. In the territory of Republika Srpska, according to current legislation, there are a total of 34 protected areas, including: two strict nature reserves, three national parks, seventeen natural monuments, three protected habitats, six nature parks, and three resource management areas. Out of the mentioned 34 protected areas, only one has adopted a spatial plan for special-purpose areas, and that is the Kozara National Park. Through this paper, spatial planning documents and protection zones in two of the three national parks of Republika Srpska were analyzed, and the effects of spatial planning documentation on construction in the protected area were considered. "Kozara" National Park, which has adopted the strategic document Spatial Plan of Special Purpose Areas, has drawn up implementation documents based on it and its guidelines. On the basis of the completed spatial planning documentation, the park has been facilitated in monitoring the construction within the park's borders, which has resulted in a reduction in wild, illegal construction in the park. "Sutjeska" National Park records a period of poor business, which is a consequence of the lack of spatial planning documentation. "Sutjeska" National Park does not have a single document defining construction rules. As a result of the absence of the aforementioned documentation, illegal construction is taking place, which is increasingly being recorded in the park area, especially in the second and third protection zones. There is a conscious degradation of the environment because the construction of small hydropower plants within the boundaries of the park, but near the borders, is being approved, which has a direct impact on everything that made Sutjeska a National Park. While all the countries in the region and beyond are fighting to ban the construction of small hydropower plants and to demolish the existing small hydropower plants, in our country, the green light is given for the construction of the same in a protected area. Wild illegal construction in the national parks of Republika Srpska is something that could be investigated and specifically presented through the next scientific work, which is the goal of this work. On the basis of this paper, the proportion of legally and illegally built facilities in the area of the national parks of the Republic of Srpska and the proportion of facilities that were built before and after the adoption of spatial planning documents should be assessed. The continuation of research for the national park "Sutjeska" should focus on the expected impact of the construction of small hydroelectric power plants on the environment. It is necessary to introduce certain subsidies and incentives to intensify the development of spatial planning documentation. New legislative solutions are a step further towards achieving numerous socio-economic goals through the adequate use of natural resources. Additionally, legislative support for planning and protecting natural assets and areas is necessary. Adequate planning solutions can significantly contribute to the preservation and improvement of the natural or living environment. Balanced planning principles and nature conservation policies are a prerequisite for the positive development of an area. Planning and development of protected areas should be based on existing capacities and values, and integrate them and all future planning solutions in the most affirmative sense.

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Objekat:
SPO Casa Mia

Lokacija:
Banja Luka

Bruto površina:
16.050 m²

Spratnost:
2Po+P+6+Pe

Period gradnje:
2019 - 2022

Osnovana davne 1990. godine u Banjoj Luci, Aragosta Invest je svoj poslovni put započela kao mala porodična kompanija. Od 1990. do danas, mnogo toga se promijenilo, ali ne i naša ideja vodilja – graditi kvalitet I povjerenje.

Iza nas je 400.000 m2 izgrađenog stambeno-poslovnog prostora te na desetine hiljada kvadrata objekata izgrađenih za posebne namjene, a od značaja za naše sugrađane, poput bolnica, škola, pozorišta te trgovačkih centara.

Aragosta Invest

Objekat:
SPO Casa Jelena I

Lokacija:
Banja Luka

Bruto površina:
7.676 m²

Spratnost:
2Po+P+6+Pe

Period gradnje:
2020 - 2022

Osnovana davne 1990. godine u Banjoj Luci, Aragosta Invest je svoj poslovni put započela kao mala porodična kompanija. Od 1990. do danas, mnogo toga se promijenilo, ali ne i naša ideja vodilja – graditi kvalitet I povjerenje.

Iza nas je 400.000 m2 izgrađenog stambeno-poslovnog prostora te na desetine hiljada kvadrata objekata izgrađenih za posebne namjene, a od značaja za naše sugrađane, poput bolnica, škola, pozorišta te trgovačkih centara.

Aragosta Invest

Objekat:
Južno krilo UKC RS

Lokacija:
Banja Luka

Bruto površina:
5.850 m²

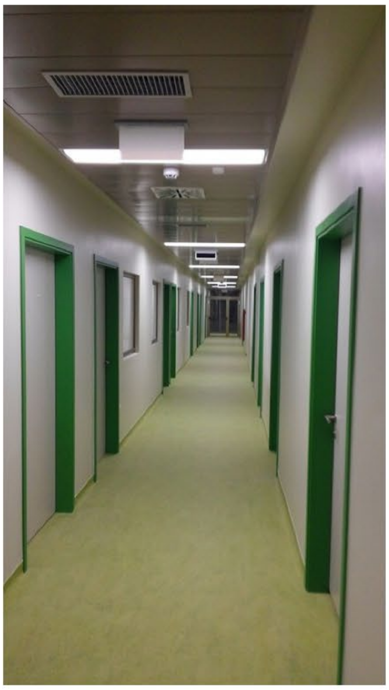
Spratnost:
Po+P+1

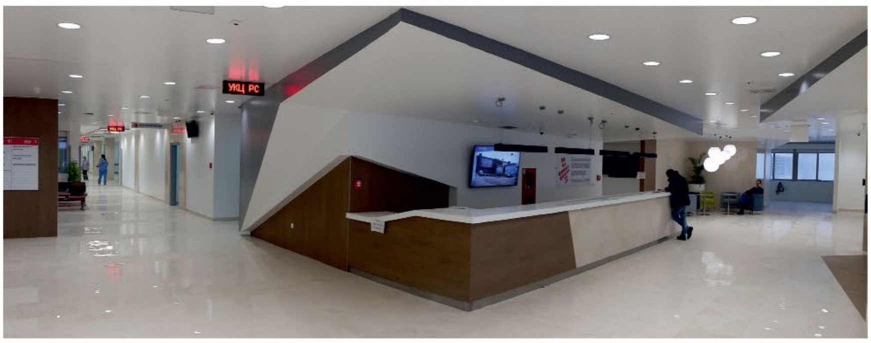
Period gradnje:
2013 - 2015

Osnovana davne 1990. godine u Banjoj Luci, Aragosta Invest je svoj poslovni put započela kao mala porodična kompanija. Od 1990. do danas, mnogo toga se promijenilo, ali ne i naša ideja vodilja – graditi kvalitet I povjerenje.

Iza nas je 400.000 m2 izgrađenog stambeno-poslovnog prostora te na desetine hiljada kvadrata objekata izgrađenih za posebne namjene, a od značaja za naše sugrađane, poput bolnica, škola, pozorišta te trgovačkih centara.

Aragosta Invest





Objekat:
RITE Ugljevik

Lokacija:
Ugljevik

Bruto površina:
1.760 m²

Bruto zapremina:
28.000 m³

Period gradnje:
2017 - 2018

Osnovana davne 1990. godine u Banjoj Luci, Aragosta Invest je svoj poslovni put započela kao mala porodična kompanija. Od 1990. do danas, mnogo toga se promijenilo, ali ne i naša ideja vodilja – graditi kvalitet I povjerenje.

Iza nas je 400.000 m2 izgrađenog stambeno-poslovnog prostora te na desetine hiljada kvadrata objekata izgrađenih za posebne namjene, a od značaja za naše sugrađane, poput bolnica, škola, pozorišta te trgovačkih centara.

Aragosta Invest

Aragosta Invest je izvođač građevinskih radova na projektu odsumporovanja termoelektrane Ugljevik. RITE Ugljevik je elektrana blokovskog tipa, koju čini jedna kotlovska jedinica, instalisane snage 300 MW. Termoelektrana proizvodi električnu energiju za čitav region (oko 8% potreba BiH), kao i toplotnu energiju za grad Ugljevik.

Izvođenje radova na izgradnji novog sistema za odsumporavanje dimnih gasova termoelektrane čine:
Izgradnja silosa krečnjaka;
Izgradnja silosa gipsa;
Objekat za prijem krečnjaka;
Objekat za mljevenje krečnjaka;

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UNIVERSITY OF BANJA LUKA

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FACULTY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY