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INTRODUCTION

We are delighted to present the latest issue of the Journal of the Faculty of Civil Engineering and Architecture. Established in 1980, this journal has undergone several transformations, evolving alongside the faculty's name to become the Journal of the Faculty of Civil and Architectural Engineering. As we celebrate the release of the 38th edition in 2023, we continue the proud tradition of this esteemed serial publication. However, this particular issue marks a significant departure from tradition as, for the very first time, we are publishing papers in English.

In this issue, we proudly showcase a selection of nine papers that were presented at the conference Synergy of Architecture and Civil Engineering – SINARG2023. This conference served as a platform for experts and scholars from various corners of the globe to converge and exchange insights at the intersection of architecture and civil engineering. We believe that these papers will contribute significantly to the discourse in the field and further the collaboration between these two closely related disciplines.

The papers included in this issue cover a wide spectrum of subjects, including the adaptation and transformation of abandoned industrial heritage buildings, a comparative analysis of test results for properties of concrete, innovative approaches to refurbishing sports halls, landslide stabilization and rehabilitation measures, a comparative study on architectural education in the Republic of Serbia, the role of fiber-reinforced polymer composites in civil engineering, strategies for improving the socio-demographic structure in rural areas of Serbia, possibilities for enhancing the energy efficiency of existing multi-family buildings, and an exploration of intelligent tools for large-scale 3D printing. These papers represent a valuable contribution to the ongoing dialogue in the fields of architecture and civil engineering.

The list of our dedicated reviewers is published at the end of this journal, accompanied by detailed formatting guidelines for authors. We invite researchers, both established and early-stage, to consider our journal as a platform for the dissemination of their valuable work. Today, as our journal becomes more inclusive than ever, we extend a special invitation to our younger colleagues, in the hope that our journal will accelerate the development and dissemination of their research.

Editor-in-chief,
Prof. Dr. Miomir Vasov, M.Arch.

Dean,
Prof. Dr. Slaviša Trajković, M.Eng.

CONTENTS

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ADAPTING AND TRANSFORMING ABANDONED INDUSTRIAL HERITAGE BUILDINGS INTO CONTEMPORARY OFFICE SPACES ON THE EXAMPLE OF PGNIG IN WARSAW, POLAND

Tadija Vasiljević[1]
Janusz Marchwiński[2]
Uroš Antić[3]

Abstract

Adapting and reusing industrial architectural heritage represents great potential for architects, conservators, and civil engineers. The subject of this research is to examine the possibilities of adapting abandoned industrial heritage, as well as to examine the conversion of former industrial structures into functions suitable to contemporary society. By interpreting theoretical foundations, this paper will talk about the importance of adaptive reuse of industrial heritage in the city of Warsaw, Poland. Analytical and descriptive methods will be used to process the chosen examples from Poland. This paper also analyses the principles of designing contemporary office spaces. As a synthesis of previous analyses, this article will elaborate on the author's conceptual design of converting a historic industrial building into a contemporary office space, as well as the visual and functional connection of the building with other structures that are a part of the industrial site PGNiG (Polskie Górnictwo Naftowe i Gazownictwo) in Warsaw. It is a historic site that produces natural gas and crude oil. The purpose of this research is to find ways to adapt industrial heritage that can meet the needs of contemporary society, but will not damage the integrity and visual identity of historic buildings, by evaluating of design proposal will on two aspects 1) the aspect od the industrial building's purpose and 2) the aspect of physical interventions. The basic results of this research suggest that it is possible to find favourable design solutions that are in line with the needs and habits of contemporary society and solutions that respect the visual integrity and architectural characteristics of industrial heritage buildings.

Key words: *industrial heritage, adaptive reuse, Warsaw, office buildings, contemporary office spaces, building transformation*

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1. INTRODUCTION

It is clear through various efforts that the recognition, valorization, and adaption of cultural heritage as one of the key supporting pillars for a sustainable, thriving European future [1]. Over the past few decades, the conversion of abandoned industrial heritage buildings into contemporary, functional spaces has gained significant attention worldwide. These buildings, remnants of the industrial era, hold immense historical and cultural value, often reflecting the identity and collective memory of a city or region. Their adaptive reuse presents a unique opportunity to preserve and celebrate architectural heritage while holding up to the evolving needs of contemporary society.

Certain qualities of industrial heritage are recognized as universal for many former industrial sights: favorable position by integrating into the central urban matrix, dimensional characteristics and constructive systems of industrial buildings enable flexibility in functional organization and provide the possibility of converting to diverse purposes, while their architecture and authentic facade elements, construction, materials and infrastructural elements bear witness to the industrial past [2]. This qualities make them suitable for adapting to different functions, and they are the reason why the conversion of such buildings is getting more popular in post-industrial countries.

Industrialization period in Poland is dated to the turn of the nineteenth and twentieth century when dynamic development of cities took place. Big scale production was developed throughout the period of partitions and continued during (till the end of) the Second World War [3]. The process of deindustrialization in Poland resulted in the abandonment of many industrial sites. Some of them are already adapted and reused, while the others are waiting for an intervention. Since its establishment in 1978, the Polish TICCIH Committee (PK TICCIH) has been supporting and initiating actions in the sphere of protection and interpretation of industrial heritage in Poland [4]. The company PGNIG (Polskie Górnictwo Naftowe i Gazownictwo) is showing interest in the preservation of architectural industrial heritage with already undertaken projects, as well as modernization of the site. This paper explores the posibilities of transforming abandoned industrial buildings into contemporary office space, using the case study of former power plant building, as well as the visual and functional connection of the building with other structures that are a part of the industrial site PGNIG. By evaluating the proposed conceptual design through various aspects, the purpose of this research is to determine wether these kind of interventions are suitable for historic industrial buildings.

2. METHODOLOGY

This research is divided into four main parts. The first part represents the theoretical background, in which the following aspects are defined:

- The definition of industrial heritage;
- Industrial development in Poland.

The purpose of dividing the theoretical background into two segments is to perceive the importance of industrial heritage as a category of built heritage, as well as to systematize the complex topic of different types of industrial buildings that the industrial development has left behind. By defining the industrial heritage through globally recognized documents (such as the Dublin Principles) and theoretical adaptation principles, a list of evaluation criteria will be derived from those documents.

In the second part, an analysis of transformed and adapted industrial buildings in Poland will be conducted. The examples are analyzed based on the following parameters;

- The location of a building;
- The original use of a budiling;
- The adapted function of a building;
- The existence of a physical intervention;
- The visibility of a physical intervention.

The purpose of this analysis is to recognize the existence of contemporary adaptive reuse practices that are widespread across the country.

The following part is the review of the conceptual design of adaptation and transformation of a building in the industrial complex PGNIG in Warsaw. It covers the following aspects:

- Historical analysis of the industrial site;
- Analysis of the existing condition of the site;
- Author's conceptual solution for the adaptation of an industrial building in terms of functional organization and design.

The division of the analysis into these three parts will help in the evaluation process, which is described in the last chapter.

The last part is the discussion chapter, where the evaluaton of the author's design proposal is conducted from two aspects:

- The aspect of the buidling's purpose (based on The Dublin Principles)
- The aspect of physical interventions (based on Danowski's industrial facilities restoration methodology)

3. THEORETICAL BACKGROUND

Industrial heritage, as an integral part of the built and cultural heritage inventory, is of great significance because it testifies about the cultural, historical, and technological development of a society, as well as the technical culture and literacy of a nation. Industrial heritage, in a form that is widely perceived today, can be traced back to the period that begins with the Industrial Revolution in the 18th century England, and relies on the phenomenon of human labor in the context of technological development [5]**.** Industrial heritage buildings can be recognized as objects of great cultural significance. However, in order to place the cathegory of industrial heritage in the globally recognized context of culture, it is important to acknowledge the institutional struggle to define the term cultural monument. ICOMOS (*International Council on Monuments and Sites*) institutionally recognizes the concept of the historic monument in 1964 [6], when adopting the famous Venice Charter that states the following '' *The concept of an historic monument embraces not only the single architectural work but also the urban or rural setting in which is found the evidence of a particular civilization, a significant development or* *an historic event. This applies not only to great works of art but also to more modest works of the past which have acquired cultural significance with the passing of time*." [7]**.** But how does the industrial heritage fit into all this? Industrial heritage has often been marginalized by the leading institutions in practice of cultural heritage protection, giving priorities to other types of built heritage [8]. However, there are attempts to systematize the built fund of industrial heritage. The Nizhny Tagil Charter was adopted in 2003 by TICCIH (*The International Committee for the Conservation of the Industrial Heritage*), and it was the first international guidance document for the protection of industrial heritage. Eight years later, the joint ICOMOS-TICCIH Principles for the Conservation of Industrial Heritage Sites, Structures, Areas, and Landscapes, known as the *Dublin Principles*, were adopted in Paris, France in 2011. This document represents the highest document on the protection and preservation of industrial heritage. Industrial heritage buildings can benefit from mindful adaptive reuse, as it is very unlikely that historic industrial buildings can meet contemporary technological needs of 21st century industries. Therefore, it is important to follow defined guidlines when adapting and transforming industrial heritage buildings. The Dublin Principles state the following when discussing adaptive reuse and transformation "*Appropriate original or alternative and adaptive use is the most frequent way and often the most sustainable way of ensuring the conservation of industrial heritage sites or structures. New uses should respect significant material, components and patterns of circulation and activity*.", as well as "*physical interventions should be reversible, and respect the age value and significant traces or marks*" [9]**.** As Danowski points out, there are two methods of restoring industrial facilities. The *puristic* method means that a building is cleaned in order to restore its original form, but with some acceptable changes that are result from a change in the function of the building. This method is applied to the most valuable buildings or to those should have a faithful reconstruction in order to highlight the prestigious or historical character of the building. The second method is the method of *active adaptation,* where the most valuable elements of the architecture are emhasized, but the dimensions of the building itself are enlarged by a construction that does not overwhelm the building [10]. This guidlines will be used as a criterion when evaluating the possibilities of adapting industrial heritage buildings .

To understand the origin of industrial heritage, it is important to understand the evolution of industrial production, which significantly differs from one nation to another. This research is focused on the industrial heritage of a specific nation, Poland to be precise, thus it is essential to review the Polish industrial development. Rosa Luxemburg [11] in her doctoral thesis titled *The Industrial Development of Poland* states that industry became widespread in Poland at the beginning of the 19th century (1820) and classified the first period of production as The Manufacturing period (1820-1850). At the end of the 19th century, as present-day Poland was a part of the Russian Empire, Kingdom of Prussia, and Austro-Hungarian Empire, a large-scale industry period has arisen due to the influence of global powers, with the 20 year transition period (1850-1870)[3]. When regaining its statehood in 1918, until the beginning of World War II that begun with the Nazi occupation of Poland in 1939, however, the country has faced severe political

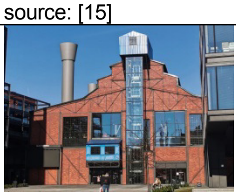
[3] This source is prone to criticism, having in mind the controversial political and ideological views of Rosa Luxemburg

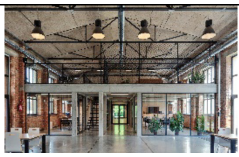
turmoil and warfare, which inevitably affected the industry. After World War II, with the shift to communist regime and socialist ideology brought the nationalization of industry, thus the revived production has actively functioned in the post-war years [12]. Socialism viewed industrial production and the industrial workers as a foundation of class struggle [13], thus the industry was thriving across Poland and the Eastern Block. The industrial prosperity in the post-war socialist years marks the third phase in Polish industrial development. However, the fall of communism in Europe took place in the late 20th century. An ideological shift, and a transition period from socialism to democracy, followed by economical unrest, marked the fourth phase in Polish industrial development – the deindustrialization process [14], which had significant proportions in Eastern Europe. Two centuries of intense industrial development have left a notable fund of industrial heritage, but due to the deindustrialization process many of those industries have been shut down, abandoned, and left to decay. The new era in Polish history, formally marked in 2004 with the accession of Poland into the European Union, has brought new views and ideas in treating historical industries, in the form of adaptive reuse and transformation. Centuries of industrial development in Poland have left a great amount of industrial buildings that can be considered a part of the industrial heritage. Various styles, forms, materials, and functions are recognized across the country. However, it is essential to systematically analyze the reused and transformed industrial buildings and have in mind the different levels of interventions on the industrial heritage in Poland.

4. ANALYSIS OF ADAPTED AND TRANSFORMED BUILDINGS IN POLAND

The analysis presented in Table 1 aims to examine the extent to which architectural practice in Poland is adapting and transforming former industrial buildings, the new functions of these buildings, and the presence of visible or invisible physical interventions on them.

Table 1. Analysis of adopted and transformed buildings in Poland

Name and architect	Photo	Original use	Adapted function	Existence of a physical intervention	Visibility of a physical intervention
Leszczynski Antoniny Manor Intervention / NA NO WO architekci.	 source: [15]	Agricu-ltural industry	Healthcare and residential complex for elderly people	Exists	Visible as an upgrade and in facade treatment
Elektrownia Powiśle / APA Wojciechowski Architekci	 source: author	Power plant	Commerci-al, office and residential complex	Exists	Visible as extensions and in facade treatment

NT Industry Polish Headquarter/ GIGAARCHITEKCI Artur Garbula	 source: [16]	Heavy industry	Office building	Exists	Visible in the interior and facade treatment
EC1 Łódź - City of Culture / Rob Krier	 source: author	Power plant	Cultural center	Exists	Visible as upgrade and in facade treatment
Headquarters of WSEIZ/ studio Archimed	 source: [17]	Factory for iron constru-ctions	University building	Exists	Visible as upgrade

The selection of adapted industrial buildings in Poland aims to demonstrate the diverse range of new, adapted functions that cater to the needs of contemporary society. In all of the chosen cases, there was a need to extend or upgrade the historical buildings to fulfill contemporary functions. The analysis of these buildings reveals that architects frequently use contemporary forms and materials to emphasize the historical and modern aspects of the construction, striving to find a balance where these two architectural approaches coexist harmoniously in a single location.

5. REVIEW OF CONCEPTUAL DESIGN OF ADAPTION AND TRANSFORMATION OF PGNIG IN WARSAW

A former gas production plant is situated at 25 Kasprzaka Street (historically Dworska Street) in the Wola district of Warsaw, Poland. It was constructed between 1886 and 1888, and in 1892, a tar distillery was opened there [18]. Initially, the gasworks included several buildings and facilities (Figure 1): a water tower, a laboratory building and experimental facility, an apparatus building, a central warehouse, an ammonia facility, a phenol plant building, system I and II desulphurization facilities, a vehicle station, a central boiler station with a chimney, and an office building [19].

Between 1886 and 1900, large casings for gas tanks were added on the side of Prądzyńskiego Street, and at the beginning of the 20th century, residential houses were constructed at the entrance to the plant from Dworska Street. In September 1939, the plant suffered significant damage, but production resumed in October 1939, though the reconstruction of the plant continued until 1944. Originally, the gasworks were owned by the Dessau Gas Society, but in 1925, they became the property of the city. Gas production at the Kasprzak plant was eventually ceased in 1978, and presently, the historical buildings at Kasprzaka Street house the headquarters of PGNiG (Polskie Górnictwo Naftowe i Gazownictwo). Furthermore, a new office building was erected at the gas plant site - the PGNiG Head Office [20].

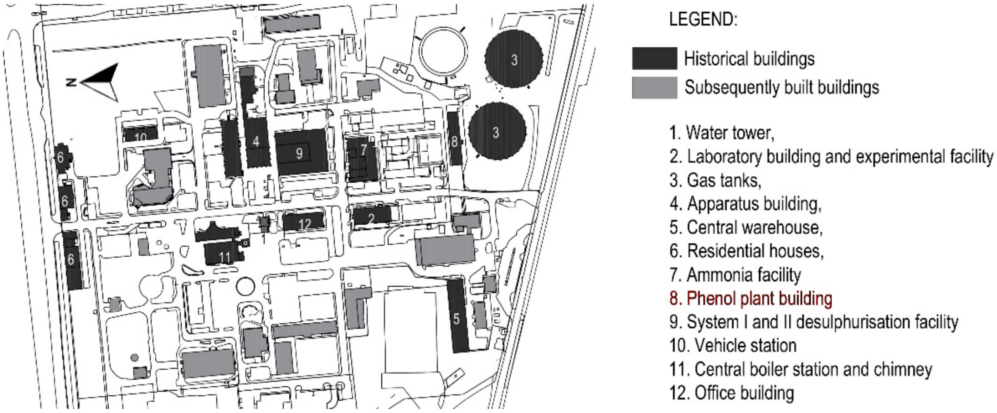


Figure 1. Current site plan, source: archive of the subject „Architectural design (II)", University of Ecology and Management, Warsaw, 2022, edited version

Table 2. Analysis of the current condition of the buildings within the site

Photo	Former use (for historical buildings)	Transfor mation/ad aptation	Current function of the building	Existence of a physical interventio n	Visibility of a physical intervention
 source: author	Gas building	No	Not in use	/	/
 source: [21]	Apparatus building	Yes	Gasworks museum	Exists	Facade refurbishme-nt
 source: [22]	/	No	Administra-tive building	/	/
 source: WSEIZ, Warsaw	Phenol plant building	No	Warehouse	/	/

In Table 2 a few examples of current buildings in the complex are presented. In situ research suggests that some of the historical buildings are revived and adapted to different functions. Despite the transformation of many buildings into different functions, some examples still remain in poor physical condition, while others have been subsequently built (see Figure 1). In the case of historical buildings undergoing revitalization, the focus is mainly on transforming them for a specific function, with only facade-level refurbishments. Subsequently built buildings are designed in contemporary styles, while still incorporating brick motifs reminiscent of the former industrial complex.

The conceptual design for the adaptation and transformation of a building within the PGNIG industrial site in Warsaw pertains to the former phenol plant building, which currently serves as a warehouse. The current condition of the building (Figure 2) reveals that it has non-historical, subsequently built extensions. The facade's brickwork is old and damaged (Figure 3), and some doors and windows have been altered. Nevertheless, the building's overall structure is well-preserved. It also retains characteristic details associated with architectural influences from classic English industries [23], such as a fully brick facade, decorative brickwork elements, distinctive arched windows and chimneys.

Figure 2, Figure 3. Current condition of the building, source: archive of the subject „Architectural design (II)“, University of Ecology and Management, Warsaw, 2022.

The task[4] of the conceptual design is to adapt and transform the building to suit contemporary administration and office space requirements. After analyzing examples of adapted and transformed buildings in Poland, as well as buildings in the industrial complex itself, the design concept foresees a visible upgrade and extension to the building to expand its capacities and improve the working conditions within the inherited structure. The concept also aims to showcase the layering of architectural practice in different time periods and is guided by the current tendency of the PGNIG complex, which aims to modernize the area while preserving and respecting the architectural heritage.

In this conceptual design, the current horizontal extension that doesn't correspond with the historical building is removed. The brick facade is refurbished, and all characteristic elements of industrial architecture are preserved and highlighted by incorporating traditional windows in damaged areas of the facade. A new horizontal extension and vertical upgrade are designed to achieve balance and rhythm in the composition while avoiding symmetry (see Figure 4). The space between the new volumes forms a terrace for formal and informal gatherings. The main materials used for the new structure are concrete and glass.

[4] This conceptual design was the subject of research for the exam „Architectural design (II) – Modernisation of Architectural Facilities“ on University of Ecology and Management in Warsaw, 2022

The building's upgrade includes large glass portals, forming double-height winter gardens within the historical buildings, introducing biophilic design into the industrial building, and providing an opportunity for abundant greenery. Green buildings not only ensure a high-quality indoor climate, including elements such as acoustic and thermal comfort, access to daylight, excellent ventilation, and access to fresh, pollution-free air, but they also have a strong influence on people's health and well-being, addressing their needs, health, and mood. Loss of direct contact with nature takes a toll on our health and well-being, leading to civilization diseases, including depression, as well as decreased productivity [24].

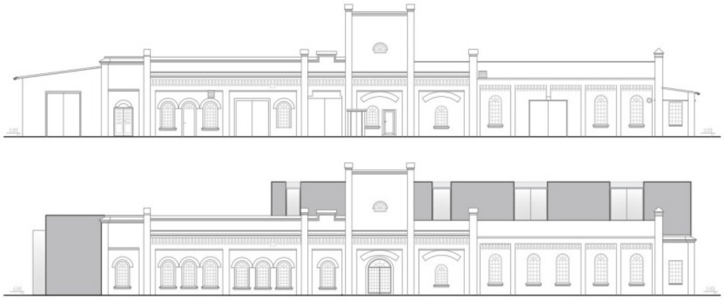


Figure 4. Current facade condition (above) and the proposed design (below), source: archive of the subject „Architectural design (II)", University of Ecology and Management, Warsaw, 2022, edited version.

The functional plan (Figure 5) provides environments that encourage informal conversations and workspace designs that provoke chance encounters. Chance encounters and spontaneous conversations among coworkers can spark collaboration, improving creativity, innovation, and performance [25]. Therefore, the authors have included spaces for informal gatherings along the corridors and a separate social room that connects to the terrace for team-building gatherings and can also be used for more formal occasions. These spaces are designed to create a more inviting atmosphere in the building. House-like offices are introduced to the design with appropriate decor, interior climate, and accessories (e.g., hair dryers and cabinets for personal cosmetics). The inclusion of shared kitchens encourages employees to cook together, and gathering rooms with comfortable armchairs and couches promote a sense of domesticity. Domestication contributes to a sense of security, reduces distance among individuals, and facilitates relationship-building, which in turn alleviates stress and positively impacts successful careers, as well as employee engagement [26]. The building is located within a large industrial site with several buildings in need of contemporary facilities. This circumstance presents an opportunity to expand the usage of the building to serve the entire PGNiG complex. The horizontal extension is utilized as an entrance and connection to the major conference room, providing toilets and multifunctional space. This space can function as a single entity, adapting to different functions depending on user needs. Additionally, it can serve as storage for chairs from the conference room, allowing the room to be transformed for various purposes. According to the research "Future of Office Space" [26], a survey of Polish citizens about their needs and wishes for contemporary offices revealed the most popular facilities desired were: inspiration classes and creative activities, spaces for yoga/fitness, and playrooms for children. The horizontal extension, either as a connection to the conference room or as a separate entity, provides the flexibility to accommodate these facilities based on the temporary needs of the staff.

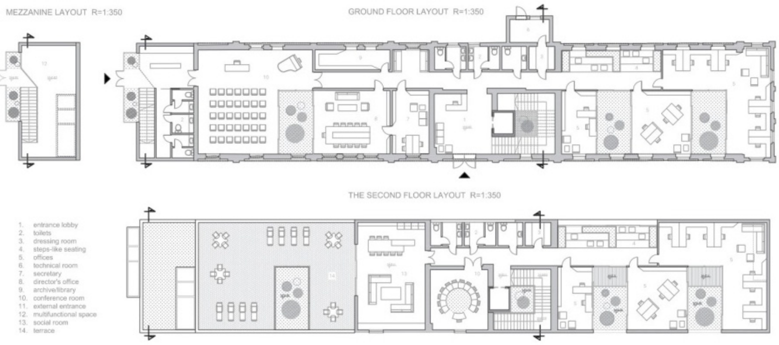


Figure 5. Proposed functional plan of the building, source: archive of the subject „Architectural design (II)“, University of Ecology and Management, Warsaw, 2022.

Figure 6, Figure 7. Visualization of the conceptual design, source: author

6. DISCUSSION

The discussion will be conducted from the aspect of the building's new purpose, defined by the Dublin Principles [9] and from the aspect of physical interventions, defined by Andrzej Danowski [10], both dicussed in chapters 2 and 3.

From the aspect refered to The Dublin Principles document, it has been concluded that converting a former industrial building into an office space benefits the sustainability and usability of the structure, especially considering the wider function of the PGNIG complex. The space is optimized for all types of collaboration, from chance interactions to large formal meetings. Conference room has the individual entrance, so it can be used not only by the workers of the budiling, but also to support the whole PGNIG complex. Neutral palette and the color of glass which is complementary to the brick color are emphasizing the historical facade. The grid pattern of the extension correlates to the original brickwork. Furthermore, the interior of contemporary office spaces is designed with light surfaces and furniture, ensuring the massivness of the brick walls to stand out as the leitmotiv. In line with The Dublin Principles state that ''*physical interventions should be reversible, and respect the age value and significant traces or marks*'' the light structures can easily be assembled and dismantled without endangering the historic structure. Minimalistic design is neutral compared to the inheritaged buidling, highlighting the details and the brickwork of historical facade These structures also stand in contrast to the inherited spaces in terms of form, scale, and materialization, thus the differentiation between old and new is easily recognized. Such approach is chosen to emphasize the original form and proportions of the building.

From the aspect of physical interventions on the building, the authors have relied on theoretical classifications by Danowski. The authors have concluded that, in the case of this buidling, it is more favorable to use the active adaptation method, as the building is surrounded by larger and more monumental industrial buildings. Also, it is up for debate wether the buildings is of great historical importance, or does it represent revolutionary achievements of Polish industrial development. Therefore, by adding contemporary extension and upgrade to the historic building, there are more opportunities for designing favorable contemporary functional organization, while the exterior is impersonating layers of arhchitectural practice over time. Contemporary extension and upgrade reffers to the intention for modernization of the PGNiG complex, which suits up with their previous interventions.

7. CONCLUSION

The discussion chapter suggests that any architectural interventions in historic structures must represent a well-balanced communication between the needs of contemporary society and the universal postulates on heritage preservation and adaptation. It proposes that it is possible to find contemporary solutions that, although built in a different style, correlate with the historical buildings, making them more suitable for contemporary urban functions. Individual proposals for the transformation and adaptation of inherited buildings should consider the historical importance of the buildings, the broader context and function of the site, as well as the needs of the users, while respecting the heritage protection framework and theoretical principles in the field of heritage management. Adopting a systematic and holistic approach in this process can greatly benefit the local community and provide sustainable spaces for contemporary cities, so it can serve as a guide on the possibilities of preserving, transforming, and reusing our collective history.

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COMPARATION OF LABORATORY AND IN-SITU TEST RESULTS OF MECHANICAL AND DURABILITY CONCRETE PROPERTIES FOR STADIUM STRUCTURE

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Abstract

One of the key issues for concrete structures exposed to weathering, besides all other loads, is durability of concrete. The most exposed concrete structures are stadiums. Destruction mechanisms for concrete structures defined by EN 1504 are: mechanical actions, chemical action, physical action, corrosion of reinforcement and fire. In this paper, the tests conducted on the case study stadium "Rodjeni" in the city of Mostar, are presented. The stadium consists of three grandstands, built in different periods, but with concrete of the same quality and class. North grandstand is 17 years old, west grandstand is 14 years old, and east grandstand was built in 2022. A series of in-situ tests to evaluate mechanical and durability properties were implemented, primarily on north and west grandstand. In addition to in-situ tests, laboratory tests were conducted on the same concrete, to evaluate mechanical and durability properties in laboratory conditions. These results are compared and presented in this paper.

Key words: *durability properties, mechanical properties, concrete, stadium*

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1. INTRODUCTION

Constructions durability is a pressing problem in construction practice today. Efforts of engineers are aimed at designing and building a structure whose durability is optimal, considering the ratio between investment and gained. It depends on the loads for which it is calculated, on the concept of encompassing the ultimate limit state and serviceability limit state, and on the reserves that the applied concept has at the beginning or during the lifespan. The durability of structures is ensured by considering the purpose of the structure, the material used, the projected service life, the maintenance program and the effects on the structure [1].

In this paper stadium "Rodjeni" in the city of Mostar, Bosnia and Herzegovina, is chosen as case study for analysis of mechanical and durability properties. Stadiums are one of the most exposed concrete structures to weathering. Stadium "Rodjeni" has been designed and redesigned several times, with multiple construction works performed. In figure 1 aerial view of the stadium is presented.

The stadium is located north of the city of Mostar and has been open since 1995. In the first years, the stadium had simple wooden and steel grandstand. Now, the stadium consists of three grandstands, built in different periods, with a total capacity of 7.000. North grandstand is 17 years old, west grandstand is 14 years old, and east grandstand was built in 2022. All grandstands have concrete of the same quality and class. The west grandstand consists of a ground floor, an upper floor and an auditorium. It is 14 m wide and 70 m long and is a combination of concrete and metal structure. The concrete pillars are followed by metal pillars, where the canopy is hung on them using tensioners. The slope of the canopy is 10%. The north grandstand consists of the ground floor and the auditorium and is not covered. The construction consists of three parts that are separated by a 5-7 cm dilation. The length of one segment is 35 m and the width is 12.50 m. The total length of the northern grandstand is 106.20 m. The construction is a combination of concrete and masonry structure. The east grandstand is similar in dimensions to the western. Their heights are the same, so the supports for the future (possible) roof are also the same.

The stadium had been analyzed several times by students and staff of the Dzemal Bijedic University of Mostar. The bearing structure is concrete, combination of beams, walls and columns, with concrete class C25/30. Walls, inner beams and columns were cast in place, and outer beams were prefabricated. The visual inspection was done, and general conclusion is that the stadium needs to be continually monitored and tested in order to apply right methods of reconstruction on time [3]. During 2022, a series of in-situ tests to evaluate mechanical and durability properties were implemented, primarily on north and west grandstand. Also, laboratory tests were conducted on the same concrete, to evaluate mechanical and durability properties in laboratory conditions. These results are compared and presented in this paper.

Figure 1. Aerial view of the stadium "Rodjeni" in Mostar [2]

2. IN-SITU TESTS

The in-situ nondestructive tests performed were: compressive strength by Schmitt hammer, concrete quality and dynamic modulus of elasticity by ultrasonic pulse velocity method, crack width by microscope. Tests were performed on the north and west grandstands, both from the outside and from the inside, on the auditorium, as well as in the interior rooms intended for offices, catering facilities etc. Beams, walls, and columns were tested. Both vertical and horizontal elements of the concrete structure were included. Specific locations were selected for testing, in order to obtain the most precise and clear results.

Used Schmitt hammer is digital in accordance with EN 12504-2 and ASTM C805. For pulse velocity method, Pulsonic analyzer is used. Ultrasound can help to detect changes in the concrete structure (cracks, nests), which results in a lower ultrasound speed. All changes in concrete are manifested through the speed of impulses. Crack width was measured using a microscope with an accuracy of 0.01 mm.

2.1. Test results

Compressive strength was tested on 24 locations on north grandstand from outside, 17 locations inside of the north grandstand, 21 locations on west grandstand from outside and 14 locations inside the west grandstand. Results are presented in table 1.

Results indicate that compressive strength for inner elements is significantly higher than for outer elements. In a way this is expected, since inner elements are protected from weathering. But, results for outer part of north grandstand are worrying low, lower than expected for concrete class. It can be observed visually that concrete elements from north grandstand have much more cracks than elements from west grandstand. This is confirmed by other tests.

Table 1. Compressive strength test results by Schmitt hammer

Measuring location	Average compressive strength (MPa)	Minimum (MPa)	Maximum (MPa)	Standard deviation
North grandstand, outer part	29,44	10,40	51,80	7,61
North grandstand, inner part	42,16	21,10	66,70	8,93
West grandstand, outer part	35,30	18,00	52,20	6,49
West grandstand, inner part	42,40	30,60	60,00	6,14

Concrete quality was tested by pulse velocity method. Changes in concrete structures are manifested through the speed of ultrasound. The equipment records time that pulse travels from transmitter to receiver, from which speed is calculated by:

$$v = {}^{L}/_{T}\ (km/s)$$
(1)

where:
L – distance between transmitter and receiver
T – time of pulse travel

Based on the speed, concrete quality can be determined by BS1881: Part 203. In addition to concrete quality, dynamic modulus of elasticity can be calculated as:

$$E_d = v^2\gamma\frac{(1+n)(1-2n)}{1-n}\ (MPa)$$
(2)

where:
v – speed in km/s
γ – concrete density in kg/m^3
n – Poisson's coefficient

Locations of ultrasonic pulse velocity test are as for compressive strength. The test results are presented in table 2.

Average pulse velocity for north grandstand is 1,915 km/s, and average dynamic modulus of elasticity is 9.509,10 MPa. For west grandstand average pulse velocity is 2,485 km/s and E_d is 15.651,35 MPa. The Pulse velocity method confirmed the results of tested compressive strength. Low pulse velocity indicates the presence of cracks, nests etc. in concrete structure, which may appear due to insufficient vibration of the concrete. Standard BS1881: Part 203 [4] grades concrete quality, and for north grandstand quality of concrete is very low (v≤2), and for west grandstand quality of concrete is low (v=2,0 – 3,0).

Table 2. Ultrasonic pulse velocity test results

Measuring location	Average pulse velocity (km/s)	Average E_d (MPa)
North grandstand, outer part	1,60	6.886,60
North grandstand, inner part	2,23	12.131,60
West grandstand, outer part	1,76	7.735,90
West grandstand, inner part	3,21	23.566,80

Crack width was measured for visible large cracks. In general, crack appearance was irregular, different length and width. Cracks labeled P1-P10 are from north grandstand, and cracks labeled P11-P13 are from west grandstand. Results are presented in table 3.

Table 3. Crack width test results

Measuring location	Average crack width (mm)	Measuring location	Average crack width (mm)
P1	2,00	P8	2,82
P2	2,98	P9	2,03
P3	2,50	P10	3,50
P4	1,97	P11	5,67
P5	2,03	P12	0,90
P6	2,33	P13	2,03
P7	2,00		

The cracks are most common under and behind the auditorium seats. They are about 3 mm wide, and they extend the entire length of the northern grandstand. From the bottom of the grandstand to the top, there are cracks on every beam. There are less cracks in the western grandstand, and only 3 that were visible were examined. Much narrower and much shorter cracks, compared to the northern grandstand.

3. LABORATORY TESTS

To determine concrete mechanical and durability properties, concrete of the same quality (eg. C25/30) and the same composition was tested in laboratory conditions. Compressive strength was tested for 7, 14, 28, 56, 90 and 365 days of age. Flexural tensile strength, absorption, draying shrinkage and carbonation were also tested. Also, samples were tested by ultrasonic pulse velocity method, to assess concrete quality with nondestructive method. Prior to hardened concrete tests, fresh concrete was tested.

Concrete was made with CEM II/B–W 42,5 N cement and local three-fraction crushed limestone as aggregate. The quantity of cement was 360 kg/m^3, aggregate was 1878 kg/m^3, with w/c ratio 0,50. In total 24 samples from three mixtures were prepared. For flexural strength and shrinkage test prisms 10x10x50 cm were used, for carbonation cylinders Ø15/30 cm, and for all other tests cubes 15 cm were used.

3.1. Fresh concrete properties test results

Fresh concrete properties were tested, and results are presented in table 4. In total three mixtures were tested, thus average results are presented.

Table 4. Fresh concrete properties

	Slump (cm)	Air content (%)	Bulk density (kg/m^3)	Temperature (°C)
Average	14,70	1,70	1.912,70	14,90

3.2. Hardened concrete properties test results

Test results of flexural strength, absorption and bulk density are presented in table 5.

Table 5. Results of flexural strength, absorption and bulk density

	Flexural strength (MPa)	Absorption (%)	Bulk density (kg/m^3)
Average	9,95	2,76	2.319,00
St. dev.	0,187	0,059	3,60

Compressive strength was tested for 7, 14, 28, 56, 90 and 365 days of age. Results are presented as average in figure 2. Drying shrinkage test results are presented in figure 3.

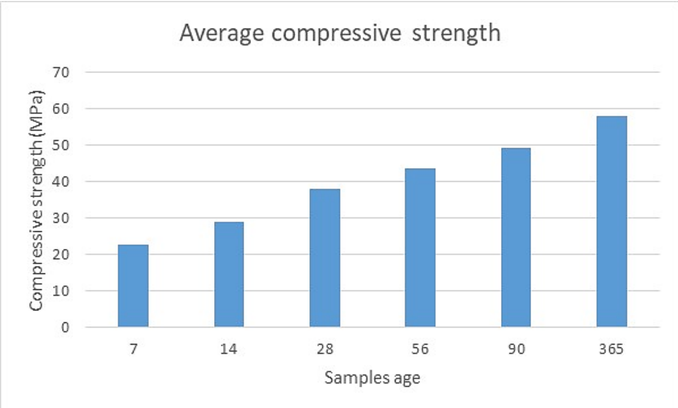

Figure 2. Average compressive strength test results

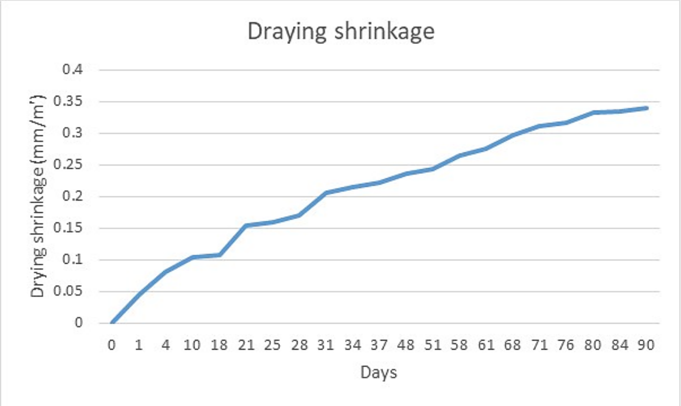

Figure 3. Drying shrinkage test results

28-days compressive strength reached expected values of about 38 MPa, and end values (90 and 365 days of age) reached about 50 MPa and 60 MPa. The final value of drying shrinkage is 0,34 mm/m', and is reached after 90 days of measures. After that, the results stagnate.

Carbonation was tested on samples 365 days of age. They were preserved outdoors in natural environmental conditions. A solution of phenolphthalein was used, sprayed on the concrete surface to detect the loss of concrete alkalinity, which is directly related to carbonation, in accordance with EN 13295 [5]. Samples were cut in half and then tested. The results are presented in table 6, and the test method in figure 4. In table 6 also are presented average pulse velocity obtained by the same method explained in 2.1 and dynamic modulus of elasticity.

Table 5. Average results of carbonation, pulse velocity and dynamic modulus of elasticity

	Carbonation (mm)	Average pulse velocity (km/s)	Average E_d (MPa)
Average	5,50	3,895	31.738,11
St. dev.	1,303	0,186	2.962,88

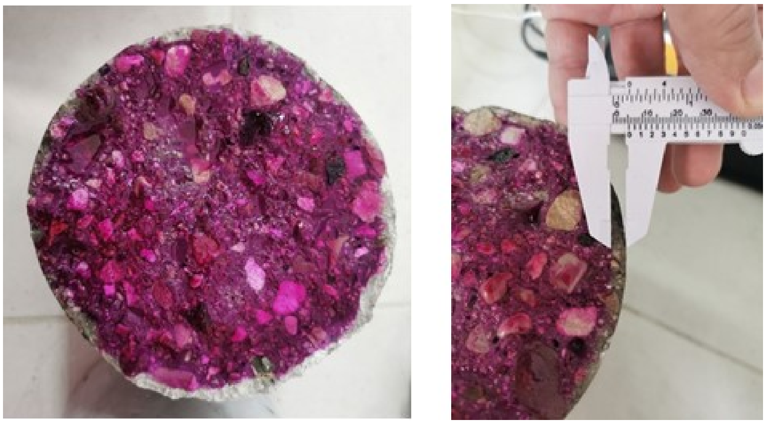

Figure 4. Measuring carbonation of concrete

4. DISCUSSION AND CONCLUSION

From the results of laboratory tests, it can be seen that prepared concrete reached strength of C25/30 concrete class. 90-day and 365-day compressive strength test results are as expected, about 50 MPa and 60 MPa, respectively. Concrete quality tested by ultrasonic pulse velocity is 3,895 km/s and is classified as "good" (v=3,5 – 4,5), according to BS1881: Part 203. Average dynamic modulus of elasticity in laboratory conditions was about 32 GPa, which is also expected for this concrete class. After 365 days of preserving the samples, average carbonation reached only 5,50 mm.

In-situ test results showed a slightly different situation. External elements of north and west grandstand showed lower compressive strength than inner elements. Inner elements have similar compressive strength for both grandstands. Test results for pulse velocity e.g. concrete quality follow the same pattern. The concrete quality of external elements for north grandstand is the lowest. Concrete quality of inner elements is higher for west grandstand compared to north grandstand. Although the north grandstand is older than west grandstand, the age difference is small to be a factor for difference in concrete quality. Poor concrete quality of elements from north grandstand can be the result of insufficient concrete curing and vibration.

On the other hand, this does not mean that whole elements are of the same quality. Sampling is needed to confirm these results by destructive tests. The visible deteriorations need to be repaired, but they do not affect construction load capacity and stability. Attention should be given to elements with small or no concrete cover for reinforcement.

The paper tends to emphasize the importance of quality control (laboratory and in-situ) during the construction process, from all parties involved. Construction durability can be significantly affected if the construction processes are not respected. This is especially visible for constructions exposed to weathering, which accelerates all degradation processes.

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REFURBISHING INNOVATIVE STRUCTURES: THE CASE OF ROMANIAN SPORTS HALLS

Ruxandra Balcanu[1]

Abstract

This paper brings an in-depth look on 20th-century built heritage by researching refurbishment opportunities for Romanian sports halls built during the communist regime.

In those times, sports played a significant role for the controlling party's general propaganda machine. Being a leisure activity it infiltrated every aspect of society, from the worker's everyday schedule to the newly constructed collective buildings.

Sports halls were part of a larger and thoroughly controlled by the state urban equipment network spanning the entire country. After the fall of the communist regime, these buildings were left untouched and unused, as the sports phenomenon diminished in importance without the state's constant implication.

Even so, these buildings continue to impress evincing some innovative features for that period, from braided steel cables to post- or pre-stressed concrete beams and prefabricated systems for the whole construction. The synergy between the structure and the architecture casts the unique monumental image of these buildings onto their surroundings.

The research investigates the opportunity for refurbishment and reuse of these buildings as opposed to the demolition alternative. We will look in their future by comparing several case studies.

Besides its historical approach, the study aims at bringing forward the communist recent built heritage issue.

Key words: *Romanian sports halls, sports complex, prefabricated structures, modern movement, 20th century heritage*

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1. INTRODUCTION

The 20th century heritage poses a great deal of controversy - while scholars consider it valuable and important for the history of ones culture, the public opinion tends to have an opposite idea. This exactly same problem is faced by the sports halls built during the communist regime.

This article is based on the continuing research for the Phd thesis, “Architecture and sport in the communist Romania”. The thesis follows the development of architecture for sport alongside the communist regime. Beside researching the recent heritage of the 20th century, the main purpose of the study is to bring some light on the built urban spaces of Romanian cities and help us understand how we should relate to these kinds of buildings built under special requirements during a dictatorial regime.

In the first part of the article we will present the general context in which these sports hall were built, emphasising the link between sports and the communist regime. In the second part of the article we will present multiple case studies that follow three sports halls built in the 70s in Romania. These case studies were chosen from a number of 48 sports halls built all over the country on criteria regarding their use of structure and engineering to create architecture and the general aesthetic.

In the third part of the article there will be presented the state of these buildings today and their nowadays issues. This is important as the refurbishing opportunities for these kind of buildings are influenced by the public opinion.

2. SPORTS AND THE COMMUNIST REGIME

The relation between modern sport and urban space was formed since the 19th century and the beginning of the modern movement. Sport was also a very popular interest after the First World War as parts of Europe started to lean down the totalitarian path. Some interesting research on this direction was made by Michael Hau considering the case of sport and its use in Germany’s discourse during the inter-war period [1]. Europe was weak, and the general conception was that it needed healthy people to recover economically from the losses generated by the war. Thus, sport was on every country’s agenda during that period. Beside that, totalitarian regimes included sport in their programs because it was an effective and efficient way to control the masses beside its genuine potential as everyday life entertainment.

As stated in official documents [2], after the rise to power of the communist party in 1945 Romania, influenced by the URSS’s model formed in more than two decade experience with sports and the masses, sport became an important tool of the propaganda.

Even if sport was already an important leisure activity in the Romanian society, the communist party made a step forward and in the next 40 years, until it’s fall in December 1989, sport and sport development became a constantly promoted topic into all society levels - from working class to children and students, everyone was practicing sports one way or another[3].

In this context, the existing sport equipment was deemed insufficient, so architects were commissioned with the task of developing the national major sports endowment network[2].

Another important worth mentioning fact is the drastic change of architecture practice from a liberal one to an institutionalised activity while the main beneficiary was the state. Through this the communist party was in charge with everything that was being built all over the country, especially if the destination of the building was of national importance [4].

At first, in the 50s, the main sports construction were mainly open football arenas set in newly made parks which were called “parks for culture and sport”. These areas were also featured with small sports fields and sports halls for performance athletes training.

During the 60s and 70s near the already constructed sports areas of the cities, new urban equipment was being added, under the form of sports halls.

Sports hall were mainly big spaces that could accommodate a significant number of people for a sport spectacle. Of course, their use expanded the sports realm, and they were used for any large organised gathering. Because of their big openings, sports halls became quickly a challenging project for both architects and engineers.

After a lot of research in terms of functions and economical solutions, the researchers from The Institute for Typified Buildings, came up with various solutions that could be implemented in the urban areas. It is important to mention that these solutions were mainly concerning the interior and the exterior of the buildings - the public space and how the building communicates with the surroundings wasn’t something they would solve for a long time. Even so, these studies were gathered in two catalogues of projects [5] and most importantly, were being built.

For the smaller and less important cities, the officials would choose typified projects that would solve the problem of big openings with the most economical solution, as this was the main concern of the communist party - the best solution was the cheapest one. In the same time, in important cities such as Bucharest, where this kind of urban equipment was more important for the fame of the city, the authorities would use an unique project, particularly made for that city [4].

Further we will present some of these unique projects that are still part of the urban fabric and most importantly, they are still used by the communities for different competitions.

3. SPORTS HALLS - THREE CASE STUDIES

For the analysis of these three case studies we followed their unique project, looking at how the structural part of the buildings are the one that create the architectural image. Just as in the 19th century metal and glass architecture made by engineers, here also their contribution was significant and important for the final aesthetic of the building.

The majority of these buildings made use of pre or post-compressed concrete systems, prefabricated elements, tie beams, cables and moving stands. Because of this, at the time of their building, they were considered breakthrough structures and they were presented at various international conferences, such as the 7th

Congress of The International Federation for Pre-compression that took place at New York in 1974 [6].

3.1 Galati's sports hall

The first project presented is a sports hall located in Galati, a South Eastern Romanian city situated on the main lower course of the Danube River. Even if it was a big city in the inter-war period, Galati had its biggest upsurge as it became an important industrial centre during the communist regime when its population increased up to the level of the 5^{th} largest city in Romania.

Similar to other important cities of Romania, during the 50's ad 60's – Galați experienced rapid industrial growth developing an important shipyard and the biggest steel factory in the country [7]. The rest of the city was developed as a "dormitory" for the workers with tall collective housing and cultural buildings such as the "House of Culture" and The Sports Hall.

Figure 1. Galati's sport hall in 2019, outside image. Source: author's gallery.

Sports played an important role for the communist regime as it was one of the instruments used to control the masses keep them busy during their free time in this case.

Starting from the importance of the city in the the country's economic scheme, these new functions were developed after unique architectural projects. The main sport zone of the city was developed in its southern outskirts that were constantly growing as new collective housing were being built [4]. The centre resided in an open football arena built in the 50s, the sports hall, an olympic swimming pool, a gymnastics hall and several training fields for tennis and basketball. This sports complex was developed alongside a park benefitting from related leisure activities.

As no programmatic document survived, we can only guess the initial intention for grouping these assets together was to create a local centre for the neighbourhood following a promotion to an important asset for the entire city.

Figure 2. Detail of the main facade. Source: author's gallery.

Figure 3. Interior of the sports hall - the public foyer. Source: author's gallery

The sports hall from Galati was built in 1971 for 2000 people and it consists of two adjacent volumes – the main volume represents the main public entrance and the playing field with stands while the secondary volume is reserved for athletes locker rooms and related functions. The main volume is an 45 metres wide square plan parallelepiped [8].

The iconic image of the sports halls is generated by the pre-stressed concrete exoskeleton, the metallic structure of the ceiling being hunged from this interlocking concrete frame. The main facade, the one that is oriented to the main public space is also decorated with three volumes destined for the radio-TV transmission stations that protrude in a sculptural manner.

The interior of the sports hall hosts 2000 people in the stands for handball and other sports competitions that require the whole field and the capacity of the hall grows to 3500 people during boxing matches.

Beside sports related events, the hall can also host conferences or concerts as the interior was finished with special acoustic treatments.

3.2 Pitești's sports hall

The second case study focuses on the Sports hall built in Pitești, another important industrial city of Romania located North of the capital city Bucharest.

The case of Pitești is similar to the one before. During the communist period the industrial part of the city experienced a flourishing development and the city population grew. Beside industrial development, architects focused on collective housing and socio-cultural urban equipments. In Pitești, sport areas were developed in multiple neighborhoods. The polyvalent sports hall that we will present was built according to the design made by architect Ion Mircea Enescu together with a team from The Institute for Typified Buildings (IPCT) [12].

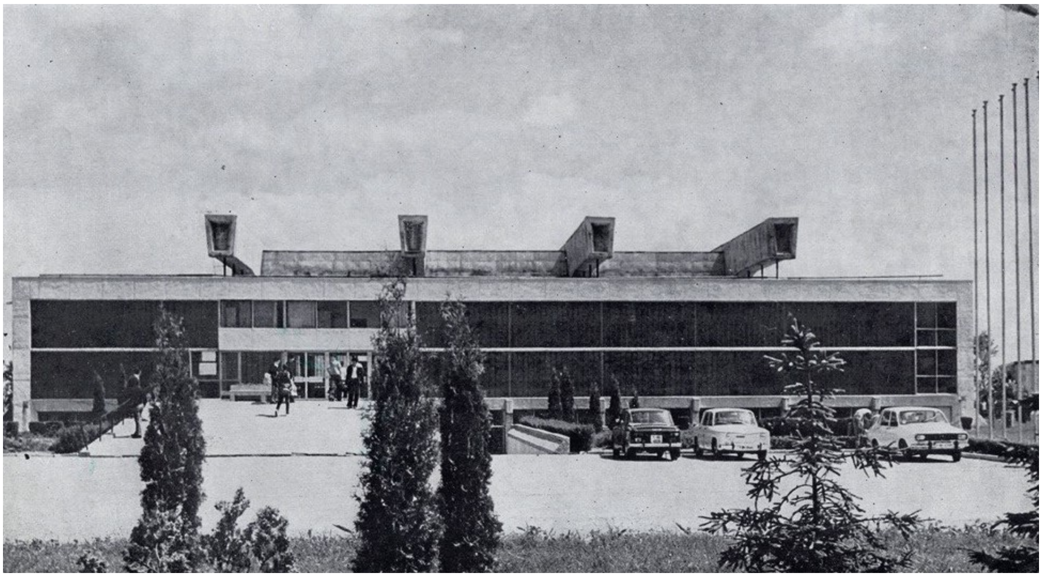

Figure 4. Pitesti's Sports Hall, main facade, source: Architectura RPR, nr. 1-2, 1978, p.22.

The design team was commissioned to study and develop various designs for sports halls suiting the needs of the growing cities thus the halls should be able to expand their capacity and also be suitable for different kind of sports such as handball, volleyball, boxing or judo matches. Furthermore, considering their significance for the urban landscape, they should also be used for conferences and concerts, entailing the importance of the interior space acoustics. After numerous studies, Ion Mircea Enescu and his team developed four types of sports hall designs that were build in various cities of Romania. Each one of them represents an experiment with space and structures [9].

The Pitesti Sports hall was positioned in the sports park, near a football arena and other urban sports equipment, in the South-East part of the city.

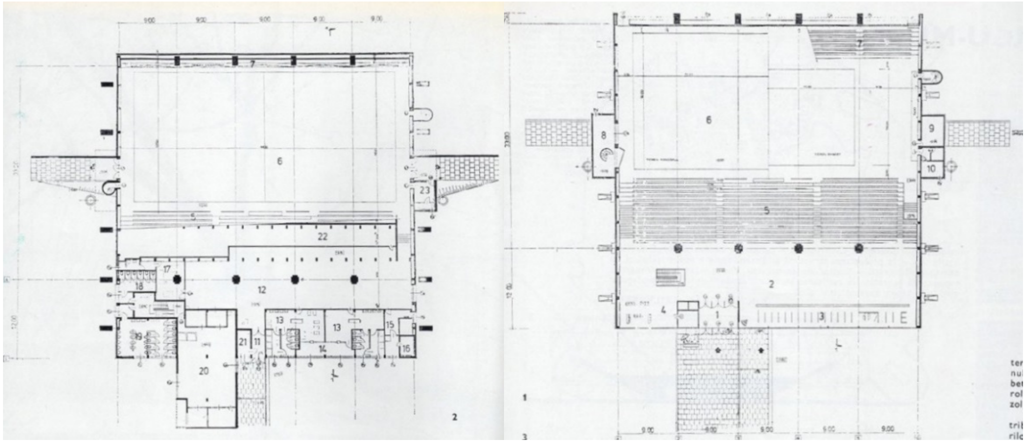

Figure 5. Playing field plan and public stands plan, source: source: Architectura RPR, nr. 1-2, 1978, p.24.

Figure 6. Public entrance detail, source: https://www.uniuneaarhitectilor.ro/arhiva-ion-mircea-enescu

The project consist of a single building that can accommodate between 1300 and 2000 people. Making use of the natural terrain, the final construction has a smaller height as it is buried 1,30 m. This way the main public access is made at the superior level of the stands through an exterior platform. The athletes' locker room, are being accessed down on a secondary ramp descending under the main public hall. This way the space under the hall’s stands is used at its maximum capacity.

The structure of the building consists of four main prestressed concrete frames with tubular section with a 33 meters opening and a cantilever of 12 meters. From these structural frames the 9 meters prefabricated concrete "TT" elements of the terrace roof are suspended on twisted steel cables. The plan is a perfect square with 46 meters sides encompassing all spaces within its perimeter.

The main structure of the roof dominates the exterior image of the hall, creating an interesting aesthetic that will later become a rule for this type of buildings. The silhouette of the building is defined by simple yet strong elements. The considerable size of the prestressed concrete structure determined the architects to keep them outside the main building. This way, much more spectacular buildings are generated than the classic ones with internal structure.

The two accesses in the hall are perpendicular on the longer side of the playing field, which means that the stands are accessed from only one side. On the other side of the playing field, a series of removable steps were arranged, which allows for expanding the halls' capacity for conferences, concerts or other sports that don’t require the use of the whole field. To allow hosting of special events the interior of the hall received acoustic treatments.

3.3 Iași Sports Hall

The third case study follows the sports hall built in Iași, located in the extreme Eastern part of the country. The design bares also architects' Ion Mircea Enescu signature together with his team from The Institute for Typified Buildings (IPCT) as it is part of the sport equipment research that the institute was assigned with.

Beside the sports competitions hosted by the sports hall, the big openings and large capacity makes them suitable for other crowd gathering activities such as conferences or concerts. It was in Iași the architect used for the first time in Romania moving stands - a system that would accommodate a bigger crowd when needed. The Iași sports hall has a capacity between 2000 and even 4000 people for ring based competitions [6].

Figure 7. Iași’s Sports Hall, period image, source: Architectura RPR, nr. 1-2, 1978, p.30

For this sports hall the main structure consists of three median prestressed concrete pillars that sustain with an articulated system three longitudinal prestressed concrete beams. These beams sustain the linear elements of the roof - 12 meters prefabricated concrete beams. The logic of this structure creates two large open spaces - one for the playing field and the stands and the second one for the public entrance spaces. Beside its aesthetics, the economical part of this structure is important, as prefabricated elements pre-made off site were a consistent part of the structure.

According to the architect, the construction site had a fast development and the structure of the roof had a quick installation as a consequence of the great number of prefabricated elements that were used.

The simple volume of the hall is once again dominated by the exterior structure. Beside this, the exposed concrete finishing, ventilation routes, both external and internal, participate in defining the volume and simple envelope of the hall, offering an austere shape that became the norm for this kind of buildings. Beside this, we must consider that these buildings were created during the 60's and the 70's, a period dominated by the Japanese Metabolism and the George Pompidou's Arts Center from Paris, references that were quite popular even in a closed society such as communist Romania.

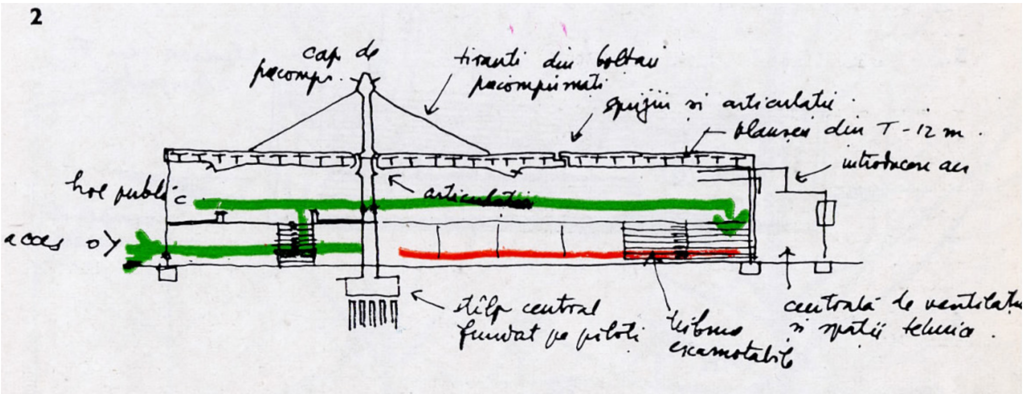

Figure 8. Sketch made by the architect, source: Architectura RPR, nr. 1-2, 1978, p.23.

4. REFURBISHING OPPORTUNITIES

All these halls are part of the todays urban fabric along with qualities and defects they are part of the recent cultural heritage which should not be marginalized just because it was built in the communist period.

As it is the case with the rest of the sports urban equipment all over the country, a very important network of the period, these sports halls were left behind in the years following the 1989 fall of the communist regime.

In this context, the sports halls still hold an central place in the urban network. Beside that, their qualities, some of which were presented above along the three case studies, promotes them as important cultural icons. the only problem resides in the perception of today's society of these buildings and its capacity to continue using them.

As an example, the sports hall from Galati stood unused until 2013 when an important refurbishing process took place. Before this it was in a continuing degraded state. Since then, the sports hall is continuously used for different sports competitions, concerts or fairs. Also the public space in front of it is used for winter fairs and various large gatherings.

Even if in todays time the requirements for such sporting venues changed, and in many cities, even the ones that were presented here, new sports halls were built after the latest necessities [10], the main idea would be that these already existing sports halls should be refurbished and used as much as possible.

Beside their cultural importance, their continuous use has also an economical part - because these buildings are ones with special structures that usually cost more, using existing ones should have less impact on the budget.

The other two sports halls presented here didn't have the same chance as the one in Galati. The sports hall from Iasi is threatened with demolition, as it occupies an important place in the continuously developing city, even if the hall is used on a current basis by the local handball team.

Meanwhile the sports hall of Pitesti isn't under the same threat, but the original facade were changed and it's general appearance was negatively affected. Since nothing irreversible happened there is still time to make things better.

Another current problem these sports hall are facing is caused by the initial beneficiary and owner of these buildings - the National Council of Sports and Physical Education under the Ministry of Culture; after the fall of the communist regime, they remained under the same centralised system, local authorities laking the power over their usage. As it is a generalised problem with most public buildings from that period, investments in these kind of buildings are only made with the implication of the National Council for Investment.

5. CONCLUSIONS

It is important to consider that today's Romanian cities are tributary to their development from the communist era. An overwhelming percentage of the population lives in communist collective housing gathered in neighbourhoods developed during that period [7]. Therefore, understanding the period's architecture and encompassing it in the present project is an important part of further developing the cities.

The issue of the 20th century heritage is a rather new topic of discussion in Romania, especially regarding buildings from the communist regime. even if 50 years have passed since their construction, these sports halls are still seen as communist edifices that should be rather demolished as they present no value to the nowadays society.

Fortunately, more and more scientific research is focused in the recent years on buildings from the communist regime, as people started to understand their value.

Thus, these buildings continue to impress evincing some innovative features for that period, from braided steel cables to post- or pre-stressed concrete beams and prefabricated systems for the whole construction. The synergy between the structure and the architecture casts the unique monumental image of these buildings onto their surroundings.

Their importance as innovative structures and their use of prefabricated concrete elements as well as their general appearance is what makes the case for including them in the 20th century heritage category.

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LANDSLIDE STABILISATION AND REHABILITATION MEASURES ON THE REGIONALEN ROAD R-1202 MAVROVO - DEBAR, NORTH MACEDONIA

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Abstract

Tectonic displacements, terrains with cracked and decomposed rocks, climate change and intense rains are the main factors that cause the emergence of new geological processes. These phenomena can cause damage to road infrastructure facilities. Such a phenomenon is registered on the regional road R-1202 Mavrovo-Debar, in the western part of North Macedonia, where on one of the lanes on the side of the slope there is a subsidence of the road construction. In this paper measures for stabilisation and rehabilitation of the landslide on the regional road are presented. This particular terrain is characterised by steep slopes, and in addition to the terrain instability reasons stated above, there is an inadequate maintenance of the drains and canals that are a part of the road structure. Therefore, the problem has been studied and recommendations are given for stabilisation and rehabilitation measures. The proposal is to build a structure to relocate and strengthen the unstable zone consisting of a slab founded on piles that will transfer the load to the lower layers. For this purpose, two software programs are used: "Slide", which analyses the stability by boundary equilibrium methods, and "Plaxis 2D", which is used to calculate deformations and straining. According to the results obtained from "Slide", the safety factor value F_s = 0.988 proves that the slope is not stable and there is a need for slope reinforcement, as well as rehabilitation of the road with reinforced concrete slabs and piles. While the design of the technical solution is simulated in several phases, according to the obtained results it is concluded that valid results are obtained from the last phase of exploitation and the maximum deformations U_{tot} = 14.23 mm are shown and they occur in the pile capping beam. The horizontal and vertical displacements are 4.50 mm or 14.13 mm accordingly. Hence, the conclusion is that the steps taken for stabilisation and reconstruction of the landslide on the road Mavrovo - Debar meet the project-exploitation requirements.

Key words: *landslides, stabilisation measures, safety factor, deformations*

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1. INTRODUCTION

Torrential rains, large temperature changes, tectonic shiftings, as well as the composition of the terrain with steep slopes with cracked and decomposed rocks are the main factors that cause the occurrence of modern geological phenomena: erosion, landslides and the like. Landslides are phenomena of instability, i.e. sliding of soil masses that most often occur on steep slopes and are of great importance in shaping today's relief map.

Inadequate road maintenance and untimely intervention after the landslide's occurrence, especially those occuring in places easily accessible to humans, can cause various material damage and also human losses. Therefore, there is a real urgent need to assess and repair potential unstable zones that have favorable slippery conditions. The most common reason for the occurrence of such geological processes is the inadequate human activity through road construction on unstable soil terrains.

This paper develops solutions for landslide remediation located on the regional road R-1202 Mavrovo - Debar, chainage km 43 + 100 (Fig. 1). It is a route with lots of pronounced problems when it comes to slope stability. This can be a case due to a poorly built road, inadequate drainage of atmospheric waters, tectonic movements and similar.

Figure 1 Landslide on the regional road Mavrovo-Debar

One of the possible solutions for remediation of an unstable zone is through indirect reinforcement of the landslide with the help of reinforced concrete piles and pile capping beam [1-2]. Two analyses were performed, i.e.:

1. Slope stability analysis;
2. Geostatic analysis of the terrain in which the structure is founded.

Global slope stability is analysed in “Slide” software to determine the critical slip surface and the safety factor. The geostatic analysis is performed in “Plaxis 2D” software and includes analysis of stresses and deformations in the substrate during four stages of performance. The analysis refer to the most critical cross section of the geological profile, with the highest height and the steepest slope.

2. GEOLOGICAL AND GEOMORPHOLOGICAL CHARACTERISTICS OF THE TERRAIN

The terrain, subject to this analysis is hilly - mountainous. In one part there are green grassy areas (pastures), and in the other part of the terrain, above the road and below it, there is a forest with low-stemmed and tall-stemmed trees. In the zone of unstable slope, the terrain has an average altitude of 650 m.

The geological structure of the terrain (Fig. 2) is defined on the basis of previous research (according to the Elaborate for geotechnical field research and laboratory tests at the location of a potentially unstable zone on the regional road R1202 Mavrovo - Debar), engineering geological mapping and based on conducted exploratory drillings.

Figure 2 Geological structure of the terrain

Based on that, it was concluded that in the geological construction of the exploration area there are: chalks, flysch sediments built of sandstones, clay shales and aleurolites, on which limestone lies. In the surface part there are deluvial creations that are a product of surface physical-mechanical decomposition of rock masses under the action of external (atmospheric) influences [3]. On one part of the slope, a crushing material was found, which was knocked down from the upper parts of the slope and settled on the slope itself. Also, on part of the terrain, presence of embankment material was ascertained, which probably originates from the excavation of the slope during the construction of the road, as well as from slope's landslide cleaning.

Therefore, the geotechnical profile (Fig. 3) is composed of:

- Flyshoid sediments: on the investigation area they form the base of the field and other lithological units lie above them. They are represented by layers of sandstones, clay shales and aleurolites;
- Limestones: lie perpendicular to the flysch sediments, as smaller or larger masses;
- Deluvial works: they are found on the very edge of the road slope and in the background of the terrain. They are made of raw pieces of crushed limestone material mixed with a finer clay component;
- Waste (deposited) material: in a large part of the investigation area, primarily on the slope under the road, there are thick layers of crushed material deposited during the construction of the road. The material is a mixture of flysch sediments and the limestone above them.

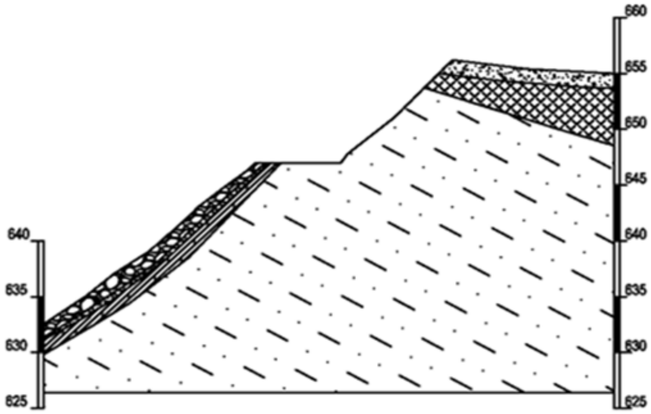

Figure 3 Geotechnical profile

The following table (Tab.1) shows the geomechanical parameters used in the analysis:

Table 1. Geomechanical parameters of materials

Material	Volume weight γ [kN / m^3]	Cohesion c [kPa]	Internal friction angle ϕ [°]
Flyshoid sediments	20	25	31
Compact flysh	23	33	33
Limestone	24	85	40
Diluvium	19	25	25
Spilled material	21	6	36

3. NATURAL SLOPE STABILITY ANALYSIS

Examination of slope's stability is one of the most complex problems that appear in the geotechnics. One of the most important steps in analysing the stability of a slope is to determine the sliding surface with the lowest safety factor [4-5]. Slide software was used for this purpose and the global and local slope stability were calculated using the Bishop method. The geomechanical parameters of the soil were used, adopted in Table 1.

Analysis was performed in static and seismic conditions with $K_h = 0.1$ and $K_v = 0.05$. According to the current regulations for slope stability, the safety factor for static conditions should be greater than 1.5, and in seismic conditions should be greater than 1.1. On the assumption that two freight trucks would diverge, the load would have had intensity of 33.33 kN/m^2. Fig. 4 and Fig. 5 show the critical slip surface together with the calculated safety factors, i.e. $F_s = 0.988$ under static conditions and $F_s = 0.842$ under seismic conditions.

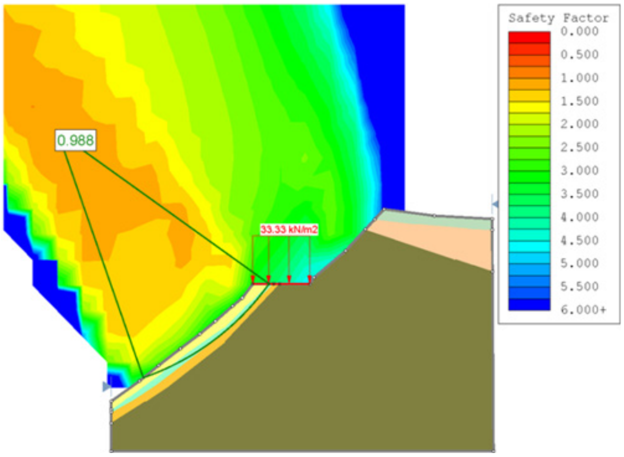

Figure 4 Critical slip surface with safety factor F_s = 0.988 in static conditions

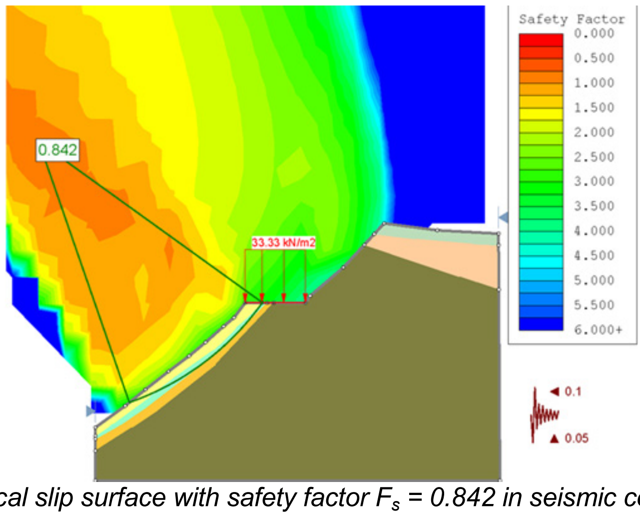

Figure 5 Critical slip surface with safety factor F_s = 0.842 in seismic condition (K_h = 0.1 and K_v = 0.05)

Based on the obtained results, it is concluded that the global stability is not satisfied, i.e. the safety factor in static conditions is $F_s = 0.988$ ($F_s > 1.5$) in a situation when the value 1.0 is a labile equilibrium. It is proven that the slope is not stable and there is a landslide.

4. GEOSTATIC CALCULATION

The calculation of the deformations and stresses in the surrounding environment, as well as the displacements of the overpiles structure, is done through a geostatic calculation in the "Plaxis 2D" software. A two-dimensional analysis of the plane state of deformations is performed where the ground as a continuous medium is approximated by the Mohr-Coulomb model. The time dependent behavior of the soils is simulated in several stages, i.e.:

- Phase I: initial condition;
- Phase II: performance of piles;
- Phase III: construction of pile capping beamand
- Phase IV: exploitation of the structure

The ground is defined by its physical-mechanical, strength and deformable characteristics shown in Table 2:

Table 2 Physical - mechanical, strength and deformable characteristics of the ground

Material	Flyshoid sediments	Compact flysh	Limestone	Diluvium	Spilled material
Volume weight γ [kN/^{3}]	20	23	24	19	21
Volumetric weight (water saturated) γ [kN/m^3]	21	24	25	20	22
Modulus of elasticity E_{ref} [kN/m^2]	25000	50000	50000	15000	20000
Cohesion c[kPa]	25	33	85	25	6
Internal friction angle ϕ [°]	31	33	40	25	36

While the figure 6 shows the computational mathematical model with the generated network of finite elements.

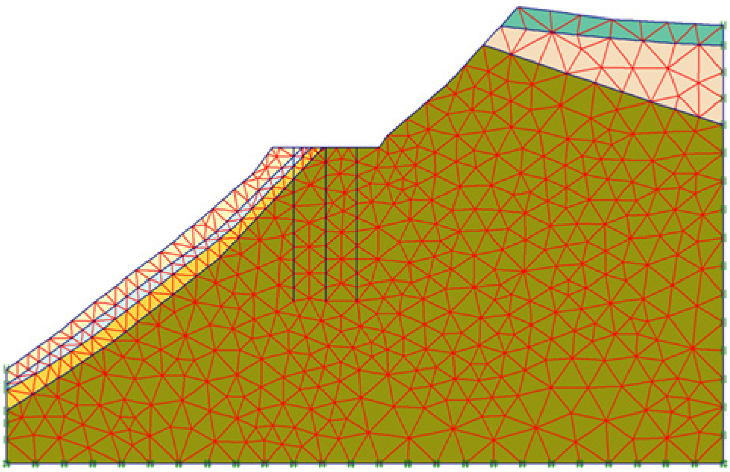

Figure 6 View of the generated network of final elements

From the initial state, it can be seen that the obtained critical sliding surface shown in Figure 7 coincides with the sliding surface from the analysis performed in "Slide". The obtained safety factor is F_s = 0.988. The small difference in the values of the safety factor between the two analyses is due to the different calculation methods used by the two softwares, i.e. the finite element method and the boundary equilibrium method.

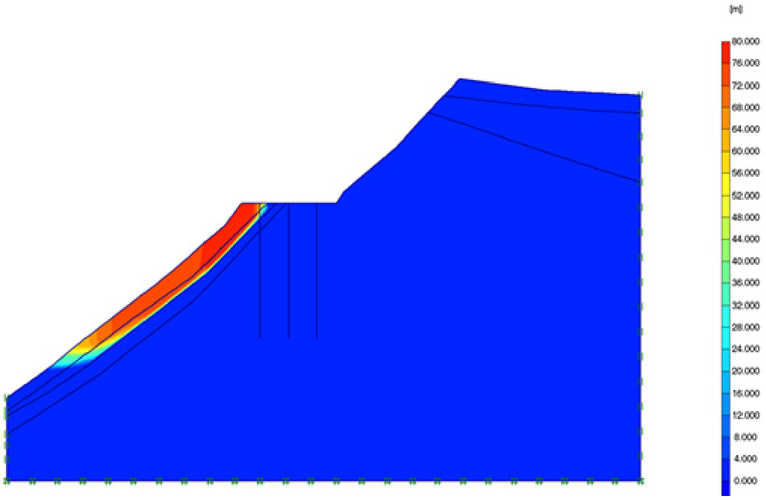

Figure 7 Critical slip surface view

The second phase simulates the performance of reinforced concrete piles modeled as line elements with an equivalent thickness of 0.431 m. The total deformations that occur at this stage are shown in Figure 8 and as expected, the maximum subsidence occurs on the slopes on the side of the slope with the value of U_{tot} = 9.06 mm.

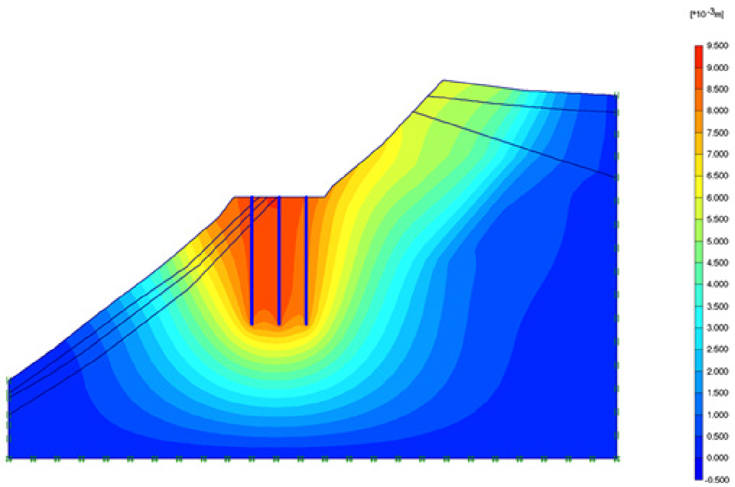

Figure 8 Total deformations of the second phase: U_{tot} = 9.06 mm

In the third phase, a steel reinforced concrete slab is simulated, modeled as a line element with a thickness of 0.50 m. There is a slight increase in subsidence of +1.36 mm due to the own weight of the pile capping beam as per the values obtained from "Plaxis 2D". The obtained results are shown in Figure 9.

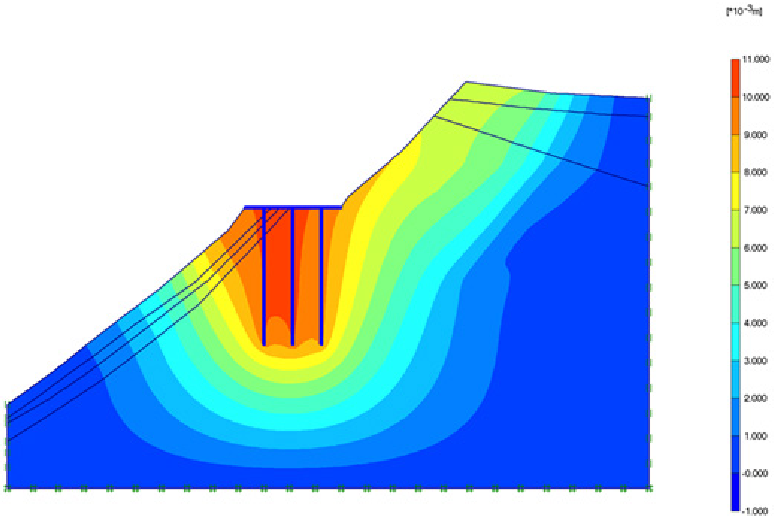

Figure 9 Total deformations from the third phase: U_{tot} = 10.4 mm

In the fourth phase, the fully constructed assembly is simulated and put into use. Therefore, the pile capping beam is loaded with an evenly distributed load with an intensity of 33.33 kN/m^2. The maximum deformations from the conducted analysis are just above the slope, on the left edge of the pile capping beam valued U_{tot} = 14.23 mm. The results are shown in Figure 10. The global stability of the landslide in the section where the construction of piles and retaining wall is above F_s = 1.6.

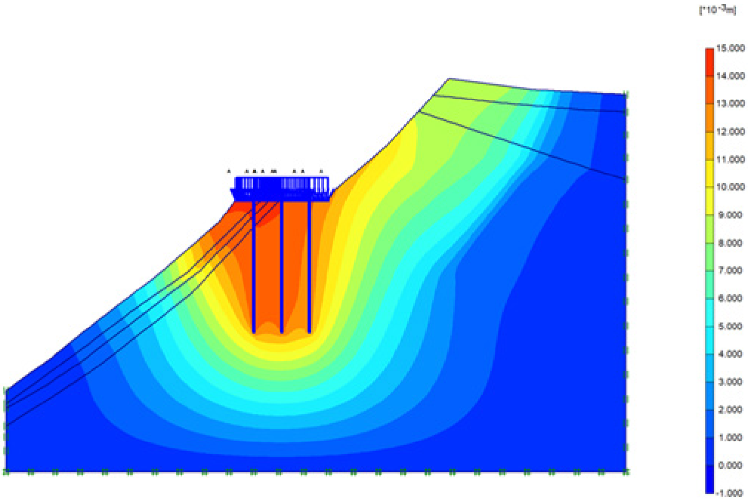

Figure 10 Total deformations from the fourth phase U_{tot} = 14.23 mm

5. CONCLUSION

In this paper, one variant for rehabilitation and stabilization of the regional road's R1202 Mavrovo-Debar landslide is presented. The solution is not a direct remediation of the landslide, but its indirect reinforcement with the help of the piles that serve as a foundation for the slab.

The performed analyses refer to the most critical cross section of the geological profile, with the highest height and the steepest slope.

The dimensioning of the reinforced concrete elements is finished for the limit load capacity and in accordance with PBBA (Handbook of practice for concrete) all controls are satisfied. As expected, the maximum deformations occur in the leftmost row of the piles and the leftmost edge of the pile capping beam. As atmospheric influences are one of the main causes for the occurrence of the landslide in question, special emphasis is placed on ensuring successful drainage of the structure itself during its life span.

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A COMPARATIVE STUDY ON ARCHITECTURAL EDUCATION IN THE REPUBLIC OF SERBIA

Olivera Dulić[1]

Abstract

Architecture plays a vital role in the development and transformation of societies, serving as a crucial component that requires highly skilled professionals. Architectural education holds immense significance as it plays a pivotal role in equipping students with the essential knowledge, skills, and competencies needed to meet the demands of the architectural profession. The particularity of teaching architecture lies in applying a unique learning model called design studio, which is entirely different from traditional forms of university education in its methodology. The research presented in this paper is a preliminary and exploratory study of teaching architectural design skills at academic institutions in the Republic of Serbia. To make an overview of the current situation in the field, the research uses the methods of document analysis and desk-based curriculum review with the aim of comparative assessment of the established structure of study programs. The research results presented in this paper represent the first step towards a comprehensive investigation of learning and teaching architecture in Serbia. Researchers still do not consider this topic adequately and systematically, although our country has a tradition of educating architects for almost two centuries.

Keywords: *Architectural education, Architectural pedagogy, Design studio, Studio methodology, Curricula comparison*

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1. INTRODUCTION

The field of architecture is a critical component in the development and transformation of societies, requiring highly skilled professionals. Architectural education equips students with the necessary knowledge, skills, and competencies to meet the profession's demands. This paper presents a comprehensive comparative study on architectural education in the Republic of Serbia, intending to assess the current state and identify areas for improvement.

Boyer and Mitgang [1] state that education in various fields of design (architecture, landscape architecture, interior design, graphic and industrial design) provides a model for cultivating critical, synthetic and creative thinking. As a vital element of this form of teaching appears the *design studio*, which promotes critical and creative problem solving – a concept recognised in the literature as *design thinking* [2]–[7]. Traditionally, the design studio is considered the most crucial component of the educational program in architecture schools. As such, students are expected to understand, present and defend design ideas and acquire new techniques and skills [8].

In the last few decades, universities and schools of architecture have invested significant efforts in improving design education, with the primary intention of enriching the purely artistic vision of architecture through the insertion of scientific knowledge and social responsibility [9]. In support of the turmoil in the development of architectural education, Wang [10] also confirms that a change in how teachers articulate their epistemology and methodology is necessary. It is precisely in this that the research presented here finds its justification and foundation.

The research presented in this paper is exploratory, examining a selection of architecture schools in the Republic of Serbia and comparing them regarding the curricula directed toward teaching architectural design skills. Being a preliminary study, this paper attempts to recognise and highlight patterns and trends in architectural education in our country, particularly the part addressing teaching architectural design skills. Furthermore, this paper presents a first step toward a better understanding the research problem and suggests further research needed in this field.

2. LITERATURE REVIEW

It is essential to establish a solid theoretical framework for local research whose results cannot be easily generalised. In addition to the theoretical framework defining the basic concepts in the field of study, it also provides an overview of related research. Furthermore, it enables discussion of the results, which become significant and valid.

Any discussion of architectural education, whether at a general or specific level, should consider the views expressed in the Charter for Architectural Education prepared by the International Organization of Architects. Therefore, this theoretical background shall find its basis in the general objective of architectural education, as stated in this Charter: "Architectural education develops the capacity in students to be able to conceptualise, design, understand and realise the act of building within a context of the practice of architecture which balances the tensions between emotion, reason and intuition, and which gives physical form to the needs of society and the individual" [11, p. 6].

There is a growing body of literature on general principles of architectural education. In a seminal paper [12], Farivarsadri analysed the pedagogical dimension of introductory design education. This paper highlights the objectives of this education, the course content and the methods used. Furthermore, it proposes a critical, participatory, and student-centred introductory design education framework. Öztürk and Türkkan [13] emphasise the importance of the design process itself as a methodological tool in architectural education. According to these authors, the process-based approach to architectural education allows the possibility of addressing elusive issues that underlie design practice. In [14], the authors investigated the theoretical aspects of the design studio and provided a theoretical framework grounded in the systematic knowledge of the mutual relationship among design, human environment and social practice. A more recent paper by Soliman [15] proposed appropriate teaching strategies for the architectural design process in design studios. The author offers a theoretical and practical approach to managing design studios in the research.

A significant study by Ghonim [16] applied analytical methodology in analysing the components of architectural competencies and investigated a sample of thirty undergraduate architectural programs worldwide. The methods presented in this paper are pivotal for the subject research. In another study [17], the same author recognises that its components and course structure should be analysed and categorised to analyse an architectural program. Furthermore, Ghonim draws our attention to the fact that the classification of these components may vary according to the perspective and intentions of each study.

A comprehensive study of architectural education in Australasia [18] provided the first detailed overview of architectural schools, curricula and students across Australia, New Zealand and Papua New Guinea. This book describes architectural education's historical, political, and cultural characteristics and outlines methods, patterns, and approaches for studying and teaching architectural discipline. Additionally, this research summarised many findings over the following categories: the curriculum, the design studio concept, methods of assessment and evaluation and the resources used in teaching [18, pp. 172–174]. Based on this very complex and meaningful study, we can see how the learning and teaching of architectural design should be observed and studied in the Republic of Serbia and eventually in the entire territory of the Western Balkans.

The first investigations of trends in architectural education in Arab countries are presented by Salama and Amir [19]. This study primarily investigates how architectural education in these countries is aligned with contemporary trends and guidelines indicated by the international community. After the presented results, this study suggests improving architectural education and respecting Arab culture and tradition. The mentioned study's importance is finding a way for the local interpretation of the general principles of architectural education.

Finally, a group of authors conducted a comparative study addressing sustainability in architectural education [20]. Although the research presented below does not deal with the concept of sustainability, the mentioned work is significant because of the methodological approach and how the architectural curricula were analysed.

3. METHODOLOGY

Architectural design skills are a part of the syllabi of numerous higher education institutions in our country. These institutions vary from strictly architectural schools through art faculties and then faculties of civil engineering, both of which focus a component of their study program on architectural design courses. Apart from the academic higher education institutions, courses with architectural design content also appear in the curricula of higher professional studies.

Taking into account the scope of the present paper, the content presented focuses solely on the architectural education programs that grant an academic qualification for registration and practice of architecture. In the Republic of Serbia, there are five such higher educational institutions, and their name, associated universities, level of study and other introductory data are given in Table 1. For the sake of clarity of the text, in the following, these institutions will be referred to by acronyms that are shown in Table 1 in the final column.

Table 1. Basic information on the higher education institutions that are the subject of the present research

	Name of the educational institution	Associated university	Study programme	Level of study	Duration of study (in semesters)	Number of newly enrolled students	Acronym in the following text
1	Faculty of Architecture	The University of Belgrade	Architecture	undergraduate / integrated	8/10	240+64	**ARHUB**
2	Faculty of Technical Sciences	University of Novi Sad	Architecture	undergraduate	8	120	**FTNARH**
3	Faculty of Civil Engineering and Architecture	University of Nis	Architecture	integrated	10	160	**GAFARH**
4	Faculty of Technical Sciences in Kosovska Mitrovica	University of Pristina	Architecture	undergraduate	8	40	**KMARH**
5	Department for Technical Sciences	State University of Novi Pazar	Architecture	integrated	10	60	**DUNPARH**

The study presented in this paper is of a preliminary and explanatory nature. It represents the first step in a comprehensive survey of architectural education on the academic level in the Republic of Serbia. The study adopts a comparative research approach, utilising quantitative methods. Data collection involved a review of existing literature and an analysis of curricula from five educational institutions presented in Table 1. The collected data was analysed to identify architectural education patterns, trends, and discrepancies. To be completely objective, all information is obtained from each institution's published media on their respective websites.

Once the schools are selected, their curricula are studied from the quantitative perspective on two levels. First, the proportion of courses dealing with architectural design for each year of study and for each school is established using descriptive statistics and Microsoft Excel software. Then, the total number of courses related to architectural design in the entire curriculum for each school is determined again using descriptive statistics and the same software. Finally, the proportion of ECTS credits for architectural design courses is determined concerning the total number of ECTS credits.

The nature of the present research requires the application of qualitative research methods for results to be fully valid and reliable. Applying qualitative methods enables a deeper analysis of the preliminary results obtained by quantitative methods. However, due to limitations in the paper's length, only the research's quantitative aspects are presented here, while the qualitative aspects will be published elsewhere.

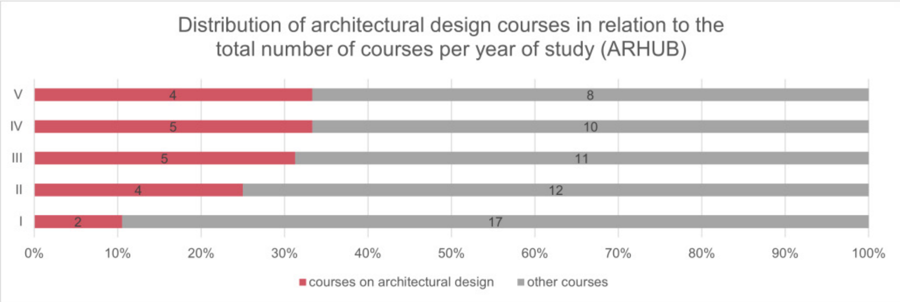
4. RESULTS AND DISCUSSION

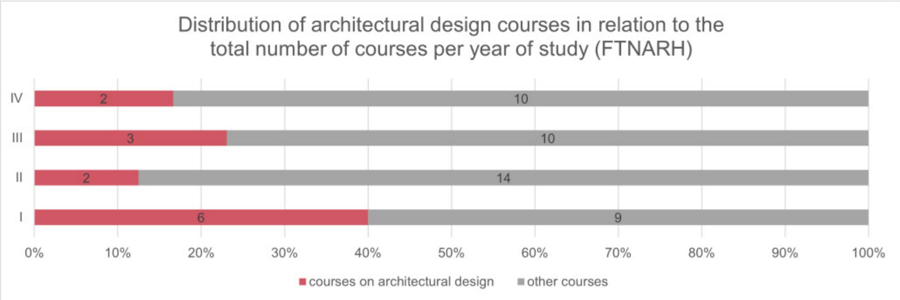
This section will present the results obtained by the previously described methods. After delivering the results, each will be interpreted and discussed in a broader context. At the end of the discussion, the results will be summarised, and guidelines for further research will be presented.

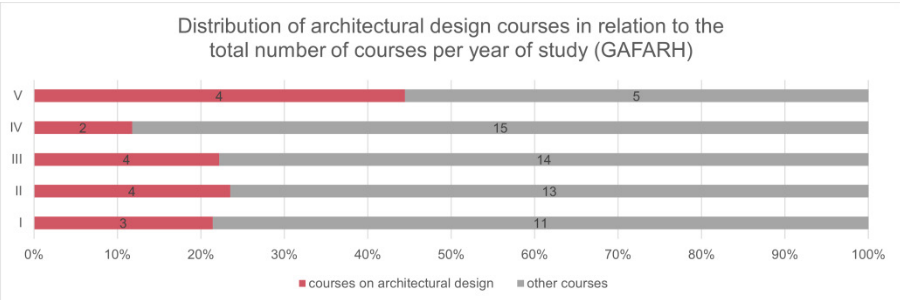
Before further analysing study programs, we will investigate Table 1, which shows the academic institutions offering study programs in Architecture. As Table 1 shows, Architecture studies are offered at five different schools and universities in the Republic of Serbia. It is also noticeable that undergraduate academic studies, lasting eight semesters (240 ECTS), and integrated academic studies, lasting ten semesters (300 ECTS), are equally offered in our country. Based on the information on the enrolment of new students available on the websites of these university institutions, enrolment for a total of 684 students was announced in the upcoming 2023/24 school year. Out of the 684 newly enrolled students, the number of state-funded enrolments at these five faculties is 417. According to publicly available data [21], the total number of state-funded enrolment places in all study programs of undergraduate and integrated studies at state universities in the Republic of Serbia in the upcoming 2023/24 school year is 17,882. Based on this, we can notice that architecture first-year students occupy only two per cent of the total number of state-funded enrolled students in the new school year. Considering the importance of the architectural profession to society, this is a relatively small share.

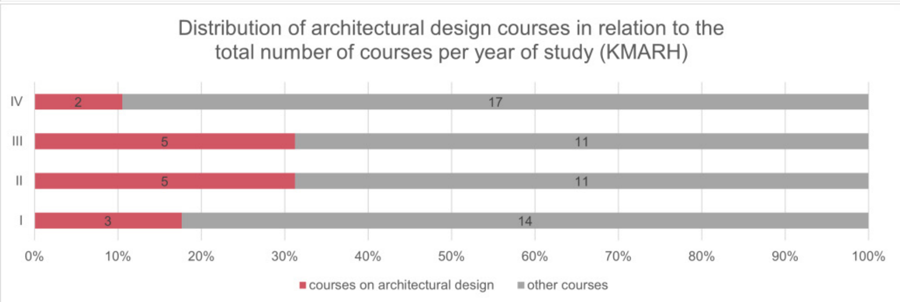
The primary results of the curriculum comparison of the five analysed architecture schools are given in Figure 1. Each of the five graphs shows the ratio of courses directed towards architectural design proportionate to all other courses per year of study. The year of study is indicated on the left side in Roman numerals from the highest to lowest. Furthermore, the percentage of architectural design courses in relation to all other courses is given.

As we can see in the graphs shown in Figure 1, the rate of courses related to architectural design ranges from 10 to 45 per cent. At the same time, we can see that the distribution of courses on architectural design per year of study does not follow the same pattern at each school. FTNARH (graph 2) has the largest number of architectural design subjects in the first year of study, while in the last year of study, that number is highest at GAFARH (graph 3). In other schools, the largest number of architectural design courses appears in the middle of the study program.









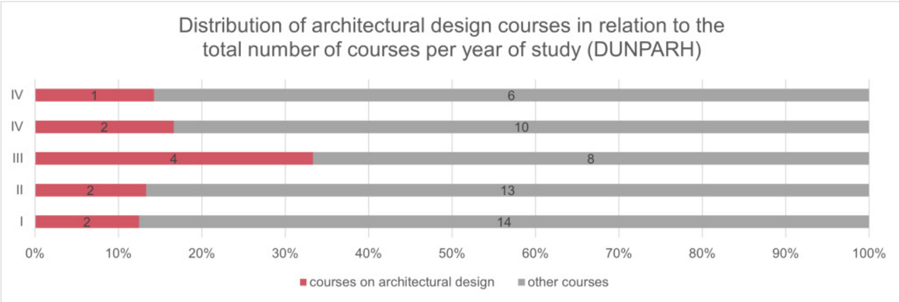


Figure 1. Distribution of courses on architectural design in proportion to the total number of courses per each year of study at the five observed study programs, source: Author

Overall, the largest number of architectural design courses appears at ARHUB (graph 1). That number is almost constant throughout all years of study, while the lowest number of architectural design courses is at DUNPARH (graph 5). We can generally conclude from Figure 1 that courses on architectural design are present in all years of study in all schools and that their percentage is approximately 25 per cent in relation to all other courses. As stated in the literature [16], design courses represent the spine of architectural education, where students apply all of their knowledge and skills. In this context, the question can be raised whether the students from our country are overloaded with other courses, while courses on architectural design, undoubtedly the most important, occupy only a quarter of the content in the analysed curricula. This is a very interesting primary result, thus further qualitative and quantitative research is needed to offer a reliable and valid explanation for this critical issue.

After consideration by year of study, the overall curricula were considered. Figure 2 (left) shows the summarised results from Figure 1, i.e., the share of the courses related to architectural design in the total number of courses for the entire study program for undergraduate or integrated academic studies for each of the five analysed architecture schools.

The results shown in this way best illustrate the facts already evident from Figure 1, namely that the courses on architectural design occupy 18% to 26% of the total number of courses in the studies. The largest number of courses related to architectural design appears at ARHUB – 26% (graph 1, left), while the lowest is at DUNPARH – 18% (graph 5, left). The number of courses related to architectural design in comparison to all other courses at the remaining three schools is almost equal and amounts to 23% at FTNARH (graph 2, left) and GAFARH (graph 3, left) and 22% at KMARH (graph 4, left).

It is well-known that students' academic load is expressed in the ECTS points or credits. ECTS stands for *The European Credit Transfer and Accumulation System* and is a European Higher Education Area tool for making studies and courses more transparent [21]. Since 60 ECTS credits are equivalent to a full year of study, the faculties we looked at have a range of ECTS points from 240 to 300, depending on whether the studies are undergraduate or integrated academic studies. Even though the level of studies differs, we were able to investigate and show the share of courses on architectural design in the total academic load of the students expressed through ECTS points. With this analysis, significant and exciting results were obtained, shown on the right side of Figure 2.

First of all, what can be observed, even by a cursory inspection of the right side of Figure 2, is that the courses on architectural design have a more significant share in the number of assigned ECTS credits compared to the total number of courses. This percentage ranges from 27% to even 40%, hinting at the importance of architectural design courses in architectural education. The largest share of ECTS points belonging to courses from the domain of architectural design is evident at ARHUB (40% – graph 1, right). It is essential to mention that this faculty also had the largest share of architectural design courses in the curriculum, as previously described. Also, this institution enrols the largest number of students (see Table 1). This result is followed by FTNARH and KMARH with 33% and 32%, respectively (graphs 2 and 4, right).

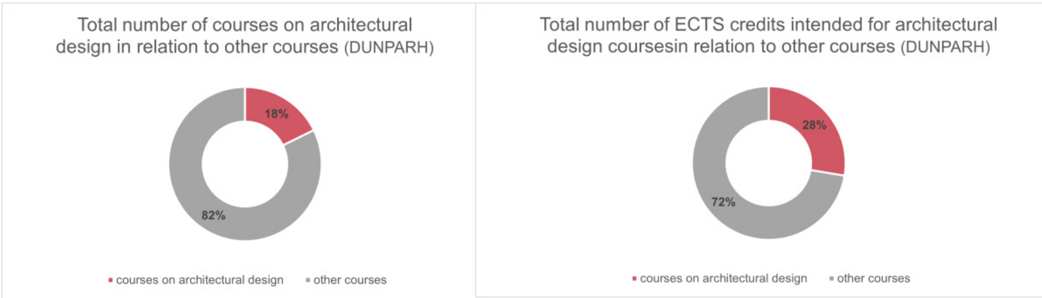


Figure 2. A summary of the total number of courses on architectural design in proportion to all other courses for the entire study program (left); A summary of the total number of ECTS credits for courses on architectural design in proportion to all other courses for the entire study program (right), source: Author

The smallest share of ECTS points intended for courses on architectural design is present at DUNPARH – 28%, followed by GAFARH – 27%. As stated in the literature [15], student work is most heavy on design courses, and therefore each course must be carefully developed to ensure that students are not overloaded. For example, the same significant research states that a design course with six credits means more than 21 hours of work per week of the semester [15, p. 25]. Therefore, these results potentially indicate that architecture students in our country are overloaded and overwhelmed by the amount of work needed to finish their studies. The fact of student overload is also recognised in the literature [15], [18], [22]. However, we must remember that the present research is preliminary, and it may still be too early to draw such sharp conclusions.

Based on the preliminary quantitative results presented in this paper, there is a clear need for a comprehensive study of architectural education in the Republic of Serbia. In terms of the direction of future research, several topics can be highlighted that would be interesting to the research community that deals with the issues of architectural pedagogy. First, based on the presented research, the curricula should be further examined to establish the distribution of courses that develop future architects' basic competencies, knowledge, skills and design. This model of architectural competencies is well established and already described in the literature [16], [23]–[25].

Then, as emphasised several times throughout the paper, it is necessary to examine the content of the courses dealing with architectural design in the Republic of Serbia more deeply. Qualitative research would make it possible to establish whether our country's approach to teaching architectural design is homogeneous or heterogeneous. Also, qualitative research would confirm whether there is a dominant methodology for teaching architectural design skills. Finally, it would be useful to examine architectural education from the perspectives of teachers and students, which is the author's plan for future research.

5. CONCLUSIONS

This research represented the first step in studying architectural pedagogy in the Republic of Serbia. A solid theoretical framework has been established that enables linking the results with the international context. Also, the methods that should allow the realisation of such a complex undertaking are presented. Bearing in mind the importance of architecture for society, both in the past, present and future, it is entirely legitimate and justified to direct the attention of the academic community to the importance of research in architectural pedagogy.

Preliminary results that potentially indicate an imbalance between the importance of architectural design courses and their position in the curriculum in our country direct attention and emphasise the necessity of further studies.

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THE ROLE OF FIBER-REINFORCED POLYMER COMPOSITES IN CIVIL ENGINEERING

Ivana Drobnjak[1]

Abstract

Fiber-reinforced polymer (FRP) composite material is a relatively new material that can be used in different types of engineering. Due to its attractive mechanical properties, it has been widely used for decades. The properties mentioned enable worth-mentioning achievements in aerospace, the aircraft and automotive industries, civil engineering, sports equipment, and marine infrastructure.

FRP composites have evolved from being special materials to common engineering materials used in a wide range of applications in civil engineering. This paper covers the advantages and limitations of their use and various possible applications of FRPs in the field of civil engineering, emphasizing different opportunities for strengthening, repairing, or retrofitting reinforced concrete (RC) structures. The main aim is to highlight the importance and possibilities of using FRP composites.

The outcomes of this paper summarize the potential of this composites for continual integration into constructions, especially RC structures, as well as the obstacles that prevent designers from using this material to its full potential. This paper can be used as an overview of the main FRP properties, a source of different references in which a reader can find more detail about the mentioned polymers, and a basis for gaining basic knowledge about this kind of modern composite material.

Key words: *Fiber-reinforced polymer composite, civil engineering applications, retrofitting of structures, reinforced concrete*

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1. HISTORY OF COMPOSITES

In general, composite materials are manufactured as a combination of at least two materials, which together form a new material with improved properties.

The use of composites dates back to ancient times. In 1500 B.C., Egyptians and Mesopotamian settlers used a combination of mud and straw to build strong and durable buildings, [1].

The first composite bow was invented by the Mongols in 1200 AD. They combined wood, bone, and natural resins derived from plants and animals to form pressed bows wrapped with birch bark.

Simultaneously with the development of plastics in the early 1900s, the contemporary era of composites began. Reinforcement was needed to provide additional strength, rigidity, and durability for composite structural applications because plastics alone could not provide enough strength.

In the 1930s, Owens-Corning launched the first glass fiber, and the modern era of the use of fiber-reinforced polymers (FRP) started. In 1938, high-performance resins like epoxies became available.

World War II catalyzed many notable developments and benefits in composites. Beyond being lightweight, which was a principal in military aircraft, engineers discovered that fiberglass composites are transparent to radio frequencies. After World War II, composites were introduced into other industries.

The first carbon fiber was patented in 1961, several years before it became commercially available. In 1966, DuPont chemist introduced an aramid fiber, [2].

Over the next twenty years, composites played a significant role in breakthroughs in aerospace components, sporting equipment, medical devices, and other applications, Figure 1.

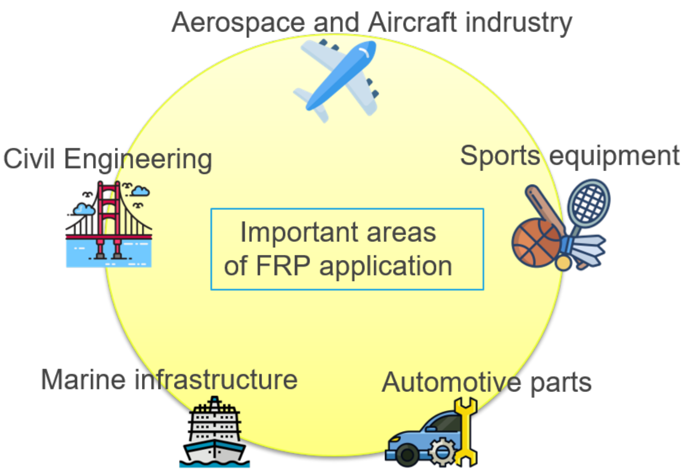

Figure 1. Fields of use of composites

The development of this material is still rising with a focus on sustainable, lighter, and environmentally friendly components.

A timeline of the history of composites is shown below in Figure 2.

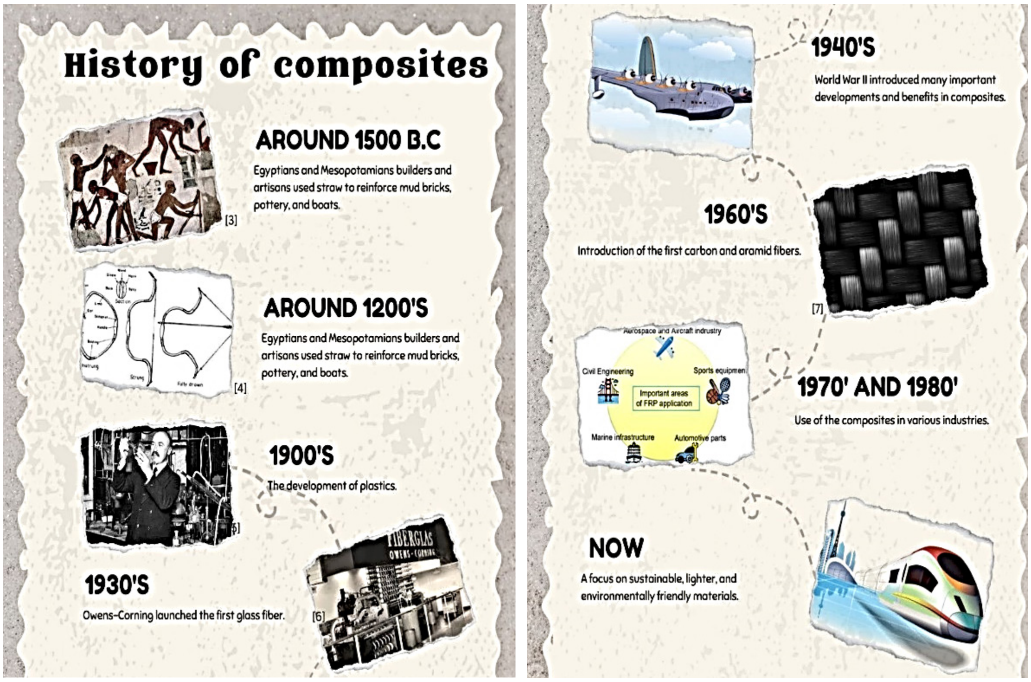

Figure 2. Timeline

2. CHARACTERISTICS OF FRPS

Fiber-reinforced polymer composites are made of two components: thin fibers that are embedded in a specific matrix (metal, ceramic, or polymer), [8], Figure 3. Epoxy resin is a widely used polymer matrix in FRPs. It is characterized by notable adhesive properties along with its strengthening ability. The matrix holds fibers together in order to form the desired shape. Different types of fibers improve the mechanical properties of the matrix, [10]. There are three main types of fibers (glass, carbon, and aramid) whose combination with epoxy resin results in glass (GFRP), carbon FRP (CFRP), and aramid FRP (AFRP). The behavior and characteristics of FRP composite material vary depending on the type of fiber and matrix, [11]. Typical stress-strain relations for different FRPs compared with the relation mentioned for steel are shown in Figure 4.

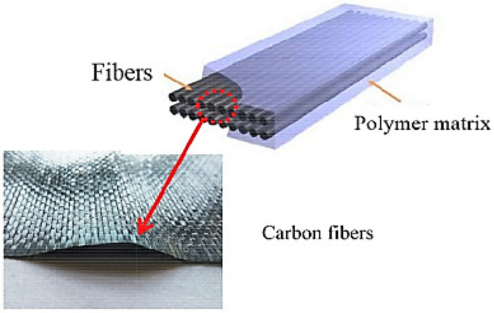

Figure 3. FRP composite material, [9]

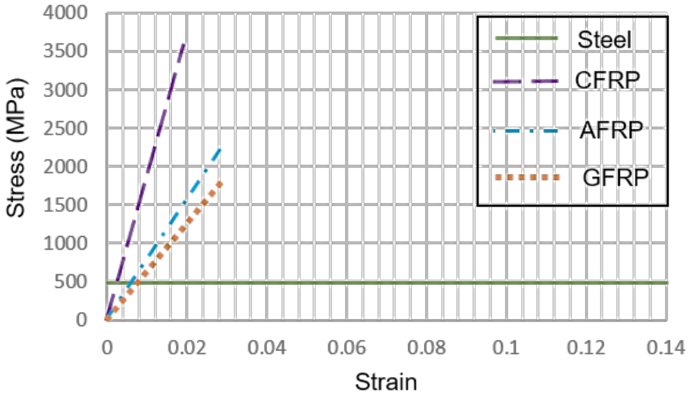

Figure 4. Comparison of stress-strain relations, modified from [11]

2.1. Benefits of FRP composites

FRP composite material has superior properties over its individual components or traditional engineering materials such as steel, aluminum, copper, etc. The main advantages that make them suited for a wide range of applications are, [12]:

- High specific strength
- High specific modulus
- Lightweight
- Good corrosion resistance
- Improved fatigue and impact resistance
- Easy to transport and install

These composites can be used for demanding applications without substantially increasing weight. Great corrosion resistance is one of the reasons for the longer service life of FRP applications. The longevity of FRP products provides cost savings over the product's life cycle. Also, its use reduces the need for heavy maintenance like sandblasting, scraping, and painting.

Composite materials provide worth-mentioning insulation because of their low thermal conductivity; thus, they perform well in different environments, from subzero to high temperatures, [13].

2.2. Limitations of FRP composites

Regardless of the various advantages of FRP composite material, there are a number of disadvantages that limit its use in different areas:

- Its strength perpendicular to the fibers is extremely low in comparison with the same one along the fibers
- Generally brittle behavior with a linear elastic response in tension up to failure
- High initial cost
- The design, manufacturing, and testing of FRP components should be highly specialized
- Low long-term temperature resistance

FRP composites are orthotropic materials; thus, the mechanical behavior of the materials is different in two directions. The material is very strong and stiff parallel to the fibers, but perpendicular to the fibers, the strength can only be attributed to the specific resin.

These composites are brittle, and failure occurs when tensile strength is exceeded. The absence of ductility is one of the main concerns when using FRPs.

The initial cost of products using FRPs appears to be higher, but reduced labor and transport costs and an extended structural lifetime increase savings compared to using conventional materials.

In general, the strength of FRPs decreases significantly above 50°C; thus, they cannot be used at high temperatures for a long time. In the case of high-temperature-resistant resins, the strength of FRPs can be stable for a long time at 200-300 °C.

3. USE OF FRP COMPOSITES IN CIVIL ENGINEERING APPLICATIONS

FRP composites enable important achievements in the functionality, safety, and economy of construction. The use of FRPs in civil engineering has evolved slowly from a special material to a common engineering material used in a wide range of applications, [14]. Due to their attractive characteristics previously mentioned, these composites have become significant materials in the construction industry as alternatives for internal or, more frequently, external reinforcement and for retrofitting and strengthening structures.

Despite the fact that these composites can be used in different civil engineering applications, they are most often used for retrofitting, repairing, and strengthening various structures.

It is known that "retrofitting" means strengthening and/or repairing load-bearing structural elements in existing structures, [11]. "Strengthening" is the first type of retrofitting that includes upgrading the structure’s initial strength or ductility in order to account for new levels of loading. Otherwise, "repairing" means restoring the original, initial load-carrying capacity, Figure 5.

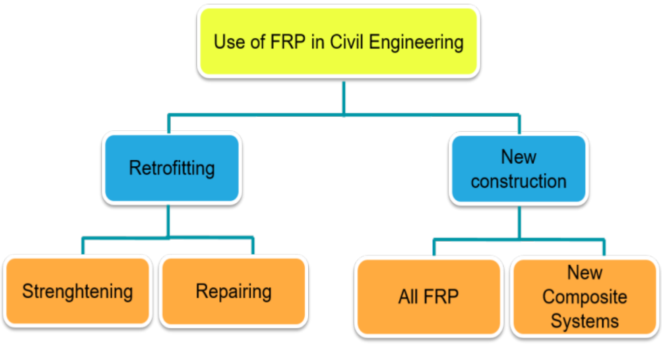

Figure 5. Use of FRPs in civil engineering applications

This paper covers FRP retrofitting of RC structural elements more in detail and highlights its main properties.

3.2. FRP retrofitting of reinforced concrete elements

Traditional seismic retrofitting methods do not always provide reliable solutions, so FRP composites are the present durable retrofitting solution. In addition, with their reduction in cost, installation without worth-mentioning disturbance to the functionality of buildings, and increased need for strengthening structures, FRP strengthening systems have become one of the most effective methods for strengthening.

It is known that these composites can be applied in various ways for strengthening beams, columns, beam-column joints, slabs of buildings, and bridges. They are available for strengthening and/or retrofitting in many forms, including sheets and wraps, laminates, and less often strings and bars, [14], Figure 6.

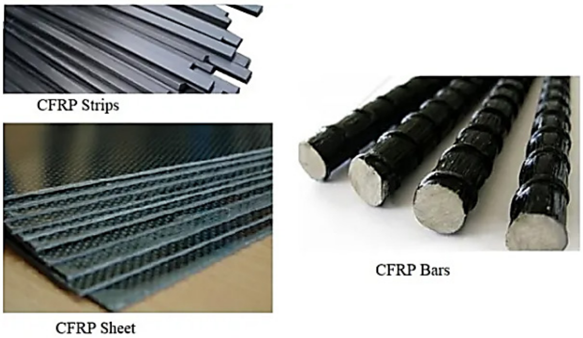

Figure 6. Examples of different forms of FRP composite (CFRP), [15]

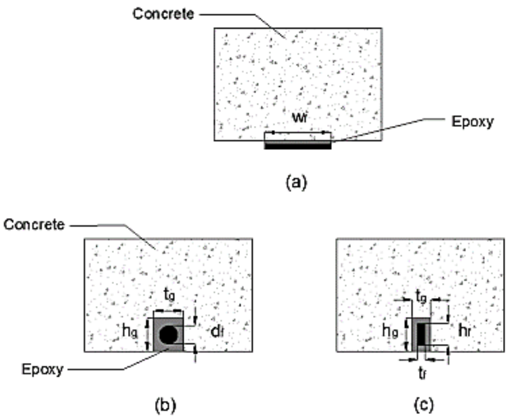

Figure 7. FRP strengthening a) EBR FRP plate or sheet; b) NSM FRP rod or bar; c) NSM FRP laminate or strip, [16]

It is recognized that there are two main ways of strengthening systems: the external bonding reinforcement (EBR) method and the near surface mounting (NSM) method. First, FRP sheets or wraps are used as an external strengthening method for enhancing the flexural, shear, torsional, and/or axial capacities of reinforced concrete structural elements. Additionally, it can increase the confinement, stability, and ductility of elements, [11]. Section wrapping using FRP sheets has become an effective and common way of performing seismic retrofitting. Second, the NSM technique is an appealing method that is based on applying a specific adhesive and laying FRP bars, rods, or strips into pre-cut grooves in the concrete cover, Figure 6. This method developed as a consequence of one of the main drawbacks of applying external bonding reinforcement due to debonding between FRP and concrete.

3.2.1. Near surface mounted technique for FRP reinforcement

FRP reinforcement is installed in specific grooves that have been prepared previously (desired depth, width, spacing in the concrete cover, cleaned, and filled with adhesive material), [16], Figure 8.

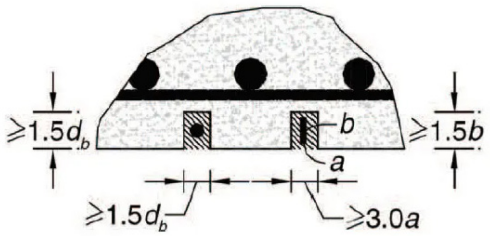

Figure 8. NSM FRP reinforcement applied in the concrete cover, [17]

The NSM technique can be used as an effective and successful method for flexural and shear strengthening of RC structural elements, Figure 9.

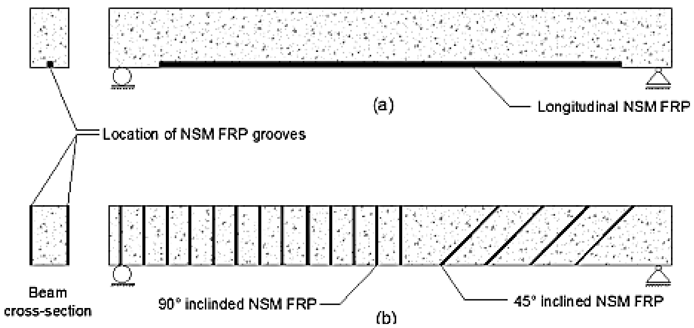

Figure 9. FRP strengthening of beam using NSM technique, [16]

This retrofitting method does not require considerable surface preparation except for the grooving mentioned. It is one of the main benefits of this technique. Furthermore, the installation of FRP reinforcement using this system is independent of the surface tensile strength of the concrete. It provides notable anchorage capacity due to the larger bond surface and reduces installation time. The use of the NSM system requires a relatively large cover depth, which is not so common in older, existing structures, [14]. It is the worth-mentioning limitation of the system mentioned, and the reason for the widespread use of externally bonded retrofitting techniques.

3.2.2. External bonding FRP reinforcement

The most common system for FRP retrofitting structural elements is external bonding of FRP sheets, wraps, laminates, or bars. They can be installed in various ways in order to enhance, increase, or restore the flexural and/or shear strength of elements (for example, RC beams). Furthermore, they can be used to increase the axial strength, ductility, and energy dissipation properties of RC columns.

The procedures for FRP installation for the RC members are shown below:

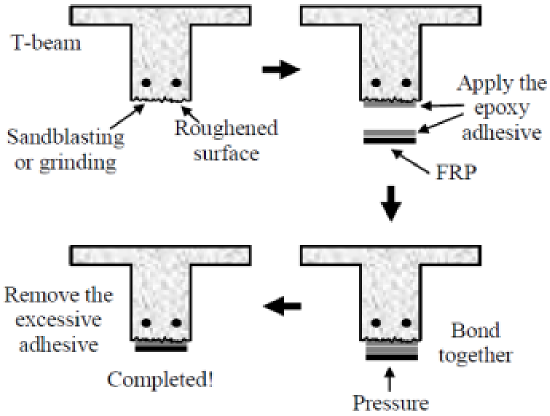

Figure 10. Procedure of external bonding retrofitting technique, [18]

Various failure modes are described in the following table, [18], and Figure 11:

Table 1. Different failure modes of FRP strengthened elements

<table>
<tr><th>Failure modes</th><th>Description</th></tr>
<tr><td>Concrete crushing</td><td rowspan="2">If premature failures are prevented, the ultimate flexural capacity of the member is reached when either the FRP composite fails by tensile rupture or the concrete crushes in compression.</td></tr>
<tr><td>FRP rupture</td></tr>
<tr><td>End cover separation</td><td>Failure of the concrete cover is initiated by the formation of a crack at or near the plate end due to high interfacial shear and normal stresses caused by the abrupt termination of the plate.</td></tr>
<tr><td>End interfacial separation</td><td>This debonding failure is initiated by high interfacial shear and normal stresses near the end of the plate that exceed the strength of the weakes element (concrete or epoxy).</td></tr>
<tr><td>Flexural crack induced debonding</td><td>Flexural crack induced debonding happens when the concentrated bond stress at the crack location exceeds flexural strength.</td></tr>
<tr><td>Shear crack induced debonding</td><td>Shear crack indued debonding occurs in the zone where both shear and bending moment are significant. It is caused by the combination of two mechanisms. The first one is similar to that of flexural crack induced debonding. The second is by the vertical movement of the inclined crack.</td></tr>
</table>

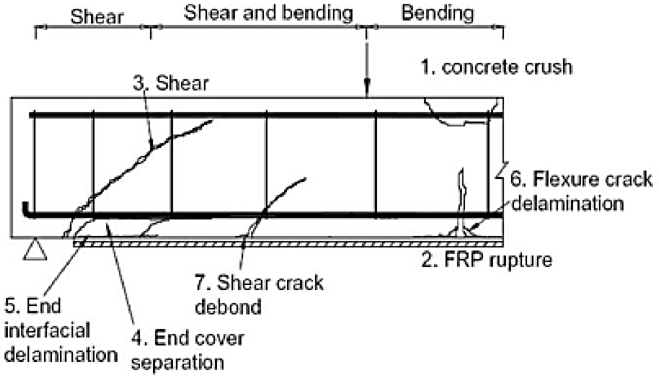

Figure 11. Different failure modes of FRP strengthened elements, [18]

Flexural and shear FRP external applications are described in detail below.

- Flexural and shear applications

The flexural strength of RC structural elements can be upgraded, or restored by different FRP schemes, Figure 12.

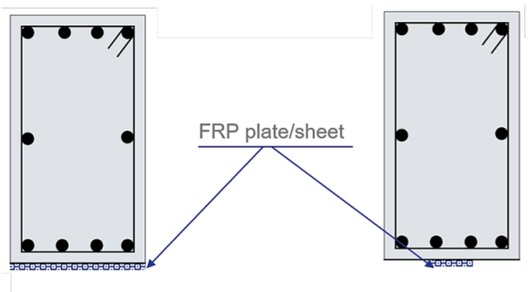

Figure 12. Use of FRP for flexural strengthening

The strengthening at the soffit of the beams is shown below.

Figure 13. The application of flexural strengthening, [20]

Figure 14. The application of flexural strengthening, [21]

The way of strengthening of RC one-way and two-way slab is shown in Figures 15 -16. FRP strips are inserted to the soffit along the required direction or directions in the case of two-way slabs, [22].

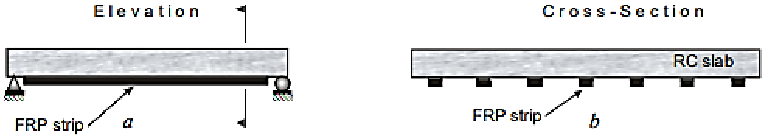

Figure 15. One-way slab strengthening, [22]

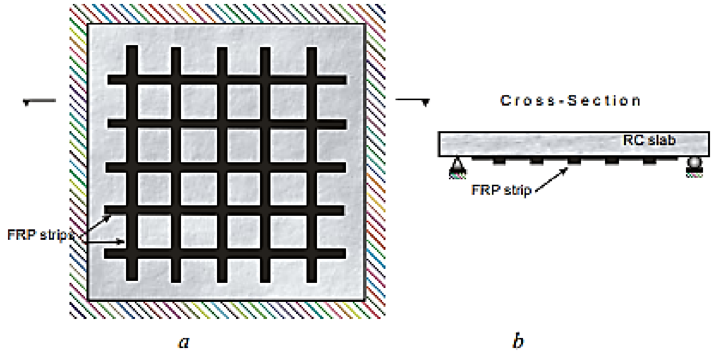

Figure 16. Two-way slab strengthening, [22]

FRP wrapping is a common way to increase the ductility, confinement, and shear capacity of walls, columns, and beams. It is worth mentioning that the fibers are oriented in the directions of the hoops, [14].

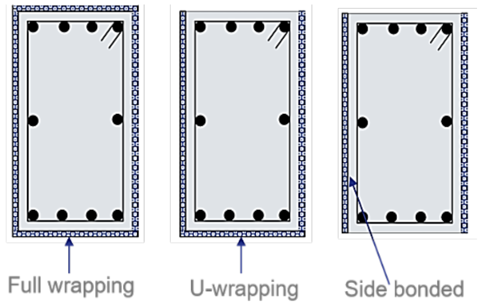

Figure 17. Various wrapping methods

The possible wrapping methods for beams are shown in the Figure 17.

Even if full wrapping of the section is the most effective method, it often cannot be used because of the presence of the slab. U-wrapping and side-bonded FRPs should be used.

The effectiveness of the new, additional layer decreases when there is more than one FRP-wrapping layer.

The example of FRP application at slabs is shown in the Figure 18.

a) midspan b) at the support

Figure 18. FRP slab strengthening, [14]

3. CHALLENGES

One of the main challenges is the installation of the appropriate anchorage system for different FRP applications and improving the bond between FRP and the concrete surface with stress transfer between them. Overlapping of the FRP sheet in the fiber direction can be a successful method in closed wrapping. On the other side, it is a significant construction challenge in open FRP systems (FRP laminates, side-bonded, U-shaped wrapping, etc.); thus, debonding is the most common, sudden, and brittle type of failure. An important condition for the safe use of FRPs to their full potential is knowledge of the long-term performance and durability properties of these modern materials.

Furthermore, one of the major drawbacks to FRPs full potential is the lack of design codes and a simplified FRP design book for structural engineers, [23].

4. CONCLUSIONS

In general, it can be said that FRP composites represent attractive materials for wide application in various types of engineering, such as civil engineering. Significant achievements can be obtained according to its benefits: high ratio of strength to density, great corrosion behavior, lightweight, and easy transport and installation. On the other side, FRPs have brittle behavior with a linear elastic response in tension up to failure and anisotropic behavior, which limits their use.

Also, this paper summarizes descriptions of different opportunities for retrofitting RC structural elements. It can be utilized as a review of FRP properties and as a basis for gaining basic knowledge about this kind of modern composite material.

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IMPROVEMENT OF SOCIO-DEMOGRAPHIC STRUCTURE IN RURAL AREAS IN SERBIA – POSSIBILITIES AND CHALLENGES

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Abstract

Rural areas occupy more than a half territory of the Republic of Serbia, and they are home for more than 50% of total population. These areas are very diverse due to different topographic structure, settlements within them emerged mainly spontaneous - adjusting to the existing terrain. Settlements in rural areas have very vibrant history and the influence of different cultures left marks on their current structure. In Serbia, rural areas are characterized with low population density, inadequate access to main public services, lack of communal infrastructure, low income and mainly agriculture-oriented economy. One of the biggest problems that rural areas are facing is certainly unfavorable socio-demographic structure due to constant depopulation process and low quality of life.

Starting from the assumption that rural population represents one of the biggest rural resources, this paper discusses possibilities and challenges for improvement of socio-demographic structure in rural areas in Serbia. Within this paper, first the current state of rural areas is analyzed and key development problems and possibilities are determined. Then, the examples of positive practice of implemented projects in rural areas in Europe are presented in order to illustrate possibilities for improvement of socio-demographic structure. Based on these findings, the aim of this paper is to propose possibilities for improvement of socio-demographic structure in rural areas. It is concluded that socio-demographic structure has influence on all other structures of rural areas and that its improvement is important for overall rural development.

Key words: *rural development, socio-demographic structure, rural population, regional development*

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1. INTRODUCTION

In the Republic of Serbia, unequal regional development caused significant differences in the economic development of different regions, which undoubtedly affected the development of rural areas. Decades of neglect of rural areas led to their stagnation in the economic, socio-demographic, functional and environmental terms, the quality of life was reduced and the physical structure was degraded, which affected the overall rural development process [1]. The continuous process of depopulation, which is more pronounced in recent years, is recognized as one of the biggest problems in rural areas in Serbia [2]. Demographic emptying in rural areas is a consequence of economic underdevelopment, reduced quality of life, inadequate or completely absent communal infrastructure, underdeveloped traffic network and devastated environmental structure. Devastated micro-rural centers are also a big problem, which are most pronounced in border and hilly-mountainous rural settlements, especially in the area of southeastern Serbia [3,4]. The absence of a developed and hierarchically structured polycentric system of settlements, underdeveloped connections between urban and rural areas are some of the specificities of settlements in rural areas of Serbia that have a negative impact on their development [5].

Rural areas occupy a significant territory in the Republic of Serbia and play an important role in overall national and regional development. These areas are lagging behind in demographic, economic and spatial terms, so their revitalization is necessary. Rural development can be seen as a process of improving the quality of life and the socio-demographic and economic structure of rural areas [6]. Rural development can also be defined as a complex and comprehensive process, which, in addition to the overall improvement of rural areas, has an economic, environmental, cultural and socio-demographic role [7]. In the process of rural development, the emphasis is on activating local resources and their efficient exploitation. The starting point of this research is that the rural population represents the main resource of rural areas, and so this paper discusses improvement of the socio-demographic structure of rural areas. The goal of this research is to determine the opportunities and challenges for improving the socio-demographic structure of rural areas in Serbia based on the analysis of their current state. Also, the goal is to propose possibilities for improving the socio-demographic structure of rural areas in Serbia based on the analyzed positive European experiences. By improving socio-demographic structure, it is possible to contribute to the further overall development of rural areas and positively impact other structures of rural areas - economic, spatial-physical and environmental.

2. METHODOLOGY

The methodological framework in this paper is based on the analysis of the rural areas in Serbia, specifically their socio-demographic structure and investigating possibilities for its improvement. At the beginning, the paper explores the main characteristics of rural areas in Serbia, primarily their socio-demographic structure and its impacts on other structures and vice-versa. Next, implemented positive practice examples of improving socio-demographic structure in European countries are presented. Based on the results, in the second part paper discusses the possibilities and challenges for improvement of socio-demographic structure in the context of sustainable development.

In order to conduct comprehensive analysis based on all specific characteristics of analyzed rural areas in Serbia, examples of positive practice were analyzed and presented within this paper. These examples were determined based on the context and problems that rural areas were facing. Presented examples illustrate cases in which rural settlements were facing similar problems as rural areas in Serbia, which were determined in the first part of this paper. Projects that are analyzed are all financed through funds from Rural Development Programme for 2014-2020 period.

3. CONTEXT – RURAL AREAS IN SERBIA

Rural areas in the Republic of Serbia occupy a major part of the territory and have been discussed within numerous legislative, planning and strategic documents. Over the years, a large number of researchers have studied rural areas and settlements in them, but even today there is no universal definition and classification of these areas. Within the Draft Spatial Plan of the Republic of Serbia for the period 2021-2035. [8], which was presented in 2021, division of rural areas is defined into 6 regions (Figure 1). The largest part of the territory belongs to the region of rural distortions. The rural territory of this region is characterized by demographic emptying, heterogeneous territory and uneven characteristics of peripheral and areas around urban centers. According this Draft, by applying OECD classification, 94,1 % of the territory of Republic of Serbia is defined as rural where population density is less than 150 inh/km^2. This territory is home to 47,8 % of total population and within there are 72,6% of total settlements.

In the Republic of Serbia, current division of settlements, according to the Statistical Office of the Republic of Serbia, is on *urban* and *other*. This division has been in use since the 1981 census [9]. Considering the division of settlements into urban and other settlements, automatically all urban settlements are urban, and all other are declared as rural settlements. Current division of settlements does not give a realistic situation, because among the "other settlements" in urban areas there are significant differences in terms of demographic and economic characteristics, availability and quality of public services [10]. Rural settlements and smaller towns are defined as other settlements - some current undeveloped municipalities and former municipalities, which have different numbers of inhabitants, structure and levels of development.

Based on the data from censuses for the 1948-2022 period, comparative presentation of population trends in “other settlements” at national and regional level is shown in chart 1. In the period 1948-1961, there was a noticeable growth in the number of inhabitants in all regions. After that, a continuous decline in the number of inhabitants is clearly visible, except in the case of the Belgrade Region. This Region is also the most developed in the country and includes mainly functional area of the capital city Belgrade. In the case of the Region of Kosovo and Metohija, there are no census data after the 1981 census. When comparing the census data [11,12] at the level of the entire country, between the 2002 and

2011 censuses, the number of inhabitants in other settlements decreased by 11.1%, while between the 2011 and 2022 censuses, it decreased by 13.3%, which is less for 388,769 inhabitants in the last decade.

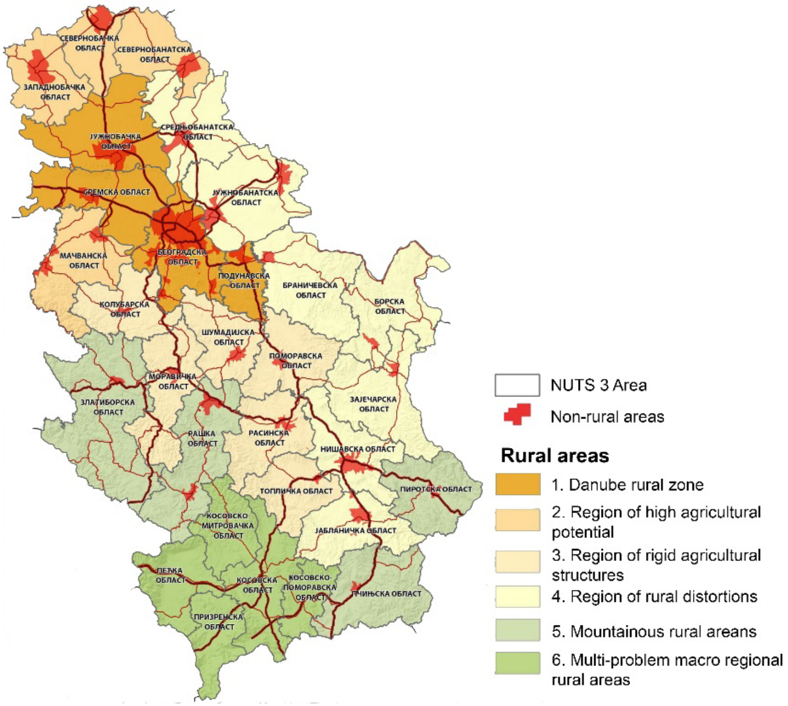
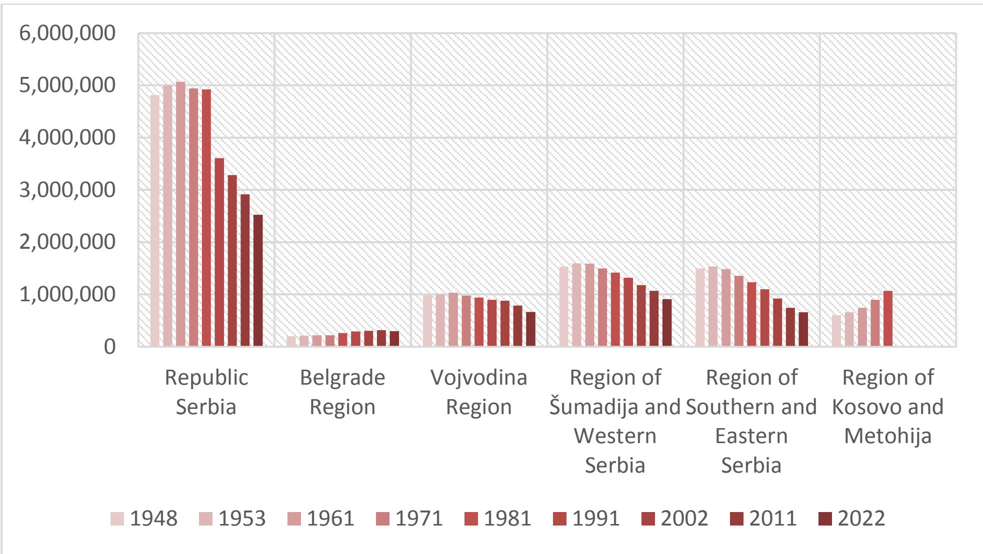


Figure 1. Map of rural areas, (Nacrt Prostornog plana Republike Srbije za period 2021-2035. god, (https://www.mgsi.gov.rs/sites/default/files/PPRS%20Nacrt.pdf)

Chart 1. Comparative presentation of the number of inhabitants in other settlements according to census data 1948-2022 (Authors according [11,12])



Demographic emptying is one of the biggest problems rural areas are facing. The reason for the decrease in the number of inhabitants is primarily uneven economic development, due to which rural areas, especially those in hilly and mountainous areas, are marginalized [13]. In addition to unequal economic development, these areas also face uneven spatial development compared to urban areas [14]. Migrations in rural areas are mostly migrations of the younger population for education because of underdeveloped network of educational institutions or for work. Due to pronounced unemployment, the level of poverty is high, and the income from agriculture is decreasing, both due to market prices and due to climate changes, which have had catastrophic effects on agriculture. Compared to the gross income per inhabitant, the income in rural areas is evidently lower, and the "gray economy" is expressed [15]. There is also social exclusion, and often there is no participation of the local community in the creation of strategic and spatial plans. An insufficiently developed and dysfunctional network of settlements has a negative impact on the quality of life in rural areas, which is already at a low level, and leads to constant migration and the demographic emptying of rural settlements [16].

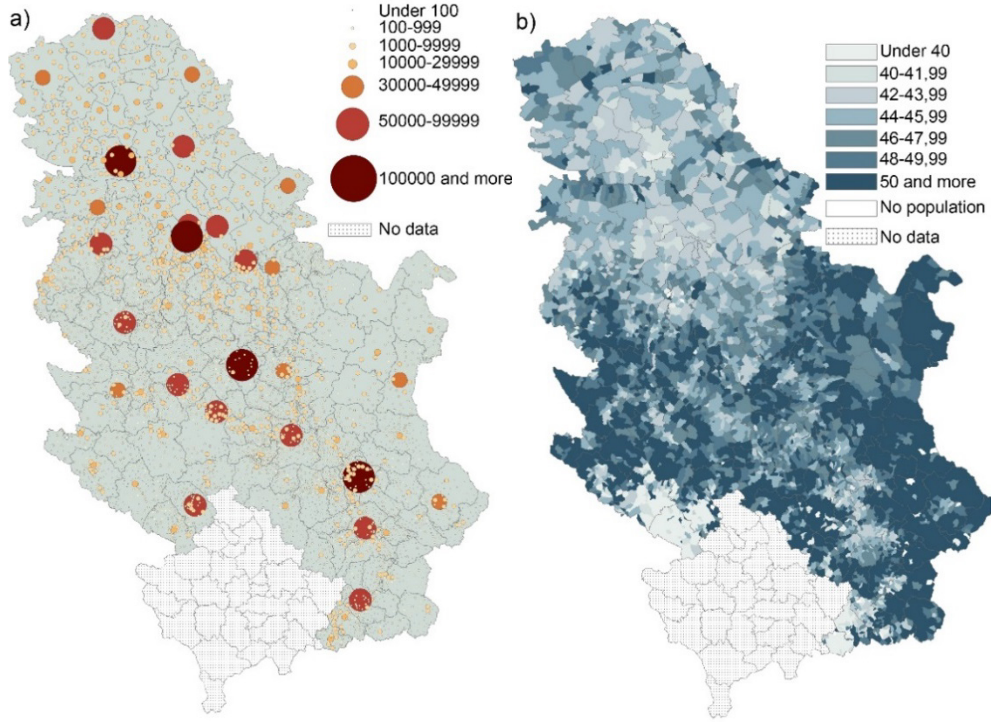


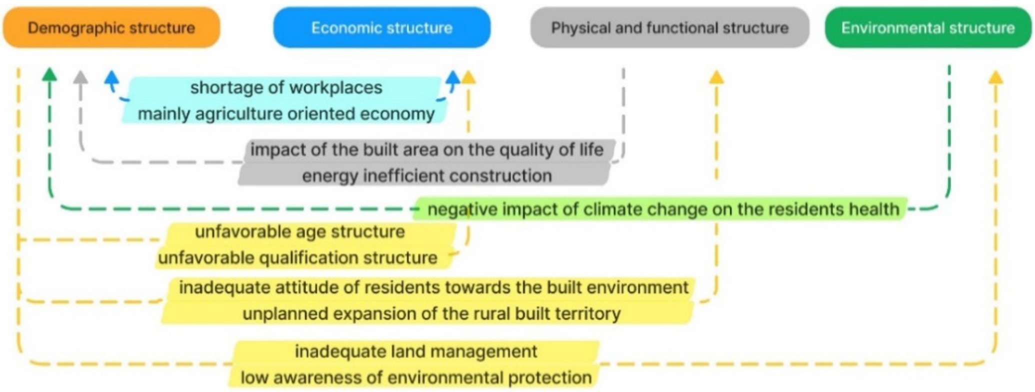
Figure 2. a) Map of population distribution by settlements; b) Map of average population age by settlements [12]

According to the data from the 2022 census, it is evident that, due to rural-urban migration, there are settlements with a smaller number of inhabitants in rural areas, which mostly gravitate to the district or regional centers (Figure 2a). Unequal population distribution and an underdeveloped functional network between rural and urban settlements have a negative impact on the development of these areas and additionally contributes to migration process. As a negative consequence of migration, there is an unfavorable age structure, especially in rural areas (Figure 2b). Based on the results of the 2011 census [12], the average age in other settlements was 43.6. Based on the results of the 2022 census it is 45.25. These data show a tendency for the share of the elderly population to increase, which is a threat to the future development of rural settlements. As far as the gender structure is concerned, the participation of the male and female population is approximately the same, according to the last census, 50.4% are male and 49.6% are female.

The problems within the socio-demographic structure are a consequence of the decrease in the number of inhabitants and constant migration to urban areas. Negative natural growth represents a direct threat to the development and existence of rural areas. Unfavorable age structure, the outflow of the younger and working capable population, causes an adverse qualification structure, which is a great threat to the improvement and development of rural economy. As a consequence of social exclusion, the rural population is characterized by passivity in decision-making and planning processes. During the period of communism, there were cooperatives and associations of agricultural workers, but after 2000, they stopped working. Since 2016, there has been an initiative to organize social cooperatives, but it is still under development. The lack of interest and inactivity of the rural population are one of the significant problems that pose a great threat to future development. Also, unlike developed countries, in the case of underdeveloped countries, rural areas are associated with a traditional society that is predominantly engaged in agriculture, and where the underdevelopment is expressed in economic, social and technological terms [17].

By analyzing the structure of these rural areas, it can be concluded that the problems within the socio-demographic structure have a negative impact on other structures of rural areas - economic, physical, functional and environmental (Chart 2). Also, the problems within other structures negatively affect the socio-demographic structure, which slows down the overall rural development.

Chart 2. Cause-and-effect relationship between different structures of rural areas, Authors



In order to overcome these problems in an efficient way, it is necessary to first determine their interrelationships. The economic structure has a negative impact on the socio-demographic one, because due to the lack of workplaces and an economy primarily oriented towards traditional agricultural production, population migration occurs. On the other hand, the unfavorable age and qualification structure of the rural population represents a great threat to economic development. Because of the lack of planning documents in most rural areas, uncontrolled construction occurs, which negatively affects the built-up space. Inadequate management and poor attitude towards the built space by residents has a negative impact on the spatial structure. On the other hand, inadequately maintained building fund affects the quality of life and does not meet modern energy requirements. As far as the environment, there is no developed awareness of the importance of environmental protection. Creation of the illegal landfills and unsustainable land management leads to the environment pollution. Rural areas, and thus the rural population, face the biggest global problem of today - climate change [18]. Climate change consequences have negative impact on people's health, lives and the environment.

In addition to numerous problems that socio-demographic structure of rural areas is facing, there is also a large number of potentials that are characterizing them. The vibrant history and influences of different cultures over the centuries have resulted in a heterogeneous ethnic structure, especially in rural border areas. After the COVID19 pandemic, the attitude towards rural areas changed, especially during the lock down period. Rural areas, which are characterized by untouched nature, have become more attractive for life due to greater freedom of movement and a more favorable quality of the natural environment. This gives the possibility of reducing rural-urban migration in the future [18]. Another potential of rural areas is the traditional way of life of the elderly rural population. Living in the rural areas is synonymous with a healthy lifestyle which is one of the comparative advantages to urban areas.

4. EXAMPLES OF POSITIVE EUROPEAN PRACTICE

Rural areas in Europe have been facing similar problems as rural areas in the Republic of Serbia. In European countries, there is more developed awareness of the importance of rural areas, as well as numerous funds for financing projects for the revitalization of rural areas. In the tables hereunder, one can explore a selection of good practices examples. The projects were selected based on the problems faced by rural areas in Europe, which are similar to the problems faced by rural areas in Serbia. Table 1 shows projects related to the empowerment and activation of the younger population. The main goals are to increase the inclusion of young people, their involvement in decision-making processes and development processes and in that way reduce migrations.

Table 1. Presentation of projects for empowering young rural population

<table>
<tr><td colspan="3">Tartu County Active and Entrepreneurial Youth, Estonia
Implemented 2018-2021
https://ec.europa.eu/enrd/projects-practice/tartu-county-youth-foundation_en.html</td></tr>
<tr><td>Context- problems:
• Inaccessibility to funds
• Lack of local community spirit
• Inactivity of the young population
• Migrations of young people</td><td>Goals:
• Connecting young people with the local community
• Developing skills in project writing
• Entrepreneurship development and youth empowerment</td><td>Results:
• 35 small scale projects, 1000 people from Tartu aged 12-26 participated
• Promotion of entrepreneurship
• Introducing young people into decision-making processes</td></tr>
<tr><td colspan="3">Centre for Social Inclusion in the village of Gilău, Romania
Implemented 2019-2021
https://ec.europa.eu/enrd/projects-practice/centre-social-inclusion_en.html</td></tr>
</table>

Context- problems:	Goals:	Results:
• Depopulation • Unemployment of youth • Young people face poverty and lack of opportunities	• Minority and vulnerable groups' access to social integral services • Involvement of young people in development processes	• Inclusion of young people • Transition from education to labor market guidance • Better connections between young's

Table 2 shows projects related to the improvement of the availability of public services and use of modern technologies for improvement of rural activities and community. The main goals are to enhance quality of life and promote use of modern technologies in rural activities. This way there is a positive impact on the age and qualification structure and the spirit of community is strengthened.

Table 2. Presentation of projects for improving availability of public services and use of modern technologies for improvement of rural activities and community

Transformation of public space in rural areas, Western Asturias, Spain Implemented 2021-2021 https://ec.europa.eu/enrd/projects-practice/transformation-public-space-offer-leisure-alternatives-rural-areas_en.html		
Context- problems: • Progressive abandonment of cultural heritage assets • Lack of local leisure and cultural spaces • Rural population inactivity	**Goals**: • Preserving architectural and cultural heritage • Improving the network of public and cultural activities • Developing tourism	**Results:** • Creation of cultural hub • Preserving architectural heritage • Diversification of activities and promotion of social inclusion • Creation of new jobs
Equipping the healthcare center in Biertan, Sibiu County, Romania Implemented 2018-2020 https://ec.europa.eu/enrd/projects-practice/equipping-healthcare-centre-biertan-sibiu-county-romania_en.html		
Context- problems: • Unfavorable age structure • Medical care and basic services decline • School dropout in families living in poverty	**Goals**: • Combat isolation and social exclusion • Establish an integrated social and medical center for minority groups and disadvantaged people	**Results:** • Improved workplaces • Social inclusion and care services are offered to people from vulnerable and minority groups
Agricultural education in the world of virtual reality, Hungary Implemented 2021-2021 https://ec.europa.eu/enrd/projects-practice/agricultural-education-world-virtual-reality_en.html		
Context- problems: • Traditional ways of agriculture • Lack of use of modern technologies in production • Lack of young people in agriculture	**Goals**: • Improve the quality of agricultural vocational training • „Bring" agricultural production closer to young people • Develop agricultural education	**Results:** • Keep agricultural education in step with the technological developments • Increase agriculture productivity • Enhance the interest of young people in agriculture
Smart Villages for Tomorrow, Slovenia Implemented 2019-2020 https://ec.europa.eu/enrd/projects-practice/smart-villages-tomorrow_en.html		
Context- problems: • Outmigration • Ageing of rural population • Lack of services for elderly people and development programs	**Goals**: • Taking advantage of innovative technology solutions • Improving digital literacy Developing appropriate digital technology for all age groups	**Results:** • Models of smart solutions for ageing rural communities • Established places for socializing of all age groups • sustainable mobility for the elderly

The analyzed projects from European countries are positive examples of how problems in the socio-demographic structure can be overcome. Depopulation, non-favorable age and qualification structure, unavailability of public services and inactivity of the rural population - especially younger people are the main problems in the examples shown. In each example, the focus is on the activation of local resources, empowering the younger population and improving the connections and activities of the rural community.

5. DISCUSSION

Based on the context analysis, it can be concluded that it is necessary to improve the socio-demographic structure and overcome the problems it is facing. In this way, its effects on other structures of rural areas would be reduced and eliminated, and it would contribute to the economic, spatial and ecological development of rural areas. To improve the socio-demographic structure, first of all it is necessary to improve the quality of life, which is one of the triggers for demographic emptying, and to reduce the negative trend of depopulation. In order to effectively improve the socio-demographic structure of rural areas, it is necessary to increase the number of inhabitants and reduce rural-urban migration. As rural areas are synonymous for a healthy way of life and untouched nature, it is possible to use this and promote urban-rural migration, which would have a positive natural increase as a "consequence". One of the possibilities is subsidies for the return of rural population. If young people were stimulated to return to rural areas, and if investments were made in the education of young people through their scholarships, it would be possible to reduce the rural-to-urban migration.

In order for residents to decide to stay and live in rural areas, it is necessary to increase the standard of living of the rural population and provide them dignified life, access to basic public functions and adequate communal infrastructure. Housing is the dominant function in rural areas, so its improvement is necessary in order to improve the standard of living. The quality of housing in rural areas is not at a high level, primarily due to insufficient and completely absent communal infrastructure and illegal construction. The quality of housing could be improved by building new and upgrading the existing communal infrastructure and by energy renovation of buildings in order to make them resilient to the climate change.

In a large number of settlements, neither basic health care nor grocery stores exist. It is necessary to ensure accessibility to basic services in rural settlements and in that way to enhance the quality of life. In order to overcome this problem, it is possible to organize a mobile ambulance service, because residents of some rural areas do not have access to basic health care. The improvement of health care is very important because of the unfavorable age structure, but also because of the consequences of climate change - primarily heat waves.

As already mentioned, living in rural areas is related to a healthy lifestyle, so in addition to promoting this advantage for increasing the number of inhabitants, the promotion of rural lifestyle can have a positive effect on increasing the resilience of the rural community. These areas are characterized by large green spaces, forests and other natural resources, so it is possible to promote a „return to nature“ as one of the advantages of rural life. In order to improve people's health and adapt to changed climate conditions, it is possible to apply nature-based solutions when planning the territory of rural settlements. By implementing modern concepts, it is possible to increase thermal comfort and thereby influence the quality of life in rural areas and mitigate the negative impacts of climate change.

Due to the decades-long marginalization of rural areas, the term rural is synonymous with something that is "backward", so a precondition for increasing the number of inhabitants and their social inclusion is improving the image of rural areas and rural life, as well as the promotion of rural identity. Because of the unfavorable qualification and age structure of rural population, it is necessary to improve the transfer of knowledge. In addition to raising awareness about the importance of the local community, it is important to enable the requalification of the rural population in order to diversify the rural economy. In this way, dependence on income exclusively from agricultural production would be reduced and the economic standard of the rural population would increase. Also, demographic structure would be more heterogeneous which could positively affect economic structure and improve rural economy. In this manner, new jobs would be created, corresponding to the actual situation and needs - the existing qualification structure of the population. In order to increase the standard of living, it is necessary to improve and develop a network of functions complementary to housing that are vital for the daily life.

Since one of the problems is the passivity - lack of interest of the rural population, it is important to improve the transfer of knowledge in order to raise the awareness of the population about the importance of their active participation in decision-making and planning processes of rural development. The rural community, as the largest rural resource, must be activated and "exploited effectively" in order to improve the socio-demographic structure and overcome the problems within it. This is possible through strengthening the local community and encouraging the establishment of associations and the development of entrepreneurship, as well as more intensive involvement of the local population on different levels in the processes of development of rural areas. Strengthening the local community is possible through the promotion of social interactions and the organization of traditional events. This can be done through arranging the existing public spaces in the settlements (squares) and activating abandoned public buildings (cultural centers, local administration buildings).

Given that rural communities face today's major global challenge - the consequences of climate change, it is necessary to define measures and reduce the negative impacts of climate change on the health and life of the rural population, with the aim of creating more resilient communities. So, it is necessary to continuously educate the population about the possibilities of adaptation and mitigating the impact of the changed climate conditions in order to increase health and reduce the risk to the life of the population. It is important to develop the local capacities to monitor impact of climate change on the health of the rural population.

Rural areas are not "globally visible" which is a major disadvantage in modern times. Therefore, it is important to encourage use of modern technologies and that way increase their visibility and promote their comparative advantages. In order to connect the population of different settlements in the rural territory, it is important to increase their availability on the internet, promote the rural community and the benefits of living in rural areas. Promotion of rural areas through social networks is particularly important for the younger population.

For the implementation of the improvement projects for socio-demographic structure of rural areas, it is possible to use funds from the National Program for Rural Development, the IPARD Fund, through IPA projects, Erasmus+ projects and other foreign projects, as well as through private-public partnerships. Significant problem for implementation of these projects is the low awareness of the rural population about their possibilities, as well as the lack of skills in preparation of national and international projects. On the other hand, in the case of financing through the National Program of Rural Development, there is a problem that the measures defined are generally intended for all rural areas in Serbia, without taking into account all the specificities of individual rural areas. In order to effectively improve the socio-demographic structure, it is necessary that decision-making and projects are made and implemented at the local and not at the national level. Only this way it is possible to anticipate and overcome all potential obstacles and adequately influence the structure of rural areas.

6. CONCLUSION

There are a large number of causes that lead to the demographic deterioration of rural areas. When planning rural development and revitalization of the socio-demographic structure, it is necessary to look at all causes and take them into account in order to overcome all potential obstacles. A large area of the territory of Serbia is occupied by rural areas, however, they are not heterogeneous and there are differences in their structure. Some of the divisions are given through planning and strategic documents, however, when planning, it is necessary to carefully look at these local specificities. In Serbia, there are currently planning and strategic documents related to rural development, but their implementation in practice is not at a satisfactory level. One of the disadvantages is that all the strategies are national rather than territorial in scope, so not all problems are considered. The problem is also the negative image of the rural in society and the lack of interest in development from the local community. The rural population's awareness of their opportunities for further development, as well as the percentage of their active participation in decision-making processes, is at a very low level. As rural population represents one of the most important resources of rural areas, it is necessary to overcome the problems they face in order to improve rural development. Rural areas occupy major part of the country’s territory and they have important role in regional and overall development, so their improvement and revitalization are priority. Improving socio-demographic structure could be a trigger for improving other structures because of their mutual interrelationship.

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POSSIBILITIES OF ENERGY IMPROVEMENT OF THE EXISTING MULTI-FAMILY BUILDINGS FROM THE PERIOD OF POST-WAR MASS CONSTRUCTION USING VOLUMETRIC ADDITIONS

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Dušan Ignjatović[2]

Abstract

The refurbishment of existing buildings with the aim of spatial-material improvement combined with the reduction of energy consumption is a very contemporary topic in recent years. The interest, both of experts and the general population, in saving energy while minimizing operating costs is constantly increasing, and it is emphasized by the uncertainties of energy supply coupled with constant increase in prices. Residential buildings built in the period from 1946 to 1970 make up one quarter of the total multi-family stock in Serbia. Most of these buildings are characterized by high energy consumption for heating due to poor thermal performance of the building envelope. Created according to the design regulations valid at that time, valued by today's user requirements, they have major spatial and organizational deficiencies, notably small apartments, outdated and inflexible spatial organization and small windows on the facades. The absence of elevators in many multi-family buildings from that period also reduces their comfort of use. The subject of the research is based on application of deep refurbishment methodology by adding volumes, as a constructive-functional element, to existing multi-family buildings. Primary goal represents achieving high energy efficiency levels combined with bettering of spatial and living standards through remodeling and modernization of residential units, and improving vertical building communications. The paper will illustrate the application of the principle of volumetric addition on three typologically different multi-family residential buildings. Based on the National Typology of Residential Buildings of Serbia, the subject of research are most common building typologies: free-standing buildings, row buildings within a city block and "lamellas". The research will analyze energy performance of the existing state on representative buildings of each type, as well as performance of improved state through application of strategy of deep refurbishment by adding a volume. The goal of the research is to review the advantages and limitations of proposed method for energy and spatial improvements in different types of multi-family residential buildings.

Key words: sustainability, deep refurbishment, energy efficiency, multi-family housing stock, volumetric addition

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1. INTRODUCTION

The refurbishment of existing buildings with the primary aim of reducing energy consumption has become a very contemporary topic in recent years. The Amended Directive on Energy Efficiency and the Directive on the Energy Performance of Buildings contain clear objectives related to long-term strategies for the renewal of the building stock in Europe [1]. In addition to these documents, the European Green Deal provides guidelines for the renewal of the existing building stock in order to improve energy efficiency and reduce energy consumption [2]. Many renovation strategies are based on energy-saving measures, such as retrofitting existing buildings to improve the building's building envelope and implementing efficient heating, ventilation, and air conditioning systems [3].

The EC's (European Community) Renovation Wave sets the objective of fostering deep energy renovations [4]. Deep Renovation represents a term that defines the process of renovation with a focus on the building shell of existing buildings that will result in achieving of high energy performance standards. The deep renovation should also deliver an optimal level of indoor environmental quality to the building occupants [4].

The approach to renovating existing buildings by adding new structures has significant functional advantages that set it apart as one of the more significant methods to the complex renovation of buildings. This refers to the possibility of adding missing functional elements to an existing building, such as elevators, fire escapes, or balconies, which can greatly improve its spatial-functional quality as well as the comfort of its users. The added volumes are enabling functional upgrades and an overall reorganization of a building's spatial structure, with improvements on many levels [5].

The research focuses on determining the approach for achieving deep renovation goals through extensive spatial interventions on building envelope in the Serbian housing stock. The most prevalent multi-family housing stock in Serbian cities was built between 1946 and 1970, with 25% of the total multi-family buildings originating from that period [6]. These buildings have functional and spatial-organizational deficiencies as a consequence of the valid laws and design principles of the time, that defined their initial design. Usually, they are described as structures with small apartments that should accommodate as many people as possible, resulting in inadequate unit dimensions, rigid spatial organization, and small windows. Moreover, these buildings are characterized with high energy consumption for heating. Therefore, this research analyses the application of the methodology of complex and integrated refurbishment by introducing the principle of volumes addition to existing multi-family buildings with the aim to achieve high energy efficiency standards, modernize residential units, and improve vertical building communications. The paper will show the volumetric addition to three typologically different multi-family residential buildings. The study includes a comparative analysis of the energy performances of existing state for three representative buildings of different types and variants for improving the energy performances through volumetric additions. The research aims to review the advantages and limitations of applying volumetric addition strategies for energy improvements in multi-family residential buildings built during the mass construction period.

2. METHODOLOGY

The research is based on several analytical methods. It starts with the analysis of the typology of multi-family housing constructed after World War II, as well as its spatial organization and functional characteristics. For further analysis, three representative buildings of different types are identified, and their spatial organization and functional characteristics are analyzed. The next step includes the evaluation of the energy performances of the selected buildings using the Knaufterm software[3]. Further, the various modalities with special attention to volumetric intervention resulting in energy improvements of the buildings are defined and analyzed. The energy performances of improved state are analyzed using the same energy calculation software. Finally, a comparative analysis of the results is conducted, and the advantages and limitations of applying the volumetric addition strategy to the existing building focused on improving its energy performance are determined.

2.1. Multi-family housing stock built in the period from 1946 to 1970 in Serbia

Of the total stock of multi-family residential buildings in the Republic of Serbia, 24.81% were built in the period from 1946 to 1970 [6]. This period is characterized by intensive housing construction, the dynamic growth of cities, the development of new settlements, and urban open city block typology.

The classification of multi-family buildings based on architectural-urban planning parameters and building characteristics includes the following types:

- A free-standing building, on a separate plot, does not border neighboring buildings on any side,
- A free-standing building consisting of two or more identical units with the separate entrances, in an open city block ("lamella"),
- A building in a row, within a series of different buildings in a closed city block, borders neighboring buildings on one or two sides,
- A high-rise free-standing building with more than 10 storeys, on a separate plot, does not border neighboring buildings on any side [7].

The buildings built in this period have common generative characteristics; the architectural form of the buildings was compact and geometrically regular, the facade was simple without decorative elements, and the windows were rather small. The buildings were built in a traditional way, in a massive construction system, with brick as the dominant material. Similarities are also noticeable in the spatial organization regardless the type of the building: central position of the entrance to the building, the position of the staircase, the absence of an elevator, and the interior and exterior finishes. Flats were characterized with rather small kitchens often encompassing a dining space so there is no separate dining room. Such similarities between the types derive primarily from the post-war housing

[3] Knaufterm is the commercial software that is the most used calculation tool for calculating energy performance and determining the energy class of a building in Serbia.

policy, which aimed to provide the minimum housing space in the shortest possible time for a large number of people using known constructive systems and traditional building techniques [6]. Rational solutions, common to all buildings, are the result of regulations for residential construction that aimed to define the minimum dimensional and technical standards. The regulation regarding thermal protection emerged only in the late 1960s [8]. Buildings from this period do not have an adequate solution for thermal conductivity from today's perspective of thermal requirements. However, the simple, cubic forms and good quality of structural elements and applied materials of the building envelope make them extremely suitable for energy renovation because significant improvements can be achieved with relatively simple measures [7].

2.2. Various aspects of refurbishment of a building using the strategy for volumetric addition

The sustainable renovation goal is to improve living conditions in existing multi-family residential buildings and achieve high energy efficiency standards. Various parameters affect the heating energy calculation: the materialization and quality of building envelope, the ratio of the volume of a building to the area of the building envelope (shape factor), the total usable heated area and the “exposure” of the building [9]. In common practice improvement measures are based on bettering the conductivity characteristics of building envelope through addition of insulation layers and windows replacement, a process which can have several qualitative levels [10]. Focus of this research investigates more complex approach based on the application of volumetric additions to the volume of a building. This method, apart from changing the thermal characteristics of envelope changes the shape factor and increases its useful living space enabling the redefinition of the existing apartments of minimal dimensions and outdated and rigid spatial organization [11]. The functional characteristics of the building, such as inadequate vertical communications, can also be improved by applying volumetric additions. A vertical volumetric addition on the roof of a building increases its useful living space (Fig. 1) which can be commercialized presenting an economic base for overall intervention. An increase in the number of floors of a building is possible only if the preliminary loadbearing analysis shows that a building is suitable for such an intervention.

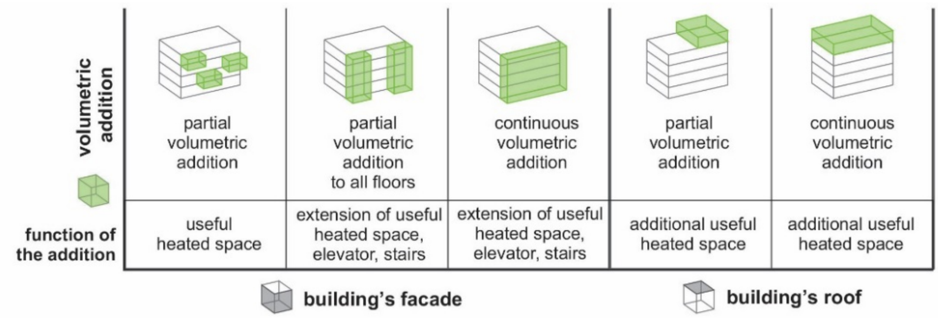


Figure 1. Variants of volumetric addition to an existing building, Image by authors

2.2. Strategy of volume addition to different types of multi-family housing buildings

The strategy for adding volumetric extensions to facades and on a roof of an existing building in a complex and integrated renovation depends firstly on urban conditions, heritage protection regime than building type, structural strength (of all described building types), and the lot size and accessibility.

As *free-standing buildings* were built in an open city block, there is sufficient surrounding space that is necessary for this renovation approach. *Free-standing buildings consisting of two or more identical units (lamella)*, can be addressed in the same way apart from dilatation spaces and walls between them. On such buildings, there is a possibility of volumetric addition to the side facades of its end units. In the case of *buildings in a row in a closed city block*, two main facades are suitable for this kind of intervention, but in general, as these buildings were built on the regulation line, extension on the street facade is only partially allowed. Interventions resulting in the increase of the volume of such a building are more applicable on the courtyard façade. Depending on the structural strength of such a building, an extension on the roof is also possible (Fig. 2). High-rise, free-standing buildings with more than 10 storeys were not taken into consideration because their percentage share in the total multi-family housing stock in Serbia is very small.

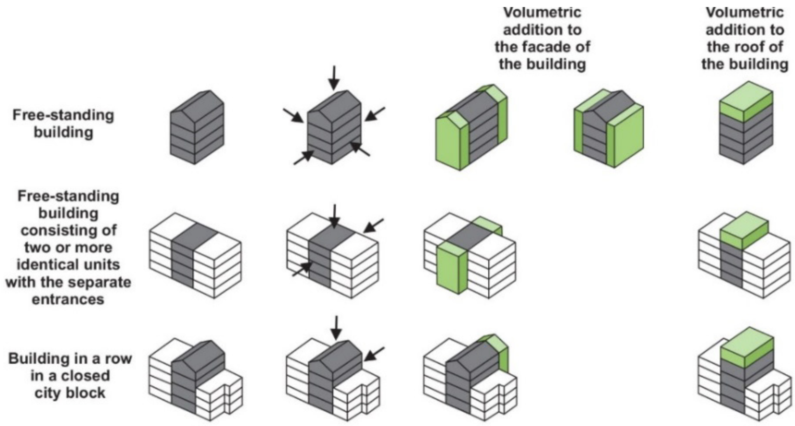


Figure 2. Variants of volumetric addition to an existing building, Image by authors

2.3. Spatial-organizational and functional aspects of the selected multi-family residential buildings

The selected buildings for the research were built in the same period in Belgrade, in a traditional way, in a massive construction system, with brick as the dominant material.

They share common characteristics in spatial-organizational and functional aspects (Fig. 3). The buildings have a basement and five or six original storeys. The basement of the buildings is used as storage space, and all other floors are for residential purposes. On all the floors, the apartments are grouped around a centrally located staircase. None of the selected buildings have elevators. All types of apartments contain an entrance hallway, a bathroom, a kitchen, a living room, and one or two bedrooms depending of usable area of the apartment.

The spatial organization of the apartments is similar in all three selected types of multi-family residential buildings. The units are designed with minimal dimensions, which was characteristic of residential buildings built in that period.

In the representative free-standing building, the spatial arrangement of four apartments, two smaller with a usable area of 50m2, and two bigger with a usable area of 56m2, is repeated on all the floors. The only difference is that larger apartments also have a separate dining area. The building does not have any balconies or loggias.

In the selected lamella building typical structural part is consisting of three units with separate entrances, on all the floors. The spatial arrangement of four apartments with a usable area of 51m2, and two apartments with a usable area of 72m2 is repeated. The apartments are grouped around three centrally located staircases. There are six apartments on each floor. The only difference is that larger apartments have two bedrooms. According to the original documentation, all apartments on the upper floors had loggias. However, in order to expand the usable heated space, many tenants closed the loggias.

In the selected building in a row in a closed city block, the spatial arrangement of two identical apartments with a usable area of 72m2 is repeated on all the floors.

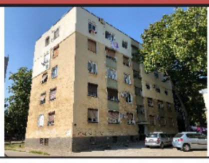
Type of the building	Free-standing building	Free-standing building consisting of two or more identical units with the separate entrances	Building in a row in a closed city block
Existing state of the building			
Location	Bežanijska kosa, Belgrade, Serbia	Profesorska kolonija, Belgrade, Serbia	Dorćol, Stari grad, Belgrade, Serbia
Construction year	1961	1950	1965
Number of floors	Basement + Ground floor + 4 floors	Basement + Ground floor + 5 floors	Basement + Ground floor + 5 floors
Purpose of floors	Basement | Storage Ground floor | Apartments Upper floors | Apartments	Basement | Storage Ground floor | Apartments Upper floors | Apartments	Basement | Storage Ground floor | Apartments Upper floors | Apartments
Number of apartments	20 (4 apartments on one floor)	36 (6 apartments on one floor)	12 (2 apartments on one floor)
Usable area of apartments	10 apartments with an area of 50 m2; 10 apartments with an area of 56 m2;	24 apartments with an area of 50 m2; 12 apartments with an area of 75 m2;	12 apartments with an area of 72 m2
Communi-cation	1 entrance and 1 stairwell, no elevator	3 entrances and 3 stairwells, no elevator	1 entrance and 1 stairwell, no elevator
Total heated area	Appartments 1091,70 m2	Appartments 2106,75 m2	Appartments 863,14 m2
Uneated area	Basement, stairwell	Basement, stairwells	Basement, stairwell
Heating system	Electric energy	Central district heating system	Central district heating system

Figure 3. Spatial-organizational and functional characteristics of the selected multi-family residential buildings, Image by authors

2.4. Energy aspect of the selected existing buildings

In all three buildings, the heated area includes the apartments on all floors, while the stairwell and basement are not heated. Calculation of heat transfer coefficients for the entire building envelope of the buildings, indicates significantly higher values than in energy efficient buildings (as required by the sub-law documents) (Fig. 4).

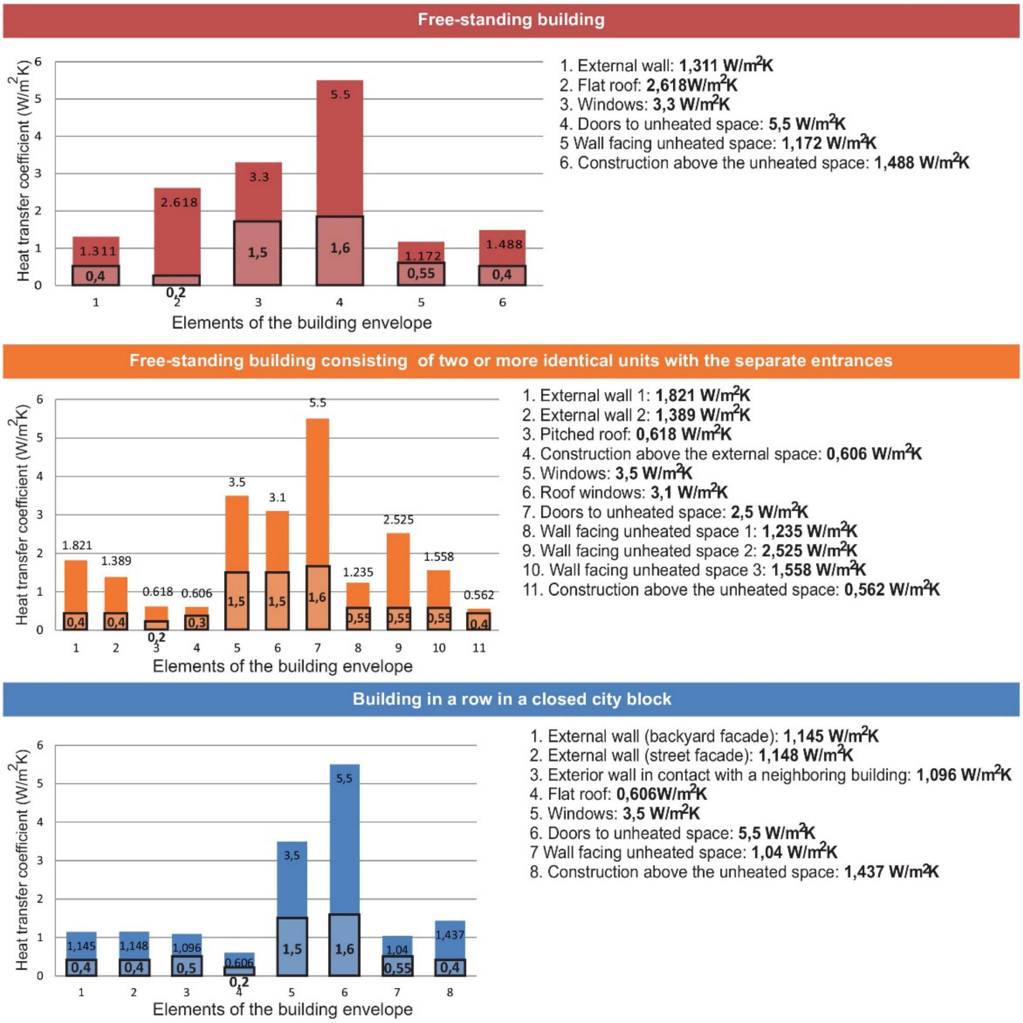


Figure 4. Comparative analysis - Heat transfer coefficients for elements of the building envelope and the highest permitted values of the heat transfer coefficient for elements of the building envelope of an existing building according to the Rulebook on Energy Efficiency [9]., Image by authors

Based on the calculation, the selected buildings have very high transmission losses and specific annual energy requirements for heating, so they belong to the lowest energy classes on the scale of energy efficiency classes for residential buildings (Fig. 5). It can be concluded that it would be extremely desirable to carry out energy efficiency renovations of the buildings to reduce the total energy for heating and, therefore, improve the energy efficiency classes.

	Free-standing building	Free-standing building consisting of two or more identical units with the separate entrances	Building in a row in a closed city block
Transmission losses	174191,31 kWh	345003,61 kWh	107674,22 kWh
Specific annual energy required for heating	163,85 kWh/m^2	193,75 kWh/m^2	135,63 kWh/m^2
Emission of CO_2	237013,16 kg	89802,05 kg	50223,32 kg
Energy class	F	G	E

Figure 5. Heat losses of the selected existing buildings, Image by authors

2.5. Energy efficiency/spatial/functional retrofit of the existing building with volumetric additions

The research represents the complex and integral refurbishment of the existing buildings by refurbishment of all elements of the building envelope according to the sub-law defined standards and by proposing volumetric additions to improve the spatial-organizational, functional, and energy performances of the buildings.

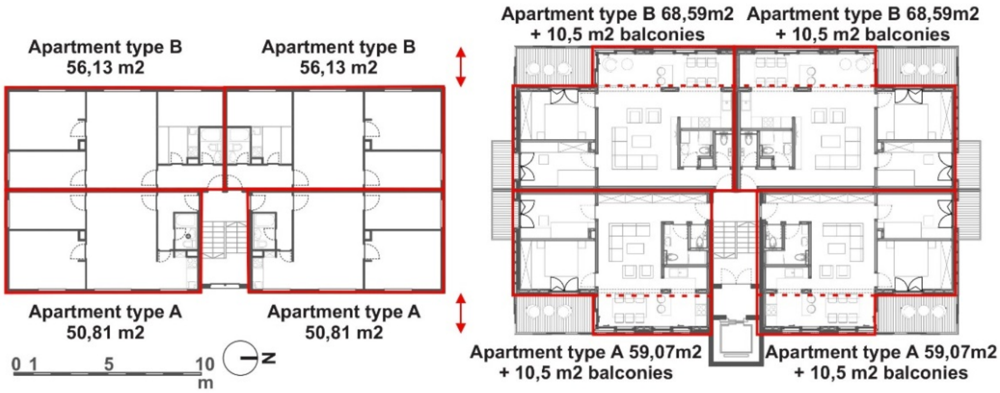


Figure 6. Spatial organization of apartments in the existing state of the selected free-standing building (left) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (right), Image by authors

For the free-standing building, the conceptual solution proposes volumetric additions on both longitudinal facades, which would increase the usable living space of residential units, and the addition of loggias on the longitudinal facades and balconies on the side facades. The solution also proposes the addition of an elevator (Fig. 6). The conceptual solution proposes a continuous volumetric addition on the roof of the building. The spatial organization of the upgraded floor would be the same as the typical floor.

For the lamella building the conceptual solution proposes volumetric additions on both longitudinal facades, which would increase the usable living space of residential units, and the addition of loggias on the longitudinal facades. The solution also proposes the addition of elevators (Fig. 7). The conceptual solution proposes a continuous volumetric addition on the roof of the building. The spatial organization of the upgraded floor would be the same as the typical floor.

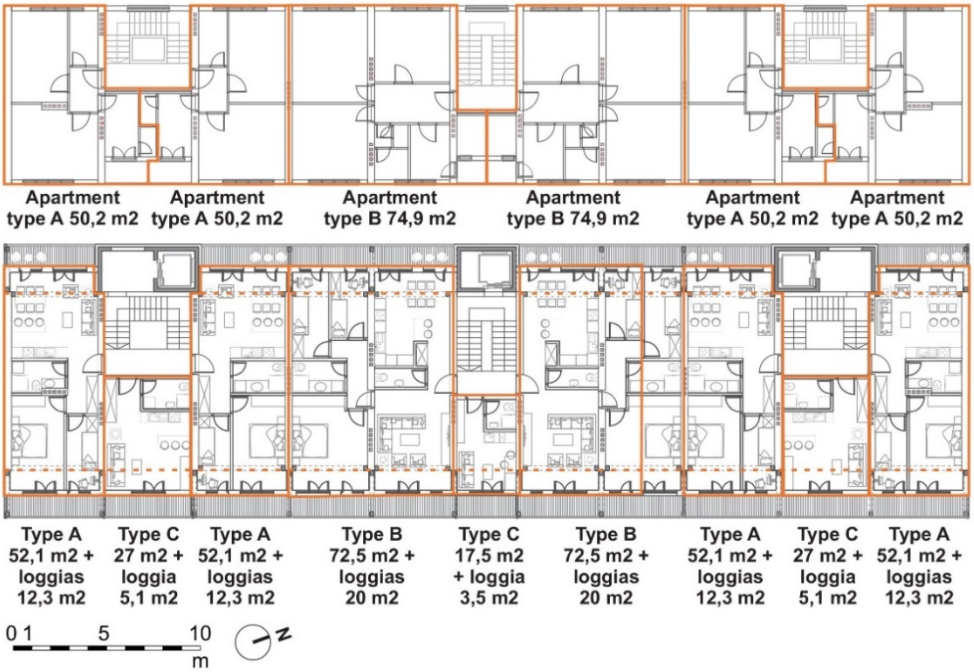


Figure 7. Spatial organization of apartments in the existing state of the selected lamella (above) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (below), Image by authors

Figure 8. Spatial organization of apartments in the existing state of the selected building in a row in a closed city block (left) and spatial organization of apartments through energy efficiency/spatial/functional retrofit of the existing building with volumetric additions (below), Image by authors

The representative multi-family residential building in a row in a closed city block belongs to the spatial, cultural, and historical complex "Area around Dositej's Lyceum," which has been declared a cultural heritage of exceptional importance. Due to its protected status, interventions on the street facade and roof of this building are not allowed in order to preserve the appearance of the surrounding architectural ensemble. Additionally, this building is situated on a regulation line, making it impossible to add additional volumes. Interventions are only permitted on the courtyard facade of this building. The conceptual solution proposes volumetric additions on the courtyard facade, which would increase the usable living space of residential units, and the addition of loggias. The solution proposes the addition of an elevator (Fig. 8).

3. RESULTS

Based on the interventions significant results were achieved in spatial-organizational, functional, and energy-efficient performances in all three selected buildings (Fig. 9).

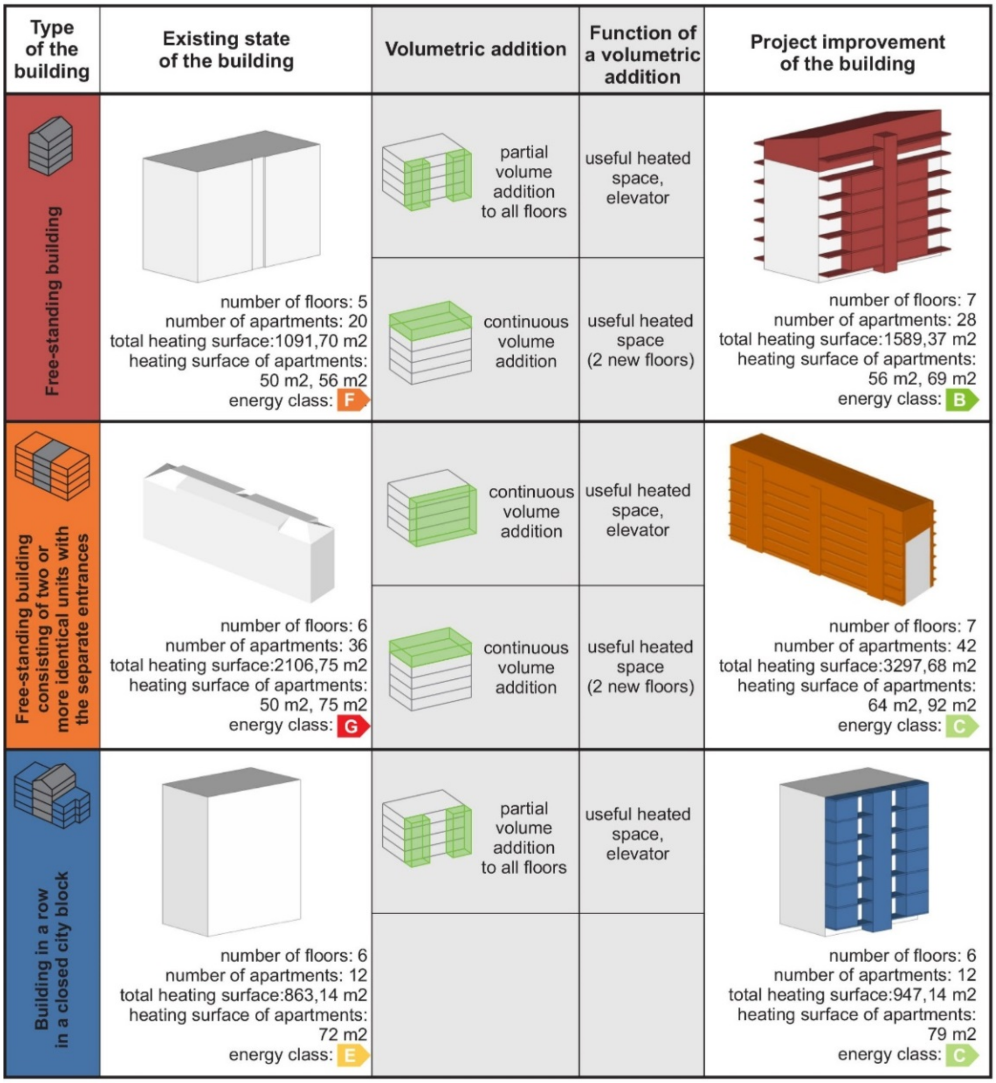


Figure 9. A comparative analysis of the existing states and the complex and integrated improvements in the selected existing multi-family residential buildings, Image by authors

4. DISCUSSION

Deep refurbishment methodology that included improvement of all elements of building envelope combined with volumetric interventions on the buildings has resulted in significant improvement of the performance of the analyzed buildings. Spatial redefinition of the units has given, at the same time, new quality to the process bringing rather outdated structures to the contemporary standards and user demands. Comparing the achieved energy levels, it is noticeable that all buildings fulfill the standards for new structures and even exceed them. As a consequence of the process significant reduction of carbon dioxide emission has been achieved (Fig. 10).

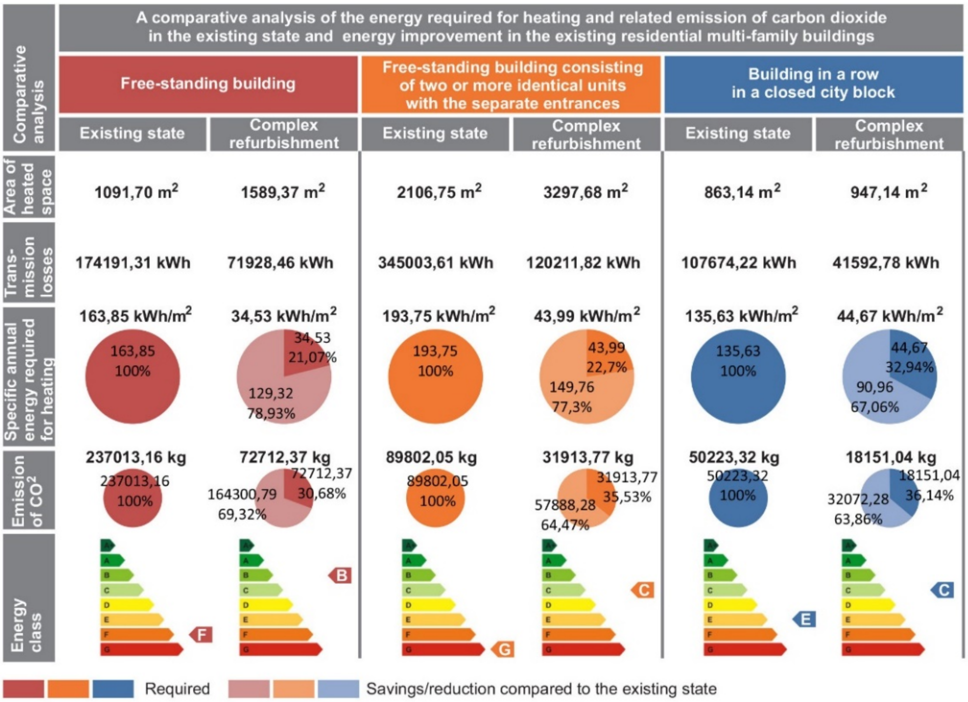


Figure 10. A comparative analysis of the energy required for heating and related emissions of carbon dioxide in the existing states and the energy improvements in the selected existing residential multi-family buildings, Image by authors

It is noticeable that the energy class of the freestanding building increased by 4 energy classes, from F to B. The same case applies to the freestanding building with three separate entrances, where the energy class transitioned from the lowest, G, to C. The reason for such significant shifts in the energy rating is due to the addition of volume to the façade walls and the entire roof surface. The usable heated space has significantly increased, along with the building's volume, and the overall building envelope has been improved.

In the case of a row building within an urban block, the energy class increased by 2 energy classes, from E to C, having smaller effect compared to the previous two cases. The reason for such a change in the energy rating is due to a smaller range of volumetric additions. Volumetric addition was applied only to one façade, while the other façade and the roof were not included.

5. CONCLUSION

The benefits that could be achieved by applying the strategy of volumetric redefinition of an existing building by addition of volumes are multiple. They are ranging from simple improvement of energy efficiency class to the redefinition of living spaces and bettering of overall performance of the building prolonging its lifespan and increasing the value. Considering that it is a very complex type of renovation that requires interventions on the entire building envelope, it can be concluded that this renovation strategy is most suitable for free-standing buildings as well as lamellas, because these buildings are mostly located in open city blocks and have facades that can be easily approached. This strategy is partially applicable to a row of buildings within a city block due to various limitations (urban, spatial, structural…). Complex and integrated refurbishment that are including the overall approach treating the existing buildings as a starting point for new design (redesign) including improving of energy efficiency but achieving, at the same time, spatial-organizational and functional improvements can be recognized as a valuable method for future practice. Having in mind modern theories of sustainable and resilient development professionals have to address the existing building fund as one of the greatest resources of a humankind and apply methodology that will enable its longevity and usefulness.

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INTELLIGENT TOOLS FOR LARGE-SCALE 3D PRINTING: A SCOPING REVIEW

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Abstract

In recent decades, building methods such as 3D printing have been increasingly researched for the design and fabrication of various architectural elements. Artificial Intelligence is another rapidly developing technology whose potential in the building industry is continuously being explored. This paper's objective lies in mapping out the field of existing Artificial Intelligence tools for large-scale 3D printing, searching for possible applications throughout the different development stages including the pre-fabrication phase with structural design, optimization, behavior simulations, and predictions, as well as the production phase through the real-time monitoring of the process. In this study, different types of Artificial Intelligence (such as machine learning, deep learning, and computer vision), have been identified regarding their role in 3D printing to assess its potentials, limitations, and the present research gaps. Finally, potential research directions and emerging topics are presented. The study's findings increase the understanding of Artificial Intelligence techniques and applications in the 3D printing process and can aid in choosing and implementing the most promising ones in further research.

Key words: *Artificial Intelligence, Additive Manufacturing, 3D Printing, Digital Fabrication, Architecture Design*

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1. INTRODUCTION

According to existing research, the limitations of 3D printing (3DP) methods and their application in the building industry, such as excessive time consumption, the inability to control the printing process in real-time, a lack of building consistency, imperfections in the printed parts, and others, could be addressed by incorporating Artificial Intelligence (AI) into the design and manufacturing process [1, 2]. Most often, AI is understood as a set of diverse computer algorithms that are capable of learning, reasoning, self-correction, and rational thinking, in a similar way that the human mind does [3]. The most researched types of AI in the Architecture, Engineering, and Construction (AEC) sector, among others, include genetic and evolutionary algorithms, neural networks, fuzzy logic, machine learning, computer vision, particle swarm optimization, deep learning, and expert systems [4]. Additive Manufacturing (AM) is a method of creating 3D objects by the layering of material [5]. Large-scale 3DP, a subset of AM methods, has the potential to allow the fabrication of non-standard elements on the building construction scale. Generally, binder jetting and material deposition method (MDM) are the two primary technologies utilized for large-scale 3DP [6].

A rapidly growing body of research can be found on the use of AI in the Architecture, Engineering and Construction Industry (AEC) [4, 7–10], as well as the phenomenon of AI-aided 3DP [11–13]. However, it was determined that there is still insufficient systematization and overview of available data needed to understand current trends and potential in the field. For this reason, this study presents a scoping review integrating both topics.

This study maps out the literature that is presently accessible on AI in large-scale 3DP and assesses the nature of the underlying ideas and techniques employed, to identify topics for future research. The research methodology is guided by affirmed frameworks [14, 15]. The main research question is pointed at the potential of different AI tools in large-scale 3DP. To answer this, a defined protocol is used which includes a systematic search strategy based on the information that can be obtained in the Web of Science (WoS) database, inclusion, and exclusion criteria for the study selection, and established criteria for the analysis of the sources of evidence. Next, a data charting procedure is established, a summary of the charted data, and conclusions are derived from the study. The contribution of this study lies in the research guided towards the presentation of key concepts and characteristics of the AI techniques and tools in 3DP technology used for large-scale applications, identification of the knowledge gaps, and informing future research on specific topics.

2. METHODOLOGY

Scoping reviews are an evolving means of informing decision-making and research that is based on the identification and examination of the literature on a particular subject or problem [15]. The primary distinction between systematic literature reviews and scoping reviews is that the former is highly specialized in an in-depth analysis of a particular research subject, whereas the latter is used to provide an overview perspective on general issues relating to the topic of interest. Because of this, a scoping review methodology was selected as suitable for this study covering a broad field of research.

2.1. Search strategy

As indicated in Figure 1, the search method is carried out using keywords and operators in the electronic Web of Science database. The search was limited to categories including Civil Engineering, Construction & Building Technology and Architecture, to get the relevant results. The papers that were chosen were published after 2013.

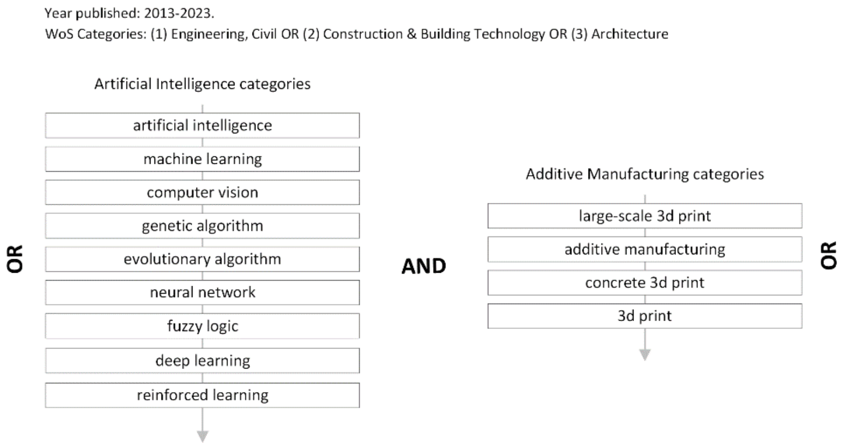

Figure 1. Keywords and operators used for the online database

This approach yielded a total of 64 results, which represent the primary pool of literature to be narrowed down using inclusion and exclusion criteria.

2.2. Data selection

After the initial search, the collected sample of literature was further assessed and filtered based on the topic, relevance, and full paper accessibility. The next step in the selection phase is the screening of the papers by reviewing the abstracts and eliminating papers that do not fall into the building science category or are not relevant to the research topic, which represents the main exclusion criteria. An important factor during the screening process is the focus of the screened papers on the specific correlation of AI and 3DP, not the processes separate. Finally, full texts were reviewed eliminating a number of papers based on the relevance to the research. The screening process left the selected papers at 14, as shown in Figure 2. The purpose of reading full articles was to develop insight and comprehension of the underlying concepts in the examined papers, providing the material for associated charts. In order to avoid selection bias the collection and screening were done as a two-step process with two researchers simultaneously screening the selected sample after the initial search and cross-checking the remaining selection while the third researcher was responsible for overseeing the process.

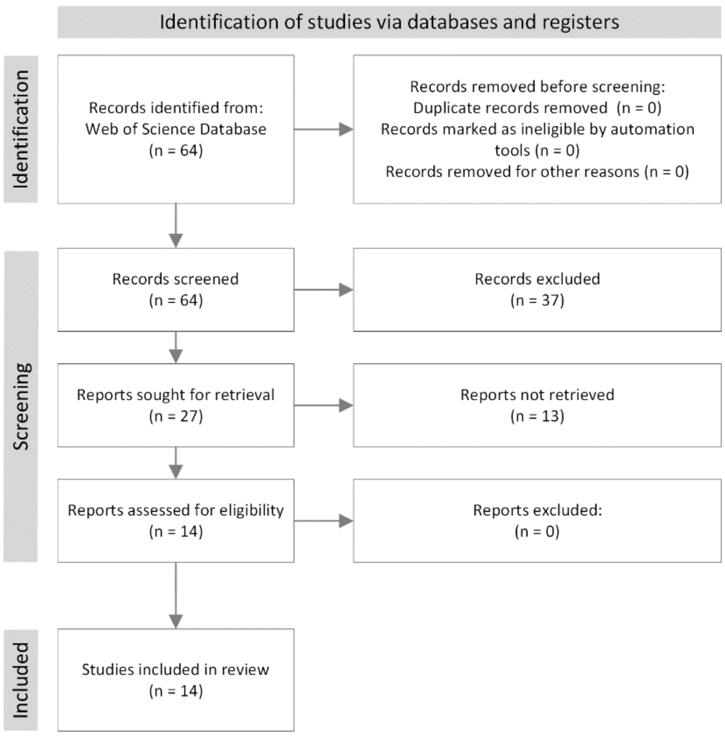

Figure 2. Flow diagram of the literature screening process

Among the selected papers, 4 are in the form of conference papers, and the remaining 10 studies are journal articles. Conferences and journals that were the source of selected papers are represented in Figure 3.

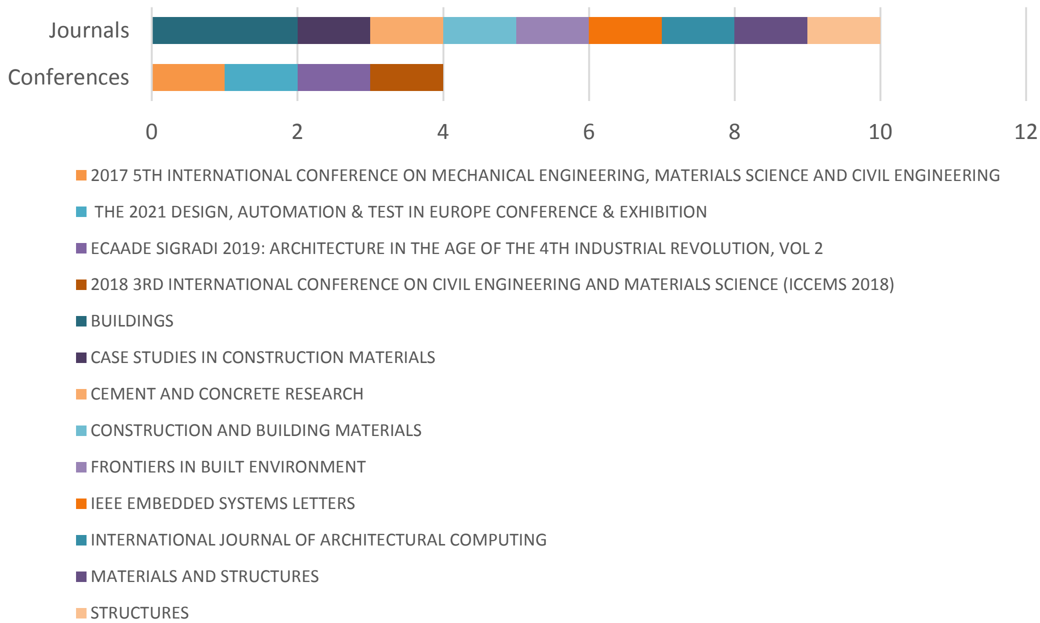

Figure 3. Names of the source conferences and journals

2.3. Data charting criteria

The data charting approach was used to discover the fundamental principles in the use of AI methodologies and tools in 3DP technology. This corresponds to the main purpose of this study, which is to acquire a broad picture of the potential of present and future applications and collaboration of the technologies discussed. The major purpose of the charting procedure is to highlight significant principles underlying the introduction of AI in the 3DP process, the main AI tools and methodologies, the function of AI in the design and manufacturing process, as well as the main findings and guidelines that the authors of the research have pointed out.

3. RESULTS

The research findings were summarized in three key aspects that together provide an overview of the concept of collaborative AI usage and 3DP: (1) the main AI tools and methods used, (2) the main applications and roles of AI supporting the 3DP process, and (3) key research findings regarding the challenges and benefits of the represented methods and techniques, as shown in Table 1.

Table 1. Summary of the main AI tools and methods, applications, and research findings

Paper	AI tools and methods	Applications and roles	Findings
[16]	Computer vision Deep convolutional neural networks	Geometrical accuracy measurements for 3DP elements	AI models are reliable in design variation detection and provide a feedback control system to automatically adjust the material deposition
		Automated layer detections	
[17]	Computer vision	Image-based object tracking	AI models are effective in tracking key features of the 3DP model
[18]	Machine learning	Conceptual design	A small amount of research of AI in 3DP is conducted in the building industry
		Design optimization	
		Geometry deviation prediction	
		Material analytics	
		Defects prediction	
		Final product performance prediction	
[19]	Multi-objective optimization	Performance-based façade panels design	AI aids in developing a performance-based iterative design of 3DP elements
[20]	Machine learning Computer vision	Timely detection of powder bed defects	The discovered issue relates to the imprecision in the image capture timing; The spattering identification algorithms have difficulty between similar defects; The process is not time consuming, except for

			normalization and active contouring
[21]	Machine learning Conditional generative adversarial networks	Performance prediction Rapid structural analysis based on unstructured point clouds	Neural networks have potential to integrate analytic and predictive information in real-time design and fabrication processes
[22]	Artificial intelligence in general	Sensor informed augmentation of the logic of 3DP processes	Not specific towards 3DP process
[23]	Machine learning	Detection of compromises in g-codes without having access to original models	Machine intelligence algorithms reduce the accuracy, therefore need to be trained and refined further
[24]	Artificial neural network	Quality control of material structural performance	The algorithm accurately predicts the structural properties; The neural network validly represents the relationship between input parameters and predicted properties
[25]	Computer vision	Online real-time extrusion quality monitoring	Computer vision is the most reliable and responsive technique for detecting printing material variations, compared to other techniques
[26]	Supervised learning Unsupervised learning Semi-supervised learning Reinforcement learning	Accurate material performance prediction Printing control through prediction models Quality inspection of construction components	For material design, the application of machine learning can improve construction production efficiency and save construction costs
[27]	No specific tool or method applied	Automated construction in 3DP in harsh environments	Current automation systems only apply on concrete materials in domain of 3DP
[28]	Deep learning	Automatic segmentation of x-ray scans of 3DP samples	Deep-learning segmentation method from the Dragonfly software was successfully used to extract the distribution of steel fibers inside the 3DP specimens
[13]	Machine learning Pattern recognition Computer vision	Material selection, optimization, quality assessment Predicting economic benefits	AI and Building Information Modelling (BIM) combined could lead to resolving multiple problems and challenges faced in 3DP

		Revising construction schemes	
		Optimizing 3DP robots, path planning	

2.1. AI techniques and applications in large-scale 3DP

The applied AI approaches are largely affected by their involvement in the 3DP process. Machine learning algorithms [13, 18, 20, 21, 23] have sub-variations in reinforced, semi-supervised, supervised, unsupervised [26], and deep learning [28], each with various capabilities and applications. Artificial neural networks [24], with variants in conditional generative adversarial networks [21] and deep convolutional neural networks [16], are the other most often used AI technologies. Computer vision [13, 16, 17, 20, 25] is another frequently employed approach in the reviewed study, with a sub-variation in pattern recognition [13].

The applications of AI can be found in different stages of the 3DP process, from design, through fabrication, to monitoring and evaluation of the manufactured parts. With the application of AI in the design for manufacture process, the conceptualization of constructions has the potential of becoming an iterative process that considers the specific manufacturing process limits and challenges [21]. This cohesion between technologies allows for the performance-based design strategy which aims at refining the initial designs to suit best the given environmental characteristics [19]. In the production phase, it is possible to establish a relationship between the digital models of the structure and the real-time extrusion process, altering the process if defects occur [16, 20, 25], as well as create accurate predictions on the material, structural and visual properties of 3DP elements and structures [21, 24, 26, 29]. The evaluation phase is mostly connected to computer vision algorithms which detect the anomalies in the printed parts [18, 26].

4. DISCUSSION

The study presents numerous relevant discussion points about the application of AI in large-scale 3DP construction. The first point highlights the gap in the number of papers discovered on different AI methodologies, with machine learning and computer vision dominating, while research on the application of evolutionary and genetic algorithms is less prevalent. Eleven of the evaluated publications focused on investigating machine learning tools, six on computer vision, and the remainder on other types of algorithms, as shown in Figure 4.

The second point relates to the stage at which AI is introduced in the 3DP process, where the studies dealing with print quality control prevail, and cost analysis is the least researched topic. Having in mind that large-scale 3DP applications are conceptually tied to the industrial sector, these topics should be of interest for future research, to enable timely integration in the building industry. The main concepts of application of AI found in the researched papers are represented in Figure 5.

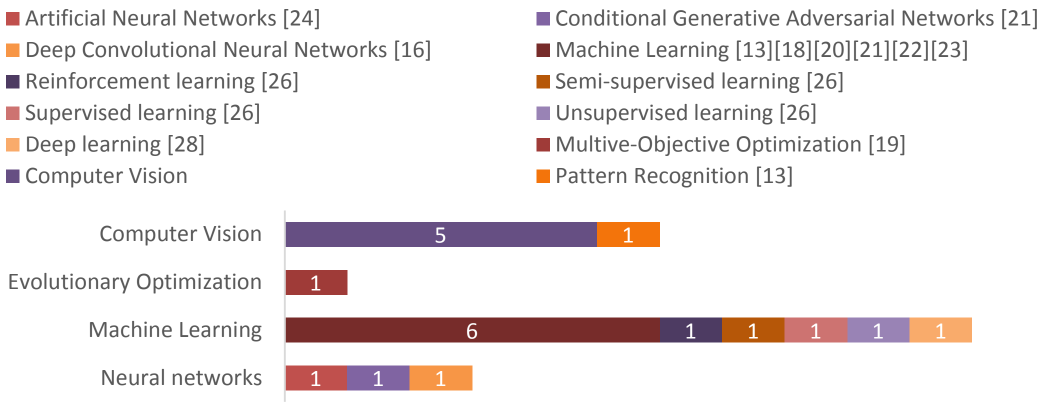

Figure 4. AI tools and methods. Paper reference stated in the square brackets.

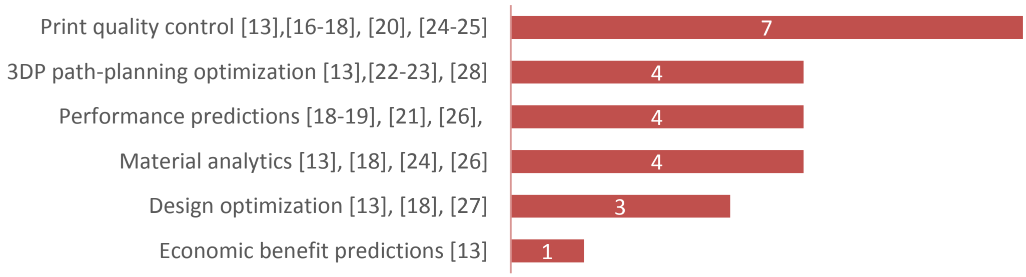

Figure 5. Applications of AI in 3DP. Paper reference stated in the square brackets.

As illustrated in Figure 6, this study emphasizes several potentials and problems uncovered during the literature assessment to select the areas most significant for prospective applications and research. One of the biggest challenges with deploying AI techniques such as deep learning and machine learning is the amount of data necessary to properly train the algorithms so that they can retrieve relevant and accurate data. The application is more complex because of the large computer power this technique generally requires. The 3DP processes have mostly been investigated in laboratory settings and for small-scale applications, and it has been acknowledged that more research is needed in the fields of building applications and real-world assessments. The papers evaluated largely deal with concrete or steel 3DP applications, limiting the conclusions to their qualities and ignoring a substantial portion of 3DP potential uses. A research gap in the study of sustainability and carbon emissions has been identified. Although some studies indicate the current development of research aiming at the reconstruction and conservation practice of architectural heritage utilizing sensing technologies in cooperation with 3DP, little evidence of such study exists in the examined literature. Several publications emphasize the need to evaluate computer vision approaches in real-world contexts, such as building sites, while keeping in mind the variations that may prevent such algorithms from operating in such conditions (such as differing light settings). The goal of applying AI logic to the 3DP process should be guided towards solving several key challenges that were posed with this technology, with emphasis on the problems that could be more efficiently resolved with computer intelligence, instead of using traditional methods.

It is important to keep in mind that the technology that is to be used on large-scale applications should at some point become profitable and accessible, which isn't currently the case in 3DP. Another challenge that is posed for the engineers and other professionals involved in the building process is the ability to use the AI tools, bearing in mind they are not trained or educated to use such tools. An important emphasis should be put on developing methods and tools which could be accessible to individuals outside of the academic environment, for it to be most efficiently integrated into current building methods.

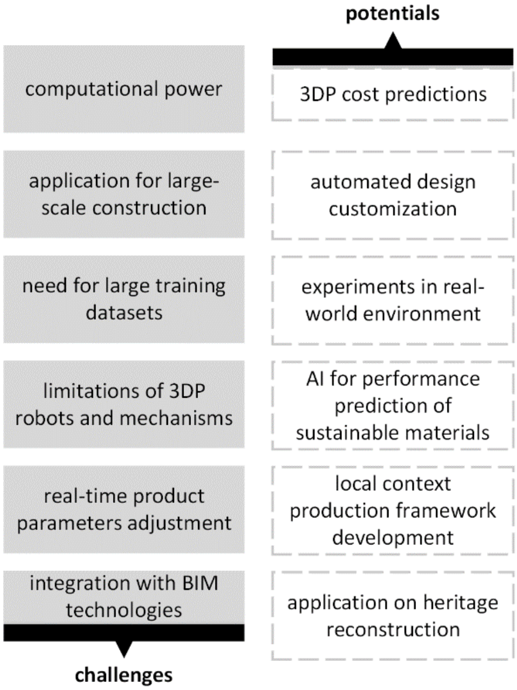

Figure 6. Potentials and challenges that accompany AI in large-scale 3DP

5. CONCLUSION

The study reviews and addresses applications and domains of AI in the large-scale 3DP design and manufacturing processes, highlighting specific underlying concepts that arise in the reviewed research. The methodological procedure was displayed, including the search strategy, data selection criteria, and charting procedure. Additionally, a PRISMA flow diagram of the selection process, as well as the main sources from which the selected papers originated have been shown. The main AI tools and methods, applications, and challenges have been identified and systemized. The several most often employed techniques have been identified and discussed, such as machine learning and computer vision, mainly used for defect detection in the printing process. Research regarding the direct linkage of the design process with parameters adjustment, and the fabrication process is less frequent in the context of AI techniques and therefore represents an important consideration for future research.

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Editorial note (will be filled in by the editors)

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[3] Nikolić Marko, Brzaković Milan: **Metodologija projektovanja**. *Građevinsko-arhitektonski fakultet u Nišu*, Niš, 2021.

[4] https://my.matterport.com/show/?m=fv7zvnF5pf6 *(15.4.2023.)*

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