UNIVERSITY OF NIŠ
FACULTY OF
CIVIL ENGINEERING
AND ARCHITECTURE

JOURNAL OF THE FACULTY OF CIVIL ENGINEERING AND ARCHITECTURE

39

ZBORNIK RADOVA GRAĐEVINSKO-ARHITEKTONSKOG FAKULTETA

vol. 39 | 2024

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vol. 39 | 2024

Zbornik radova Građevinsko-arhitektonskog fakulteta
Broj 39/2024.
www.gaf.ni.ac.rs/nip/zbornik/
zbornikGAF@gaf.ni.ac.rs
+381 18 588 200

Izdavač
Građevinsko-arhitektonski fakultet Univerziteta u Nišu
Aleksandra Medvedeva 14, 18000 Niš, Srbija
www.gaf.ni.ac.rs

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ISSN 1452-2845
ISSN 3009-4674 (Online)

UDK 624
Učestalost objavljivanja: jednom godišnje
Tiraž: 100
Štampa: Grafika Galeb Niš

Journal of the Faculty of Civil Engineering and Architecture
Volume 39/2024
www.gaf.ni.ac.rs/nip/zbornik/
zbornikGAF@gaf.ni.ac.rs
+381 18 588 200

Publisher
Faculty of Civil Engineering and Architecture, University of Niš
Aleksandra Medvedeva 14, 18000 Nis, Serbia
www.gaf.ni.ac.rs

For the publisher
Dr. Slaviša Trajković, Full Professor, Dean of the Faculty of Civil Engineering and Architecture of the University of Niš

ISSN 1452-2845
ISSN 3009-4674 (Online)
UDK 624
Publication frequency: once a year
Circulation: 100 copies
Printed by: Grafika Galeb Niš

PREFACE

We are proud to present the latest issue of the Journal of the Faculty of Civil Engineering and Architecture, now in its 44th year, with 39 volumes published. Two years ago, we recognized the need for the journal to evolve. Last year's volume marked our first publication in English, and this year, we have continued to develop. We are pleased to announce that the journal is now indexed in the CrossRef database, and all papers in this volume have been assigned DOI numbers. This development is crucial for enhancing the visibility and scientific impact of both the journal and its authors. We also plan to retrospectively assign DOI numbers to all previous volumes, starting from the very first, thereby digitalizing all past issues to preserve and protect them.

Internationalization is a top priority for the Journal of the Faculty of Civil Engineering and Architecture. As an initial step, we have strengthened the Editorial Board with experts from various countries. We plan to further reinforce the Board in the coming years. We expect the new website of the journal to be operational in time for submissions to the upcoming 40th jubilee volume. This new platform will streamline the submission, editing, and review processes, modernizing the journal. Additionally, we aim to apply for indexing in other significant databases.

We extend our gratitude to our authors for their continued support of the journal. This volume features 10 peer-reviewed papers from authors representing five countries: Italy, Poland, Austria, Bosnia and Herzegovina, and Serbia. Our 20 reviewers hail from five countries: Montenegro, North Macedonia, Romania, Croatia, and Serbia. Notably, 80% of our reviewers are external to the Faculty of Civil Engineering and Architecture in Niš. We are deeply grateful for their contributions and look forward to their ongoing support. The list of reviewers is published at the end of the volume.

Finally, we invite researchers to consider our journal for disseminating their research, and we pledge to continue working on increasing the journal's scientific impact.

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

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

CONTENTS

submitted: 08.02.2024.
corrected: 02.04.2024.
accepted: 07.04.2024.

Research scientific paper

UDC : 711.4(497.6)
https://doi.org/10.62683/ZRGAF39.1-12

BANJA LUKA URBAN AXIS AS THE ARCHITECTURAL RECORD OF HISTORICAL DEVELOPMENT

Miroslav Malinović[1]

Abstract

The paper reviews the connection of the historical timeline and principal stages of development, on the one hand, and the urban axis – the main street in Banja Luka, on the other, as a very accurate historical record of urban development. The urban development axis in Banja Luka is a vast resource in terms of architectural layers that chronicle architectural evolution in general and live history of historical chronology with extraordinarily distinct and recognisable expressions reflected in the built environment. Present-day architectural heritage is the most solid evidence of that development. It is linked to ruling regimes, bringing up in focus the relation of each stage to their benefactors, examining their influence on the image of the urban cityscape in Banja Luka as it exists today.

The architecture along the analysed urban backbone is studied using historical research methods to examine the relationship between historical growth and its impact on urban development, focusing on the geographical shift of main activities on the same street.

The paper begins with a brief overview of key historical events that shaped Banja Luka's development to properly assess its impact on this single road, which was transformed from an ancient communication route to a modern four-lane street. Beginning with the Ottoman era, with the first documented and some remaining traces of architecture, each successive historical period is shown through the overview of the built heritage, linked to its functional and social role in the city. The architecture and cityscape properties heavily influenced by this urban backbone are evaluated and presented, along with stylistic adherence, key facts, development, and current status.

The primary goal of this paper is to address the architectural heritage of Banja Luka's urban backbone – the central axis that has remained the focal point of all authorities and a rich source of inspiration for notable achievements, decisively influencing the image of modern-day Banja Luka. It is intended to demonstrate that all major construction activities, regardless of their benefactors, historical era, or function, occurred along the same route, historically and still widely regarded as Banja Luka's urban axis.

Key words: *Banja Luka, Urban Axis, Historical Development, Architectural Heritage*

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1. INTRODUCTION

Present-day Banja Luka is the second largest city in Bosnia and Herzegovina, resting on four rivers with evidence of human settlements since the Eneolithic. Its historical and contemporary development axis is aligned with a street stretching through the heart of the city in the direction south-north. During the Roman period, it was the stretch of the vital route connecting the towns of Servitium and Salona, located in the provinces of *Panonia* and *Dalmatia*, respectively. So-called *Salts Road,* unfolding through present-day Banja Luka, was adjacent to the Roman fortifications along the Vrbas River. During the Ottoman period, when Banja Luka started to receive its present shape, it connected *Gornji Šeher* and *Donji Šeher* (tur. *şehir* – town, city). Besides the Medieval fortifications, the Ottoman period holds the first preserved urban fabric traces witnessing the importance of the axis – featuring two large waqfs with mosques as main buildings. The axis was named *Kaiserstraße* during the Austro-Hungarian period when it received the look and condition of a European street. It was lined with tree alleys and expanded significantly with buildings for several newly established institutions – public, military and sacred, as well as private constructions that were all built northern from the old Ottoman, Donji Šeher. After World War I, the street was renamed Kralja Aleksandra, and quickly after 1929, it was further expanded with palaces for the new administrative bodies. Even after World War II, the practice of significant construction activities along the axis continued with another renaming – *Titov drum.* First, in the Yugoslavian era, among others were built the main city shopping centre, main square, and new military headquarters, followed by post-1995 development stages featuring new national headquarters and government buildings, slipped into free construction lots along the same street, currently named *Kralja Petra I Karađorđevića.*

The study explores the architectural character that shapes the urban environment along the analysed urban backbone. It delves into the relationship between historical development and its impact on urban growth using historical research methods, a published bibliography, and national and international archival sources, followed by on-site analysis and explanatory patterns. At the same time, it focuses on how vital social activities have shifted geographically within the same street over time.

2. HISTORICAL OVERVIEW OF SOCIO-POLITICAL CIRCUMSTANCES

Banja Luka's growth is similar to any other middle-sized town in Southeastern Europe, with a moderate climate and appealing topography supplemented with various natural resources, primarily rivers and farming land. The initial emergence of habitation on the site of current-day Banja Luka dates back to the prehistorical age. Historically documented traces of urban development on the site of modern Banja Luka date as early as the Roman era. A station, possibly a military camp with a small settlement named Castra, can be identified at a location corresponding to modern-day Banja Luka on the banks of the Vrbas River. Its position can be seen in *Tabula Peutingeriana* on the so-called *Salts Road,* connecting the Roman settlement of Servitium (modern-day Gradiška) and Salona (near the modern-day Split). Following the demise of the Roman Empire, Slavic tribes quickly acquired control of the western Balkans, establishing the first Medieval nations, forerunners of current states on the Dinarides' slopes. [1]

Following the fall of the great Serbian empire in 959, the settlement that would eventually become modern-day Banja Luka was discovered in one of the newly created states – Bosnia. Later, during the decades, it changed borders, sovereignty, independence, and crown monarchs – indigenous from local dynasties and outsiders, mostly Hungarians. After the defeat of Bosnia under Ottoman raids in 1463, Banja Luka was included in Banate Jajce, which the Hungarian Empire administered. Soon, in 1494, the name Banja Luka was mentioned for the first time in written sources. It was the charter of King Vladislaus II of Bohemia and Hungary, in which he sought to help protect the country against the Ottoman Turks and named all fortresses, among which was Banja Luka. [2] That Banate lasted in this vassal status until 1528, when the Ottomans took over the remaining areas of the Banate. [1]

The Ottomans initially settled in *Gornji Šeher*, presently Banja Luka's suburban district of *Srpske Toplice*, possibly the site of a Medieval fortification, and then in *Donji Šeher*, later to become modern-day downtown with surviving fortification Kastel. The affluent time lasted until 1638, when Banja Luka was demoted to the level of *kadiluk*, bringing its development chart to a very flat, almost downstream line.

The Treaty of Berlin (June 13th- July 13th1878) made crucial choices for Bosnian Vilayet's future growth. According to the Treaty, Vilayet of Bosnia and Sanjak of Novi Pazar remained in the Ottoman territory and under its formal sovereignty. Still, the Austro-Hungarian Empire got permission to exercise military control and administer the area. [3, 4] Banja Luka was a small provincial town in Eyalet of Bosnia and Herzegovina during the Austro-Hungarian occupation. It was later transformed in social, religious, economic, and educational contexts, moving one step closer to the image of a Central European town of similar size and recognition.

Establishing banates, newly introduced administrative regions, was the most rewarding growth throughout the Kingdom Period (1918-1941). Its first governor was Svetislav Tisa Milosavljević. During his reign (1929-1934), he built a large number of public buildings that were placed over the urban fabric laid out by the Austro-Hungarian authorities, particularly along the central axis of *Bulevar kralja Aleksandra* – King Alexander's Boulevard, a former Austro-Hungarian Kaiserstraße. Significantly, Milosavljević's goals left enough open – unbuilt space, which proved crucial for post-World War II urban growth.

Bulevar kralja Aleksandra, later renamed *Titov drum – Tito's Road*, was recognised as a solid urban axis after World War II. However, new politics performed by The Federal Urban Planning Department, seated in Sarajevo, plotted the axis dissolution in 1952, with new focal points of development along the Vrbas River. [5] A natural hazard in 1969, caused by a large earthquake, halted such initiatives. The following planning activities brought back the historical longitudinal layout along the central axis and foresaw new residential neighbourhoods around the downtown.

Civil war and its aftermath did not benefit the cityscape in the late XX century. On the other hand, the isles of greenery along *Kralja Petra I Karađorđevića*, which is the most recent and current name of the axis, and unused public spaces have been converted into construction sites, continuously harming not only historical layers of architecture but also the atmosphere, the luxury of green zones, the parks, and the climate, with constantly arising traffic contributing to overheating in the downtown.

3. THE URBAN AXIS ORIGIN AND DEVELOPMENT

3.1. The Ottoman era (1528-1878)

The architectural layers predating the Ottoman era do not exist along the length of the axis, except the Kastel stronghold, which is a fusion of the Medieval core and Ottoman add-ons. The only beneficial time for the development of Banja Luka in terms of urban, social, and economic environment during the Ottoman rule was from 1553 until 1638. In 1553, the seat of Sanjak bey was moved from Sarajevo to Banja Luka, resulting in new construction activities and settlement expansion along the route of Gornji Šeher – Donji Šeher and further to the northern suburbs – creating *Carski drum* – Tsar's Road, a recreation of the *Salts Road*. The following significant year was 1574, when Sokollu Ferhad Pasha rose to power. This is the first period in the city's history that records extensive works, the construction of significant sacred, public, and private buildings, and infrastructure development.

That resulted in the Vrbas River's meadows becoming the development's southern axis. Some traces of the Ottoman era are still visible in the urban fabric in the city's southern suburbs – dominant mosques with belonging graveyards that marked the positions of tur. *mahalle* – residential settlements, groups of small single-family houses in an irregular urban pattern, with narrow streets and walls outlining the borders between neighbours. Non-Muslim settlements, predominantly Serbian, Croatian, and Jewish, were located in the northern part of the town, Latinska Varoš, which started to develop more after the *tanzimat* reforms in 1839. [6]

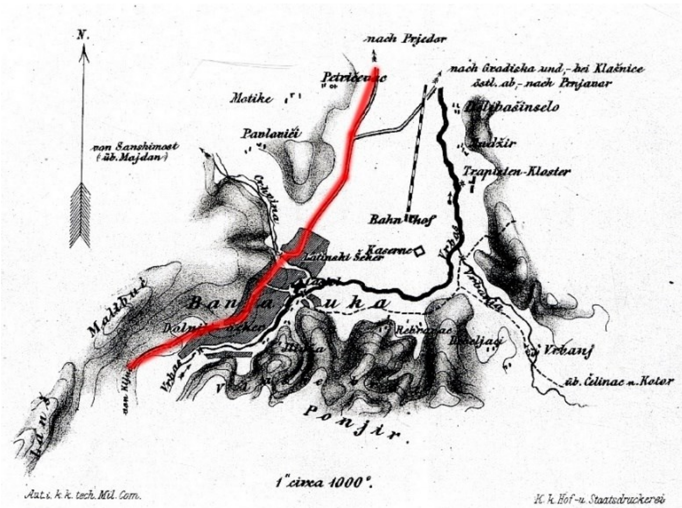

Figure 1. Banja Luka and its surroundings are on one of the Austrian maps dating from 1863. This map edition was issued in 1863 on a “Wiener Zoll” scale, 24x20cm. The axis route, Carski drum, is highlighted, stretching from northern to southern suburbs through Donji Šeher and Latinska varoš (Archive collection of Austrian National Library (K I 112916,1 Kar), Map Department, Vienna)

The old Roman road, however, which was identified and utilised as the primary road along the fortress Kastel and upstream of the Vrbas River, was recognised as a viable backbone, which was subsequently confirmed to be correct. By the end of the Ottoman rule, the road became known as the *Tsar’s Road – Carski Drum*. The Ferhadija mosque and the Clock tower – Sahat kula, were erected at the intersection of Carski drum and the Kastel's western entrance road. Sokollu Ferhad Pasha sponsored the mosque's construction and commissioned one of Mimar Sinan's disciples to design and construct it. With its aesthetic authenticity to sixteenth-century traditional Ottoman architecture, it is considered one of the finest achievements in the Vilayet and beyond. [7] It was recognised as a UNESCO-protected heritage site and a National Monument in Yugoslavia. In 1993, during the Civil War, it was destroyed. It was reopened in 2016 after being fully repaired and furnished by its historical predecessor. Bojića Han was another Ottoman structure on the northernmost section of the axis. Han is a typical Ottoman building typology that often includes a multifunctional market, trade areas, and accommodations. Bojića han is one of six complexes retained in Bosnia until the end of the Ottoman administration, and it is considered one of the most well-equipped. During the Austro-Hungarian era, it was demolished. [8] Between 1858 and 1860, almost towards the conclusion of Ottoman rule, the Tsar's Road was widened, critical for the subsequent growth phases. [5]

3.2. The Austro-Hungarian era (1878-1918)

Unlike other occupied cities in Bosnia and Herzegovina, the urban fabric established during the Ottoman occupation was left intact, with the shift of the centre of the new European *varoš* (town) away from the Ottoman *čaršija* (downtown) and the Vrbas River towards Latinska varoš, already inhabited by non-Muslims. The flow of the Crkvena River, very close to the Ferhadija mosque, was set as a natural barrier between the old – Ottoman and the new – Austro-Hungarian Banja Luka by newly-arrived engineers, who were sensitive to the Oriental expression in the construction of traditional Ottoman mahalas, thus preserving the historical legacy of previous rulers. Construction of several public buildings began in that environment as early as 1879. In most cases, new authorities constructed buildings for newly established organisations and amenities such as railway stations, banks, hospitals, courts, schools, and industrial and military facilities, which did not exist in the preceding system. Kaiserstraße was home to the majority of these structures. The joint Imperial and Royal Army troops played a vital part in construction activities, primarily through the construction of railway infrastructure and stations, as well as an enormous number of military facilities and whole cityscapes enclosed for their activities.

Apart from a few exceptions, like Franz von Mihanovich's Elementarschule in Gornji Šeher, completed in the Orientalizing style in 1896 [9], growth was concentrated in the northern, at the time, suburbs, with predominantly non-Muslim communities and poor infrastructure. The newly widened main road, Kaiserstraße, was wisely used to support the future modern city, opposing southern, old Ottoman mahalas between Gornji and Donji Šeher.

Closest to the Ottoman urban fabric were built the Prison or the "Black house" (1889) and the Tsar's School, also known as *Volksschule* (built 1885, reconstructed 1907). Its architecture strangely combined the traditional Dinara house with Classic Revival. It was demolished in 1969, and the Faculty of Electrical Engineering was later built on its site. [10]

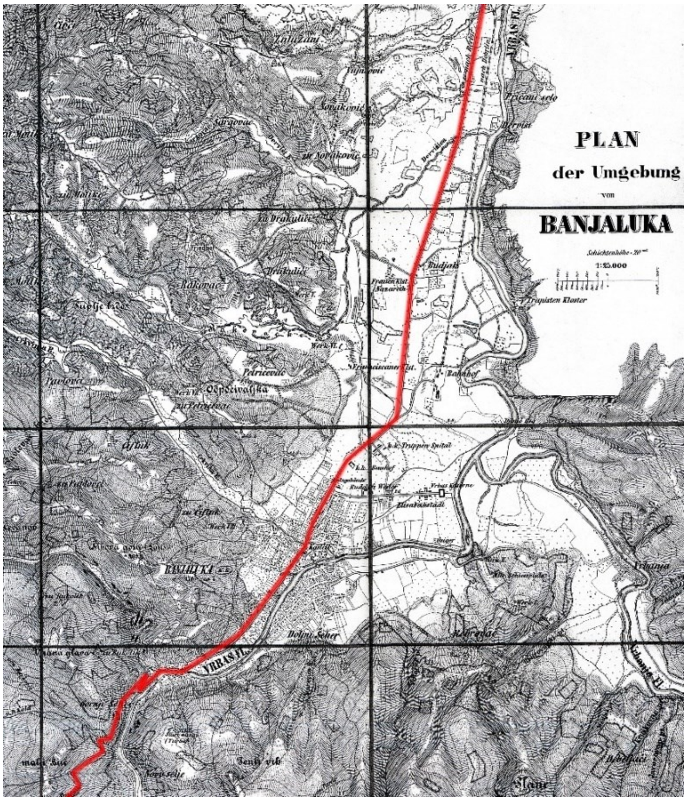

Figure 2. Banja Luka and its surroundings between 1880 and 1884, also known as the "Austrian map" with Kaiserstraße highlighted. This map edition was issued in 1890 in scale 1:25.000, dimensions 41x48cm (Archive collection of Austrian National Library (KB 111072 Kar), Map Department, Vienna)

A Muslim library or tur. *kiraethana* was built in 1890 on the mosque's northern flank. It was designed by Croatian architect Ćiril Metod Iveković [11], who is most known for his work on the city halls of Sarajevo and Brčko. [8, 9] Between WWII and the 1969 earthquake, it was utterly demolished in favour of Kaiserstraße widening. It was designed in the Orientalizing style, often indicated as Moorish Revival or pseudo-Moorish in older research findings. It had a square foundation with the ground and one level above, with a simple cornice tracing its outline. The façade was done with horizontal banding, probably dark yellow, red, or orange. Windows were arched, with a wooden segmented layout in a glass pattern. The northern corner oriented towards Kaiserstraße was accented with a wooden oriel bay, often seen as a divanhana element in traditional houses.

Along the Kaiserstraße, north of Kiraethana, were erected the Renaissance Revival *Banja Luka Stadt Bahnhof* – Main Railway station, in 1891, the Herrengasse – the city's main pedestrian and retail zone, and *Militäramtsgebäude* – Military Headquarters – in 1879. [12]

Many sites were constructed for the Roman Catholic Church, a significant player in many elements of Banja Luka's life, not only religious. The Serbian Orthodox Church had substantial assets in the city, although their actions throughout the Austro-Hungarian period did not result in many notable architectural works.

The Church's most significant site was the Cathedral Church with the Diocesan headquarters, located next to *Militäramtsgebäude* on the eastern side of

Kaiserstraße. The cathedral was constructed between 1884 and 1885, following the design of the Trappist monk Eberhart Wegnant, the architect of several other sacred buildings in Banja Luka. [12] The original church was destroyed after being damaged during the earthquake in 1969. The School of Adorers of the Blood of Christ was another significant structure built by the Roman Catholic establishment. The school was located across the *Militäramtsgebäude*, on the western side of Kaiserstraße. It was constructed in 1903 and was undoubtedly one of Banja Luka's most famous secession structures. Simple corpus geometry, shallow Avant-corps with highlighted gable walls, and mighty structural ornamentation with floral motifs were levelled up from the ground zone to the peak in the roof above. The school was in operation until 1943, when it was confiscated and turned into a public Gymnasium for girls on September 18, 1946, as part of the nationalisation process. That school was operating until 1969, when it suffered earthquake destruction and was torn down [10], later to be replaced by yet another military facility.

On the site of former Bojića han, on the northern part of the axis, just after the occupation, an army recovery hospital was established. Featuring vast greenery and a park, it was eventually revealed to be the city's central park, which is now known as *Park Mladen Stojanović*. The Evangelical church and parish house, jointly in one building, designed by architect Ludwig Huber in 1895 in Classic Revival Style, was erected next to the park on its southern boundary. It lost its original use after WWI but is still used as an office building, with most of its architectural characteristics intact. [13]

Along the Kaiserstraße, industrial facilities were also constructed. On the ground between the Cathedral and the Kaiserstraße railway station, the *Tabakfabrik* - Tobacco factory complex was built. Even though it was designed without original architectural features, its contribution to the landscape and intact building condition make it unique for industrial archaeology in Banjaluka, where the Tobacco plant is located. [1] Another railway station, *Kaiserstraße Bahnhof* – Kaiserstraße Railway station, was erected in 1891 between the Evangelical church and the Tobacco plant. A tiny station building with oriental characteristics was utilised until 1969, when it lost its original role and is currently being used as a restaurant.

The western side of Kaiserstraße is occupied by a line of luxury urban villas – *Kaiserstraße Villagegend*- erected for highly placed army or diocesan officials. They are all built according to authentic residential architecture, as seen in the XVIII and early XIX centuries in high hills in Austria and Switzerland, which makes them very unique and odd at the same time for the local setting. They are still considered the most valuable residential houses in Banja Luka. [1]

Beginning with the *Militäramtsgebäude* and ending with Mladen Stojanović Park, the whole cityscape is recognised as the National Monument of Bosnia and Herzegovina. [14]

3.3. The Kingdom (1918-1941/45)

Even very modest, later results were decisive infrastructural projects and constructions undertaken during the occupation and annexation period (1878-1908 and 1908-1918), which were not perceived as such at the time. Only later growth phases revealed how accurate the decisions were between 1878 and 1914. During the Kingdom of Serbs, Croats, and Slovenes, then the Kingdom of Yugoslavia, primarily during the Vrbaska Banovina 1929-1941, all major planning activities occurred among focal points established during the Austro-Hungarian period. New constructions were occurring adjacent to the buildings mentioned above, along Bulevar kralja Aleksandra, the newly established name of the axis.

Near the Ferhadija mosque, another mosque with a graveyard was located. Both the mosque, located on the eastern side of the axis, and the cemetery on the western were demolished in the early 1930s. A modern hotel, Palace, replaced the mosque in 1933 [15] according to a design by Dionis Sunko, and on the western side of the street, the park devoted to writer Petar Kočić, which will receive a famous sculpture by Antun Augustinčić and Vanja Radauš in 1932. [5]

The complex of *Banski Dvor* and *Banska Uprava – the regional governor's palace and the town hall* – is undoubtedly the most prominent complex constructed during the Kingdom. The buildings were built in 1930 and 1931, respectively, in academised Byzantine Revival style with Classic Revival components, according to designs by Belgrade architects Jovan Ranković, Anđelija Pavlović, and Jovanka Katerinčić-Bončić. According to a design by Belgrade architect Duan Živanović, the Orthodox Cathedral of the Holy Trinity was erected between the structures of Banski Dvor and Banska Uprava between 1925 and 1930. It is regarded as one of the pinnacles of Byzantine Revival sacred structures constructed in Yugoslavia before World War II. It was demolished in 1941, just at the start of WWII. [15]

Another essential building constructed during the Kingdom was the first multi-family residential building in Banja Luka, built for newly arrived administration staff, next to the Park Petar Kočić. It was designed by Edgar Kobenzl and constructed in 1929, with distinctive elements of late classic revival architecture combined with modern housing systems incorporated. [16]

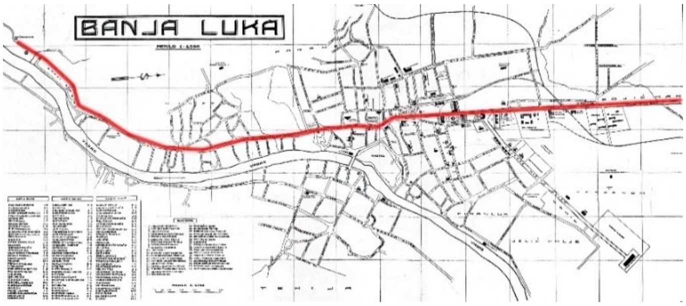

Figure 4. Highlighted Bulevar kralja Aleksandra in the central section on the tourist city map, original map issued in 1936 in scale 1:4200, dimensions 54x25cm (Archive collection of Austrian National Library (K I 102678 Kar), Map Department, Vienna)

In 1934, the National Theatre, then known as the House of King Peter the Great, was constructed on the western side of the Kaiserstraße, between the Ban's Palace and the *Militäramtsgebäude*, designed by Josif Goldner. Its aesthetic adherence, sometimes seen as a reflection of the Bauhaus, mixes Modern and Classic Revival architecture. It remains primarily kept in its original state and function [15] and is recognised as the National Monument of Bosnia and Herzegovina. [14]

3.4. Yugoslavia (1945-1991/5)

Until the catastrophic earthquake that struck the city in the fall of 1969, the growth of *Titov drum* (Tito’s Road), the new name of the axis after being named after Ante Pavelić (1941-1945), was not as intensive as it had been in earlier times.

First, in 1955, a headquarters of the Post Office was built by Bogdan Stojkov on the eastern side of Tito's drum, next to the residential building for civil servants. [17] It was designed with International Style components and a striking white-grey Bauhaus colour scheme, similar to the business Čajavec high-rise administrative structure erected across the road in 1965-1967. An administrative building of the significant industrial conglomerate, Čajavec, was built on the site where the previous Kaiserstraße was split into a pedestrian-only zone, Herrengasse. It was the highest building in Banja Luka at the time, with 13 floors, and it overlooked the whole landscape of low-rise structures. A local architect, Josip Vidaković, designed it with clear reflections of the International Style. Both structures are used according to their original functions. [1, 18]

The city was severely damaged during the earthquake, resulting in several immediate and later demolitions. After a large residential building next to the Palace Hotel, the so-called Titanik, was demolished, a big open area in the heart of the town opened up for new designs. An idea for a massive retail mall and public square was chosen for development in 1974 as the outcome of a significant international competition. *Boska* was the most important centre of its sort in Bosnia and Herzegovina at the time, designed by Velimir Neidhart, Ljerka Lulić, and Jasna Nosso as a highly meticulous blend of Socialist Modern and Brutalist architecture. [5] It still marks the Krajina Square; however, its purpose has been modified.

Following the destruction of a small section of Herrengasse, market house Triglav, today known as Kastel, was built in 1982, according to the design of Nebojša Balić. [19] It perfectly encapsulates the 1980s architectural approach, which was "trapped" between Western European tendencies and locally based Socialist Modernism.

Some transformations and new constructions took place on the northern stretch of the axis. Militäramtsgebäude was transformed into a regional building and later became the national archives building. Next to it, the Cathedral, also demolished in the earthquake, was replaced in 1972-1973 by the church designed by Veya Gazibara and Ljuboslav Matasović (façade design by Danilo Fürst, 1987), inspired by the shape of the Old Testament's tent. Boštjan Fürst designed the tower, which was added in 1991. Across the axis, the authorities appointed the Yugoslav Army to confiscate the land on the site of the demolished School of Adorers of the Blood of Christ post-earthquake period. Army's Cultural Centre was erected on the site of the demolished school in 1974-1975, according to a design by Kasim Osmančević. [18] Currently, it serves as a National Assembly.

3.5. Bosnia and Herzegovina (1995-)

In some ways, the healing process following years of war devastation is still ongoing. With several still unresolved destructions of religious buildings across the town and without active warfare operations in Banja Luka during 1991-1995, economic expansion and social image left little imprint on the urban fabric, which had been frozen for a long time in the post-war era.

The rebuilding of the destroyed Orthodox cathedral church began during the war, and it was fully restored in the early 2000s, restoring the secular and religious core of modern-day Banja Luka to its former glory. Except for one development at the turn of the century, the southern section of the Kralja Petra I Karađorevića, the current name of the urban backbone, did not alter significantly. Budimir Sudimac and

Milan Vujović designed the business centre *Ekvator* in the late Postmodern style. The seat of national institutions on the opposite, northern side of the urban axis is yet another example of the late International style, anyhow not genuinely linked to the early XXI century. Located next to the *Kaiserstraße Bahnhof* building, between the Tobacco Factory and the Mladen Stojanović Park, this complex features two high-rise buildings housing the national Government. Besides being the biggest administrative complex in Banja Luka, the latest addition of a larger scale shows how the post-war development works very well: largely questionable treatment of heritage and cityscape preservation, unclear architectural aesthetics and misuse of early XX-century principles in the early XXI century.

The period from 2020 remains highly disputed in the local community, with several ongoing constructions and announcements of new sites speaking in favour of questionable architectural values introduced along the axis. With the rise of public activism, unresolved questions in the planning process appear to open further discussions examining the responsibility of the critical stakeholders in the process.

First is the case of a private hotel located in the line of urban villas – *Kaiserstraße Villagegend,* on the site of a previously demolished building that had earlier replaced one of the villas damaged in the earthquake, yet featuring arguable proportion, size, and volume. In that case, applying fake wooden façade decorations, violet light shows, and inappropriate free-standing bronze sculptures are handy to demonstrate present-day aesthetics. Still, again, they truly reflect the image of society. The second questionable design is located across the Banski Dvor. Likewise, it is another case of demolition of 1960s architecture with intended design falsely attributed to Classic revival, according to the owners – very similar to what is seen in present-day Skopje downtown.

The most recent projects are located along the southern part of the axis. Last year, the extension of the Palace Hotel was announced and is currently under construction according to the project done by Hani Rashid. The project announcement has disturbed the spirits in the local community, polarising the groups supporting contemporary development and those arguing for preserving the cityscape, disregarding the actual needs of the growth. A similar case occurs across the axis, next to the Park Petar Kočić, where one of the historical buildings from the 1930s is entirely demolished and meant to be replaced by highrise development. Even though the methodology used to review and understand the architecture from a historical perspective requires additional time and distance, such cases speak for themselves and with certainty will permanently pollute the urban cityscape, but again, very honestly reflect the present era – deeply stuck in the mud of globalisation, self-identity loss, and controlled media.

4. DISCUSSION

As a reflection of general principles of the town establishment process, the occupancy of particular streets or limited urban zones for crucial governmental, public, religious, and other notable roles was a natural process before the constitution of the discipline of urban planning. What distinguishes the situation of Banja Luka is the succession of historical reversals that were always followed by new political regimes, all of which stayed inside the same, elongated geographical zone of interest – a single street or the urban axis, as addressed in this paper. That contradicts the fact that the reversals provided opportunities for significant changes in planning and downtown growth, hence not directed to other city areas. Moreover, even in far-distant historical discourse, it is proven that the same street remained the scope of the most potent landowners, both with private and public backgrounds.

It is merely a guess as to how the city might have evolved if all of the constructions occurred in different neighbourhoods and how it would represent urban development in general. One must accept that the XXI century presents yet another shift in social patterns and acts, finally reflecting the urban fabric and the city's image in the future. The most recent constructions along the axis testify in that favour. Those are standard post-war practices in transitional countries, where rules are purposefully evaded, as are consequences for offenders, resulting in irreversible blunders and damage to aesthetics, legacy and perception of a specific cityscape.

5. CONCLUSION

Even though the modern development of Banja Luka was initiated only during the Ottoman era, a series of settlements around the rivers of Vrbas, Crkvena, and Suturlija are recorded as early as the pre-Roman era, leading to their later expansion along the main route connecting Roman provinces of Slavonia and Dalmatia. All subsequent development eras, distinguished by various political ruling regimes, focused on building erections along the same street, which was later modernised and widened. Its contemporary image is a stylistic combination of single-family houses and administrative high-rise buildings, ranging from the traditional Ottoman to glass structures. Authorities used it to solidify their image of power and present social, economic, and religious aspirations by constructing religious, public, cultural and military architecture, open public, and green zones. Such an approach resulted in a precise image of a single street as a historical record of urban development, witnessing its ups and downs. Present-day architectural heritage is the most solid evidence of the development mentioned and reviewed. It is linked to ruling regimes, bringing up in focus the relation of each stage to their benefactors, examining their influence on the image of the urban cityscape in Banja Luka as it exists today.

In this regard, the paper re-evaluated the role of architectural development in Banja Luka, not in a specific period or precise time, but rather along a historical timeline and along the exact route that has proven to be the significant street – the urban axis of today’s second largest city in Bosnia and Herzegovina. Even though the image of Banjaluka is based on very colourful, separated, and secluded stories, such as its greenery planted by the Austrians, vast public and sacred constructions undertaken during the Kingdom, and intense development activities taking place in the post-Earthquake period, few people consider the present-day Banjaluka in the context of a mutual relationship between each of those layers, as seen in the urban backbone, subject in this paper.

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submitted: 28.03.2024.
corrected: 25.04.2024.
accepted: 30.04.2024.

Research scientific paper

UDC : 625.732.4
https://doi.org/10.62683/ZRGAF39.13-21

INFLUENCE OF VEHICLE SPEED IN FREE TRAFFIC FLOW ON DISTRIBUTION OF ROADWAY SUPERELEVATION

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Abstract

In this paper, the theoretical concept of roadway superelevation based on speed in free traffic flow is derived. The influence of the radius of the horizontal curve on speed in free traffic flow as a basis of this analysis is taken from a more detailed experimental research for two-lane rural highways. This method is new and differs from others that use constant design speed value. However, this method gives similar results when compared to the empirical methods of computing roadway superelevation, where design speed is constant but it is assumed that when the curve radius is greater than the minimum, the driving speeds are greater than the design speed. Presented work defines and explains that assumption and takes it into account when computing roadway superelevation.

Key words: *Free Traffic Flow Speed, Roadway Superelevation, Roadway Cross Slope*

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1. INTRODUCTION

In the road designing process, beside technical requirements dealing with the constructive problems, there is a need for further improvement of traffic safety, which can be achieved only if real circumstances that occur on the road are accounted in the process of road design. In many countries, the engineering praxis deals with a term called design speed (V_d), and all constructive elements of the road are dimensioned based on that speed. Design speed is a value that tends to be valid for the whole road or at least, for a large sections of it.

However, driving experience suggests that speed is a changeable value that depends on the changeable elements of the road, such as: radius of horizontal curve, sight distance, etc. Having this fact in mind and the requirements about traffic safety, a logical conclusion is that all constructive elements that depend on the speed of the vehicle must be adjusted to account a changeable velocity of the vehicle. That velocity is called the speed in free traffic flow (V_F) and $V_d<V_F<V_{max}$, where V_{max} represents the maximum speed that can be achieved. Among constructive elements of the road that depend on the vehicle's speed is most certainly the roadway superelevation rate (e) of the horizontal curve when $R>R_{min}$. (R) is the radius of the horizontal curve and R_{min} is the minimal value for the radius adopted based on V_d.

In this paper a new method for the derivation of the needed e is proposed. The derivation is based on the experimental data that has been collected on the Department of Road Construction at the Faculty of Civil Engineering and Architecture in Nis, Serbia, and deals with the influences of the road geometry on V_F [1]. Method gives one clear advantage in comparison with the other more complex methods [2,3,4,5,6,10,11] since the idea is to isolate a single construction element, such as the radius of the horizontal curve, and then observe how that isolated element affects V_F. The obtained expression for the required e is very simple, it can easily be programmed and yet the results are very close to the one obtained by methods given in [6].

2. EXPERIMENTAL RESEACH RESULTS

The influence of the radius of horizontal curve, on the speed in free traffic flow V_F is a part of a complex research that deals with influences of all road–geometric elements on V_F [1]. In this research, there were five experienced amateur drivers to whom instructions were given to drive the same way they usually drive, but with maximum safe speed that road elements allow. The experimental drives were done during the day on two-lane rural highways, where asphalt pavement had very good characteristics and when it was dry. The experimental vehicle had the following characteristics:

- Engine power, N=50 kW,
- Weight of the vehicle, G=12 kN,
- Maximum speed, V_{max} =150 km/h.

During the experimental drive, specially constructed device was recording the following:

- Position on horizontal alignment,
- Speed of the vehicle,

- Bending of the trajectory,
- Heart rate of the driver.

It has been concluded in [1] that all drivers were driving with the changeable speed that depended on curve radius R. When they accelerated, the maximum capability of the vehicle was not used; when they wanted to slow down, most of the time they were easing the gas pedal, and only occasionally pressing the brakes pedal. Interesting is the reaction of all drivers when approaching the critical point as a reason for slowing down; they did not want to take any measures until seven seconds of driving distance before that point. If in that time frame they could not reduce the speed to the maximum safe speed by easing off on the gas pedal, they used the brake pedal. However, in both cases the drivers did not react until seven seconds of driving distance before that critical point. It has also been observed that the radius of the current horizontal curve does not exclusively impact V_F. The size of the radius of previous and next horizontal curves has impact on V_F as well. This is a limiting factor for achieving the expected speed in a specific horizontal curve and it is due to the limited vehicle acceleration capability and the usual driver's behavior. The impact of this phenomenon can be quantified through the use of bendiness of the road (B), which represents a sum of the deviation angles of all horizontal curves on the observed kilometer, and it is expressed in [°/km]. The results of speed in free traffic flow measurement on 5 road sections are shown in Fig.1.

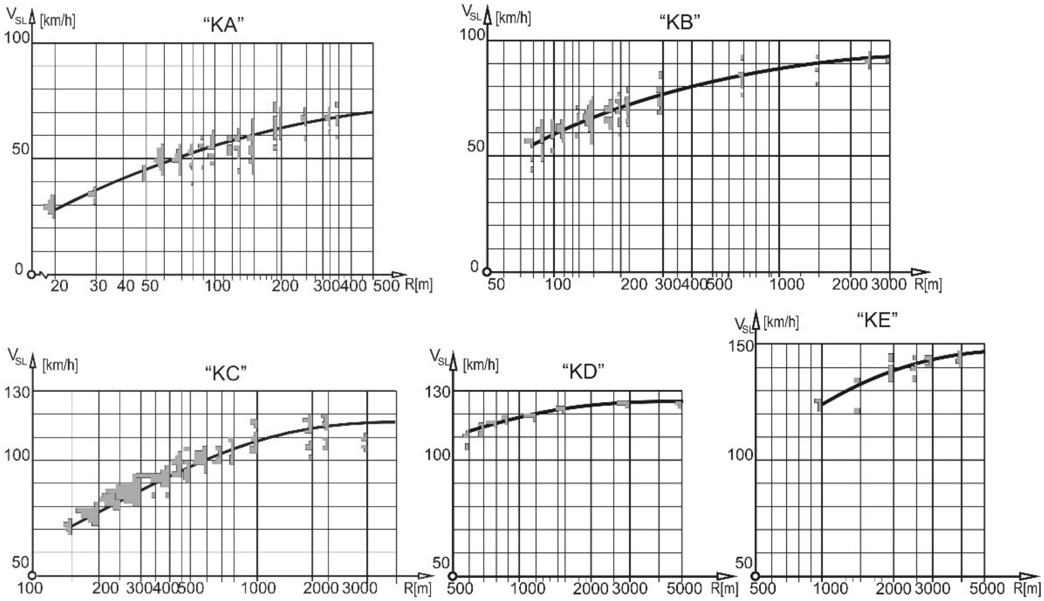

Figure 1: The measuring values of the radius of horizontal curve influence on speed in free traffic flow: road sections "KA", L=13.4 km and bendiness of the road B=457°/km, "KB", L=6.9 km and bendiness of the road B=178°/km,"KC", L=32.7 km and bendiness of the road B=86°/km, "KD", L=10.0 km and bendiness of the road B=37°/km,"KE", L=16.0 km and bendiness of the road B=18°/km,

After processing of the measured values, the diagram shown in Fig. 2 has been constructed [1].

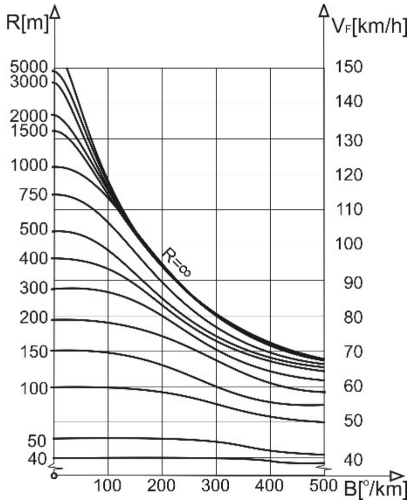

Figure 2: Speed in free traffic flow (V_F) *as a function of the bendiness of the road* (B) *with the radius of horizontal curve* (R) *as a parameter.*

The figure shows the average V_F as a function of B, where the radius of the current horizontal curve, R, is taken as a parameter. Since B depends on the number of applied horizontal curves, their radii and turning angles, it can be different for the same value of V_d. For a specific V_d, the average values for B are computed and used to transform the diagram presented in Fig.2, into the diagram presented in Fig. 3, which shows the influence of R on V_F for the specific V_d with average B [1]. The statistical indicators for Figure 3. show that the statistical error of regression is larger for $R>R_{min}$ than for $R=R_{min}$. This suggests that V_F has a smaller variance in the critical than in the non-critical curves.

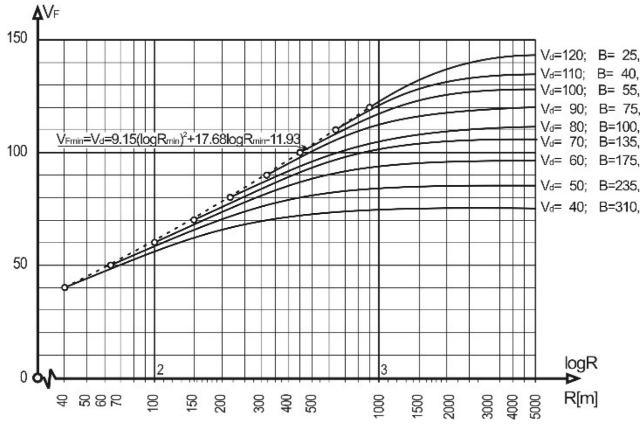

Figure 3: Speed in free traffic flow (V_F) *as a function of the radius of horizontal curve* (R) *with designed speed* (V_d) *and the average bendiness* (B) *of the road as a parameter*

Table 1. Statistical indicators for Fig. 3.

Statistical indicators	Label	$R=R_{min}$	$R>R_{min}$
Number of measurements	N	320	479
Coefficient of correlation	R	0.9953	0.9188
Standard error of regression	S	2.02 km/h	3.53 km/h
Percentage of mean value variation	P	2.87 %	4.17 %

3. REQUIRED RATE OF ROADWAY SUPERELEVATION IN HOROZONTAL CURVE

The roadway superelevation in the horizontal curve compensates a part of the centrifugal force. Before entering the curve, the driver can successfully predict only the curvature of the road, and based on that observation the he adjusts the speed. The driver cannot predict the rate of the roadway superelevation, but it is possible to feel effect of superelevation when driving through the curve.

Most of the engineers calculate the rate of the roadway superelevation, as proportional to the value of centrifugal force for the whole design section of the road, by using the following equation [1]:

$$\frac{e}{100} = k \cdot c\,, \tag{1}$$

where (k) is a reduction constant, and (c) is the coefficient value of the centrifugal force in the road curve. Roadway superelevation should give positive psychological effect on drivers [7,8,9], but because of the mistake in assumption that the drivers use V_d for the whole section of the road, this positive effect is missing. It is very obvious that neither are the drivers familiar with a term called design speed, nor they are driving with that speed. It has been determined experimentally in [1] that the drivers adjust the speed based on the radius of the horizontal curve and the capability of the vehicle. Having this fact in mind, in designing the rate of the roadway superelevation, real changeable speed should be used, instead of design speed. By doing this, the desired psychological effect for the driver's safety in any specific horizontal curve with arbitrary radius size is modeled.

Since c_{max} is determined by V_d and R_{min} and V_F=V_d at R_{min}, it should to be computed k first as:

$$k = \frac{\frac{e_{\max}}{100}}{c_{\max}} = \frac{\frac{e_{\max}}{100}}{\frac{V_d^2}{127 \cdot R_{\min}}} = \frac{127 \cdot e_{\max} \cdot R_{\min}}{100 \cdot V_d^2}\,, \tag{2}$$

where e_{max} is determined based on the climate conditions (in Serbia regulations e_{max}=7%). Since it follows from (1) and (2) that:

$$\frac{e}{100} = k \cdot c_F = \frac{127 \cdot e_{\max} \cdot R_{\min}}{100 \cdot V_d{}^2} \cdot \frac{V_F{}^2}{127 \cdot R}\,, \tag{3}$$

finally e can be expressed as:

$$e = e_{\max} \cdot \frac{R_{\min}}{R} \cdot \left(\frac{V_F}{V_d}\right)^2, \tag{4}$$

which gives the general formula. Fig. 4. shows superelevation rate as given by equation (1) by using the values of the design speed, V_d, and the values of the speed in free traffic flow, V_F, where c_d and c_F are the corresponding coefficients of centrifugal force. R_n is a radius where e reaches its minimum value (in Serbian regulations e_{min}=2.5 %), which is determined by the efficient side pavement drainage, and f_{max} is the maximum side friction factor. The figure illustrates different values for R_n when V_F is considered instead of V_d.

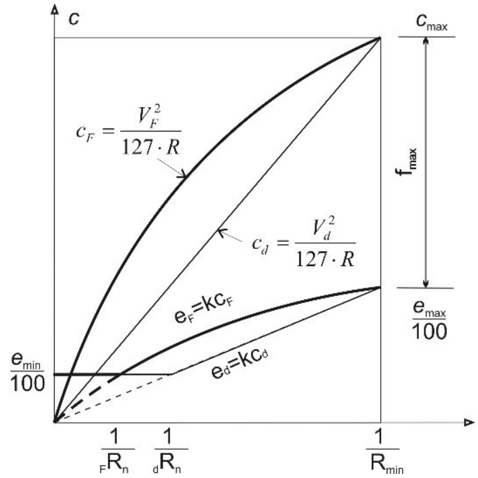

Figure 4: Distribution of the centrifugal coefficient on superelevation and side friction factor.

For the adopted maximum and minimum values of e, e_{max}=7% and e_{min}=2.5%, it can be constructed a curve, e=F(R), where the design speed is taken as a parameter, as shown in Fig. 4.

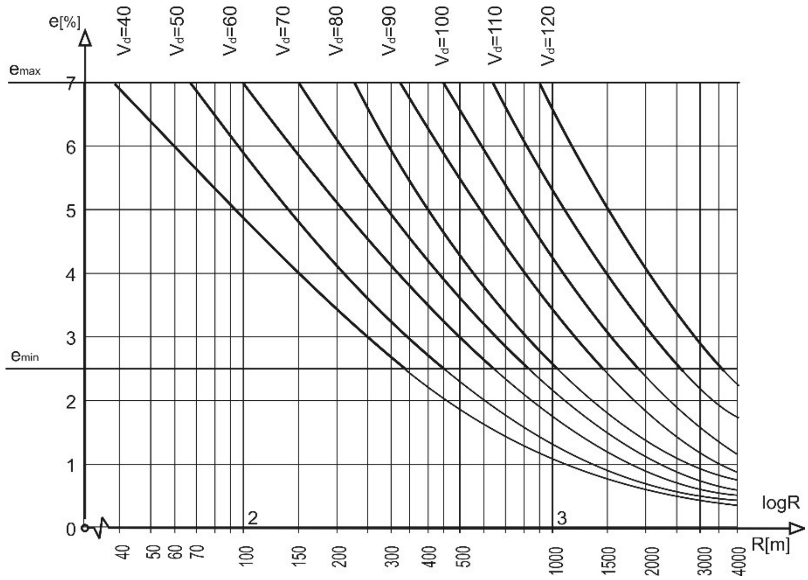

Figure 5: The roadway superelevation as a function of the radius of horizontal curve with design speed as a parameter.

It can be seen from the Fig.5. that coefficient η is the ratio of R_n determined by e_{min}, and R_{min} determined by e_{max}. Ratio $\eta=R_n/R_{min}$ is decreasing as V_d is increasing. Using parabolic regression η is expressed as a function of V_d as it is shown in Fig. 6. The figure emphasizes the importance of the considering V_F instead of V_d, especially for small values of V_d. Moreover, in the same figure this new method with much more complex procedure from [6] is compared. Method 5 [6] is chosen because it represents a superelevation and side friction distribution reasonably retaining the advantages of both methods 1 and 4, and represents a practical distribution for superelevation over the range of curvature.

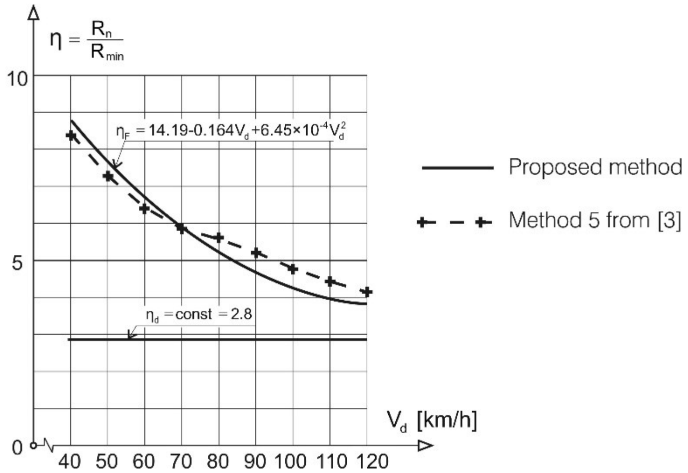

Figure 6: Ratio η as a function of design speed.

The results obtained using when e_{max}=7% and e_{min}=2.5% are shown and close agreement between two methods is obvious.

If a general formula given by equation (4) is used in the variation range of the mean speed value in the free traffic flow when $R>R_{min}$ for the amount of P=4.17 %, we come up with the wide range for the roadway superelevation $_{15\%}e$ - $_{85\%}e$, where:

$$_{15\%}e = \left(1 - \frac{P}{100}\right)^2 = (1.0417)^2 e = 1.085e\,, \tag{5}$$

and

$$_{85\%}e = \left(1 - \frac{P}{100}\right)^2 = (0.9583)^2 e = 0.918e\,, \tag{6}$$

Equations (5) and (6) represent the range of e variation, when considering variation of V_F for the amount of mean value variation P=4.17 %, taken from the statistical indicators for Fig. 3. The values of speed variation, 1.0417 and 0.9583 are squared since V_F effects c_F as square and that finally effects e as square.

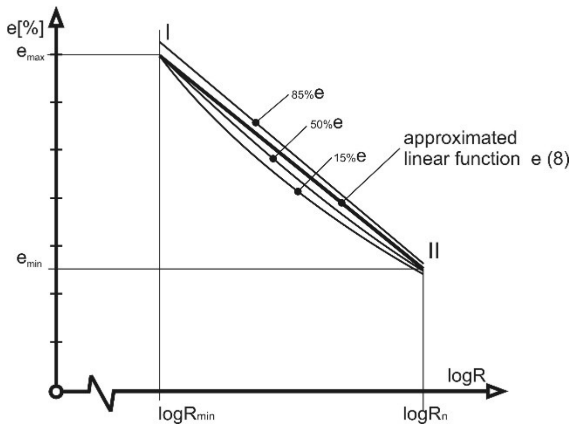

Figure 7: Logarithmic form of the roadway superelevation (e) for R>Rmin.

Comparison between $_{15\%}e$, $_{50\%}e$ and $_{85\%}e$ is given in Fig. 7. It is obvious that there is a little difference among them and that there is approximately linear relationship between e and logR. Therefore, in order to simplify the calculation, the linear function e=F(logR) is constructed. In that aim, two known points, point I ($\log R_{min}$, e_{max}), and point II ($\log R_n$, e_{min}) have been taken, and the following linear relation between e and logR is obtained:

$$e = e_{\max} - (\log R - \log R_{\min}) \frac{e_{\max} - e_{\min}}{\log R_n - \log R_{\min}}, \tag{7}$$

which can be reduced to:

$$e = e_{\max} - (e_{\max} - e_{\min}) \frac{\log\left(\frac{R}{R_{\min}}\right)}{\log\left(\frac{R_n}{R_{\min}}\right)}, \tag{8}$$

Finally, when $\eta = R_n/R_{min}$ which was obtained earlier is included in the equation (8), it is obtained:

$$e = e_{\max} - (e_{\max} - e_{\min}) \frac{\log\left(\frac{R}{R_{\min}}\right)}{\log(14.19 - 0.164 \cdot V_d + 6.45 \cdot 10^{-4} V_d)}, \tag{9}$$

which represents the final equation for roadway superelevation.

4. CONCLUSION

In this paper it is proposed a method that determinates the required rate of the roadway superelevation in the horizontal curves. The method is based on the real changeable speed – speed in free traffic flow, V_F. For values of $R>R_{min}$, it gives almost the same results as Method 5 [6]. The final equation is a mathematical model for distribution of the roadway superelevation in the horizontal curve for $R>R_{min}$. Value of e can be calculated by just knowing design speed, V_d, and the minimal radius, R_{min}, or by knowing just design speed since the minimal radius also depends on in V_d. The results are in compliance with real conditions in traffic, and expected effects of roadway superelevation in the horizontal curve.

Considering that the research that led to the results presented in this paper was based on measurements with vehicles from the end of the 20th century, it would be good to make new measurements, with vehicles that are in use today, because the dynamic characteristics of modern vehicles are significantly different from those of that time. This procedure would thus be modernized, which would lead to the designing of safer roads in the future.

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submitted: 27.02.2024.
corrected: 08.04.2024.
accepted: 13.04.2024.

Review paper

UDC : 72.012:502.15
https://doi.org/10.62683/ZRGAF39.23-34

DEVELOPMENT AND APPLICATION OF ENVIRONMENTAL PARAMETERS AND BIOCLIMATIC PRINCIPLES IN THE ARCHITECTURAL DESIGN OF BUILDINGS

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Emily Trummer[2]

Abstract

In modern conditions of consumption of natural, primarily energy resources, and environmental pollution, buildings are ranked among the biggest consumers and polluters, and that at the world level. The paper provides an overview of contemporary trends, as well as challenges regarding the use of created and available natural resources, by determining the relationship that exists between the economic, efficient, and effective use of natural resources on the one hand, and the reduction of environmental pressures of buildings on the other hand, but also by considering alternative scenarios in the future, in which ecological parameters and bioclimatic principles would be more relevant for the design of ecologically correct, sustainable buildings. The emergence, development, and application of ecological parameters of bioclimatic principles in architectural design, as it was concluded in this paper, was motivated to a lesser extent solely by requirements to reduce negative pressure on the living environment, and to a greater extent dominated by the desire to ensure continuity in the supply of resources. This conclusion is supported by the fact that it was only in the last decades of the last century that awareness regarding the condition and negative contribution of human activities in terms of environmental pollution has matured sufficiently. Accordingly, the paper analyzes the reasons for the application of ecological parameters and bioclimatic principles in the context of the architectural design of buildings.

Key words: *Building Design, Contemporary Concepts, Sustainability, Challenges*

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1. INTRODUCTION

With the development of civilization, people learned to exploit and later cultivate natural resources, ensuring humanity's survival, growth, and development. The feedback connection with the natural and created environment is the basis of life on the planet. The industrial revolutions intensified human activities and the use of resources available in the Earth's systems. But, there have been changes with unpredictable and irreversible ecological effects. The impacts on nature have been particularly pronounced in the last two hundred years. However, human awareness of them developed only at the end of the 20th century when the political and sociological focus of our issue of environmental protection [1]. In general, the impacts of human activity on nature can be created in three groups of effects:

1. Immediate or direct environmental impacts – pollution that can be proven in situ (related to a specific area). For example: penetration of polluting substances into water, soil, or air during the production of building materials.
2. Medium-term effects - pollution occurs in a wider spatial and temporal range, disturbs the natural balance, and later manifests itself in humans. For example: uncontrolled deforestation first causes soil erosion, then air quality deteriorates, which in the medium term has consequences for humans.
3. Long-term effects - manifest themselves after a long period and affect humanity. For example: greenhouse gas emissions, as a consequence of human activity, lead to a series of chain reactions and to climate change (global warming, rise in world sea level). [2]

The time and space distance from the place of generation of the negative impact to its manifestation on the environment is a determining factor that affects the type and extent of the required reaction. This means that knowing the effects of human activities leads to an understanding of the pressure on the environment and is the basis for reducing degradation.

2. ANTHROPOGENIC, ESPECIALLY CONSTRUCTION INFLUENCES ON THE ENVIRONMENT

People have an innate tendency to focus on life and life processes. Man's complex relationship with nature and built heritage is based on biological, cultural, psychological, and ethical connections. The primordial need for a harmonious relationship between man and nature dates back to the earliest examples of human creativity. Ecological systems include living entities and their created environment. Symbiotically, they function in complex cycles, which have changed over the past years, along with changes in environmental conditions. [3] According to knowledge from the natural sciences, in the previous 12,000 years, a climate favorable to the survival and development of human society was developed on Earth, and this period began after the ice age and was called the Holocene era or the interglacial period. In this phase, only negligible climatic changes occurred, such as cold periods during the 16th and 17th centuries [4].

Buildings and written evidence of the development of civilizations enable the reconstruction of past systems of human action, ways of using available resources, and impact on nature. Through their construction activities, people have influenced the natural environment for centuries, primarily through changes in the soil surface. Innovations and technological development, especially since the 19th century, led to intensive exploitation of natural resources; at the same time, they encouraged the appearance of pressures that are known today as anthropogenic impacts on the environment. Industrialization continuously encourages the consumption of resources, and consequently, the environmental impact increases with the accelerated rate of change in the natural and built environment. Economic growth in the years after World War II resulted in the mass production and supply of various devices, available to a large part of society. This growth in living standards and comfort is accompanied by a significant increase in energy consumption. The boom in the construction industry has led to the mass production of a wide variety of building materials, and their environmental impact during the life cycle is only now being examined. The continuous growth in the use of natural resources, such as non-renewable sources of energy, water, soil, raw materials, and materials, is accompanied by the intensification of the production of residuals that are disposed directly into the natural environment. People believed in the inexhaustible power of nature to constantly regenerate the raw materials that man needs, but also that nature recycles all the waste created by human activity. Such a belief has led to the pollution of water, air, and soil, and the generation of huge amounts of waste and emissions, which the modern human population faces. The result of the modern way of life is that the connection between humans and other segments of nature has largely been broken. New, created products in the built environment and its expansion at the expense of the natural environment have become sources of environmental pollution and degradation. At the same time, the number and intensity of environmental accidents and extreme weather events are increasing with the increase in the average global temperature and increasingly pronounced climate changes. In order to ensure continuity in the development of civilization, it is necessary to study the trends in the consumption of resources, with constant concern for future needs. At the same time, it is necessary to deal with the consequences of past anthropogenic impacts and activities, such as, for example, climate change. This further implies that bioclimatic factors must be regularly and seriously taken into account when performing all activities, including those related to construction, especially when considering that the results of this activity have a long life continuity

2.1. Sustainability and environmentalism - development and place in construction

The warnings of scientists in the 19th century regarding the dangers to nature were more the exception than the rule [5], while the generally accepted reaction to the state of the environment was consolidated only at the end of the 20th century. The publication of the book Silent Spring (Carson, 2002) is considered the originator of the development of the environmental movement in the USA. For the first time, on April 22, 1970, Earth Day was celebrated, while in 1972 the Greenpeace organization was established, and the Club of Rome published the report The Limits of Growth, in which the picture of the near future was shown as dramatic [6]. Although the predictions regarding the depletion of oil deposits by 1990 turned out to be incorrect, the translation of this report into thirty world languages is evidence of the spread of international interest in environmental problems.

In the Brundtland report Our Common Future [7], the consequences of human action and relationship with nature expressed global concern. The very term sustainability is again actualized and generally accepted. (Originally this term comes from the context of forestry, created in the 18th century to describe the extent of forest cutting, i.e., the amount of cut trees should not exceed the amount of seedlings used to regenerate the forest.) To explain the interrelationship between sustainability and the ecological movement, the author O'Riordan [8] defined the term "new environmental movement" as the aim "to devise a series of strategies that enable people to see how their interests, as well as the interests of the planet as a whole, are affected by reforms within the triad of sustainability, environmentally sound development on at the local level, and realization of basic needs and political rights".

Today, the term sustainability is applied in a broad social context, so its meaning is also complex. According to the Oxford dictionary, the verb to sustain can refer to "the goal of continuing for a long period of time or without interruption" [9]. Sustainability represents the main condition of continuous global prosperity, and today it includes aspects of ecology, economy, and society, their mutual correlations. In the design of architectural objects, sustainability refers to the ecological and economic dimensions.

3. ECOLOGICAL MODELS FOR MODERN BUILDING FRAMEWORKS

In 2016, the European Commission included nature-based solutions among the focus areas of environmental research and innovation and gave the following definition: nature-based solutions are 'solutions that are inspired and supported by nature, that are cost-effective, while providing ecological, social, and economic benefits and help build resilience. Such solutions bring more and more diverse nature and natural features and processes to cities, landscapes, and seascapes, through locally adapted, resource-efficient, and systemic interventions' [10]. Nature-based solutions addressing social, economic, and environmental challenges have also been promoted in the context of global policy, by scientific organizations, the World Bank, and the United Nations [11].

The analogy with living beings, applied to the ecologically sustainable building system, linked to the intelligence component, as well as the basic design concept, aims to support the efficient use of natural resources and reduce the negative impact on the environment. Ecological parameters and bioclimatic principles are applied to achieve energy efficiency of the building, i.e., to reduce the demand for energy and for energy production (e.g., by introducing solar panels based on photosynthesis). Some measures based on biological parameters are multi-beneficial: facades with integrated algae, for example, capture carbon, produce oxygen, and generate renewable energy [12]. A special contribution of living water efficiency systems is recognized in the domains of water collection and wastewater recycling. Similarly, living organisms can contribute to the decomposition of organic waste *in situ*. However, the greatest progress in the application of ecological parameters in the modern construction context has been achieved so far in the field of materials. Frei Otto's experimental and research work in the field of minimum surfaces and their analogies with natural principles could be compared today with the optimal use of building materials covered by the concepts of sustainability and circularity. In addition, there is a wide range of bio-inspired building materials whose modified characteristics ultimately result in better environmental quality, from improved durability (e.g., self-healing materials [13]) to improved interaction with the environment (e.g., intelligent glass that responds to changes in temperature or light), to carbon storage [14]. Green movements emerging from the 1970s shed new light on plant and animal-based materials and raised awareness of their environmental benefits, including abundance, renewability, low CO^2 emissions, low ecotoxicity and toxicity, ensuring good indoor air quality, biodegradability, recyclability, etc.

The desire to reduce energy consumption and the generation of greenhouse gases in the building sector puts passive and sustainable architectural objects in the foreground. Simple methods and techniques that permeate with appropriate design measures and the choice of materials and systems and that reflect the consideration of elements of the local environment, such as air and solar radiation, ensure thermal and visual comfort with less use of non-renewable energy sources. These techniques are called ecological parameters and bioclimatic design principles. There are two basic types of measures: passive and active.

3.1. Different approaches in designing sustainable buildings

Several authors have considered the implementation of energy-saving strategies in the context of their organization based on several different parameters. Thus, in 1991, Lechner proposed a three-level approach to the design of sustainable buildings [15]. The first level involves the application of basic design strategies such as orientation, insulation, and the use of external solar protection. If this is not enough to meet the requirements, which is often the case in warm climates, a second level of measures is introduced that includes passive and hybrid systems. The second level measures are based on natural energy and concern the introduction of evaporative cooling, land use, and day/night ventilation. Finally, as part of the third level of measures, mechanical equipment can be introduced into the building that was previously passively optimized if necessary. Herzog, Krippner, and Lang similarly defined two sets of strategies for managing the regulatory functions of facades [16]. Here, priority is given to consideration of measures such as thermal insulation, use of solar protection, and even vegetation. This is followed by interventions in the field of introducing additional building services such as artificial lighting and air conditioning, but only if necessary. The authors also considered the use of thermal collectors or photovoltaic panels, which are linked to the hybrid use of natural energy that Lechner described as an alternative to the use of fossil fuels. In 1996, Lysen introduced the term 'trias energetica' [17] to rank sustainability measures in the construction industry. In the first place, there is the prevention of energy use, then the use of renewable sources to the greatest extent possible and, finally, if it is still necessary, the use of fossil fuels in the most efficient way possible. International acceptance of the energy trinity began in 2001 with the adoption of the model by the former president of the International Solar Energy Society [18]. For zero-energy buildings and, in particular, houses, the third step suggests a very efficient use of finite energy sources and 100% compensation with renewable energy [17].

In recent times, the energy trinity has been replaced by the New Stepped Strategy. Here, a significant step was introduced between the minimization of requirements and the use of renewable sources, and a waste flow strategy based on the Cradle-to-Cradle principle was included. The previous last step, which nevertheless accepted the use of fossil fuels, is obsolete with the new model [19].

Common to all mentioned approaches is the fact that the measures applied in the design of environmentally sound buildings can generally be classified as passive and active. Passive measures refer to the design of the building and the properties and function of its envelope, while active measures refer to the use of mechanical equipment. The purpose of both passive and active measures is to enhance the flow of heat to and from the useful space, with the ultimate goal being to achieve thermal comfort.

3.2. Passive and active design strategies

In this part, passive and active measures are presented that are in accordance with ecological and bioclimatic principles and are applied to ensure thermal comfort in buildings with minimum or no use of non-renewable energy sources. The main activities involve the prevention/minimization of energy requirements for heating and cooling and the efficient use of energy from renewable sources. The presented measures, summarized in Table 1, are related to the way heat is treated by the building envelope and its systems. Since these measures are not opposed, but interact with each other and complement each other, they should be considered in parallel when designing, while avoiding skipping the necessary steps. While the application of passive measures results in providing thermal protection, achieving solar heat gains, and rejecting unwanted heat, active measures are associated with heat dissipation and energy generation. Finally, energy use in buildings is related to user requirements and behavior. When describing the measures, energy requirements, such as heating, cooling, and ventilation, were taken into account, and user satisfaction was considered a prerequisite. The user's energy requirements related to the use of energy required for the operation of devices, artificial lighting, and water heating, for example, are not directly influenced by the building design. However, some of the considered measures, for example, generating electricity or increasing natural lighting, can contribute to reducing energy consumption.

Table 1. Overview of passive and active measures and their purpose in the context of environmentally sound design [20]

	Energy Management Systems and Processes	Building Energy Efficiency Technologies and Strategies	Materials and systems
		Isolation	Organic Mineral Petroleum products Other

Passive design measures	Thermal protection	Insulated windows	Insulated glass panels Insulated frames
		Infiltration	
		Solar protection	Permanent elements (consoles) Fixed solar cells Movable/adaptable solar cells Glass with solar protection function
	Solar heat gains	Direct solar gains	
		Solar buffer spaces	Winter garden Double facade
		Indirect solar gains	Trombe wall Add a greenhouse
	Heat rejection	Ventilation	Daily ventilation Night ventilation
		Evaporative cooling / adiabatic cooling	Directly Indirectly
Active measures and equipment	Heat generation	Heating with efficient use of non-renewable sources	Boiler Thermal pump Combined systems (heat + electricity)
		Heating using renewable energy	Solar collectors Renewable fuels Geothermal energy
	Heat dissipation	Electric cooling Vapor-compression cycle	Fully air systems Fully water systems Air and water systems Direct systems with cooler
		Alternative cooling systems Cooling by heat	Sorptive With desiccant
	Electricity	Day light	
		Electrical devices	Efficient lighting Efficient devices
		Generation of electricity from renewable sources	Photovoltaic panels on the building Integrated photovoltaic panels Microturbines

Passive design principles tend to minimize the energy demand in the building. Proper consideration of local climate conditions and environmental elements, building shape, and material properties makes the reduction of energy requirements possible. According to their basic function, passive principles can be divided into passive measures for thermal protection, realization of solar heat gains, and heat rejection.

Active measures - applying passive design principles alone cannot meet all energy needs throughout the year. Even after the application of passive measures, the necessary additional energy is provided by the building's technical systems, i.e., single or combined technical equipment for heating, cooling, ventilation, water heating, and lighting.

4. CHALLENGES, CURRENT RESPONSES AND FUTURE SOLUTIONS

Despite progress, the application of ecological parameters and bioclimatic principles in building design is still under development [21]. Sustainable construction is one of the most important segments of sustainable development, and it includes the use of building materials that are not harmful to the environment and the energy efficiency of buildings. Additionally, there is a pervasive desire for simultaneous economic growth and preservation of the environment and for sustainable development. On a larger level, in the process of more massive construction, the compact city is seen as an appropriate concept and model that can support the realization of the strategy's goals, because it represents a potential effective response to growing global challenges and problems such as rapid urbanization and climate change [22]. The importance of designing and building energy-efficient buildings is reflected in the financial effects of the exploitation of such superior buildings, the comfort and quality of housing, the extended operational life of the building, and the contribution to environmental protection and the reduction of harmful gas emissions into the environment, as well as global climate change. Simple systematizations of the application of ecological parameters and bioclimatic principles in the construction context can be made according to:

- Types of living organisms;
- Characteristics of individual living organisms or entire ecosystems, e.g., in terms of content, structure, form, function, or process;
- Scope of analogy: from mono-characteristics to system solutions;
- Type of analogy: argumentative transfer of biological characteristics or actual introduction of living organisms into the context of the building;
- Hierarchy of analogy: materials, components, or structures.

The study of living organisms from the point of view of analogy in the process of architectural design includes several related biological branches, primarily these are: 1) external morphology or bionomics, which studies the external appearance of living beings; 2) anatomy (internal morphology); and 3) physiology. Anatomical studies are divided into microscopic anatomical studies of structural units that are small enough to be seen only with a microscope, and macroanatomical studies of those body structures and forms that are large enough to be examined without the aid of a magnifying device [23]. Physiology studies the functions of living organisms and their constituent parts - tissues and cells. These functions include: metabolism, transport, information transfer, and regulation [24]. Therefore, studies of form and function can be conducted at different scales of living organisms. Therefore, the application of biological principles in the modern construction context requires "the transfer of knowledge from biology and ecology to architectural design in a way that goes beyond poorly understood and applied analogies or metaphors" [25]. The establishment of interdisciplinary and multidisciplinary design and research teams is an imperative for future development.

It is reasonable to ask the question: what affects the slow environmental impact when it comes to architecture and construction? The famous saying of the architect Le Corbusier that a building is a "machine for housing" has had a strong influence on the realization of many buildings for decades, given that it is sometimes taken literally by architects and admirers. Many buildings created under this influence, in their expression of the environment in which they were built, have a dehumanized character. Static observation of the object is important in scientific analyses (daylight, ventilation of the object, energy flow), but increasingly complex environmental problems point to new considerations. Buildings are part of a complex interaction between people, climate, and environment. New approaches to the design, construction, and use of the facility should support the ecosystem, not destroy it. The urban environment was created as a product of the relationship between society and nature. For a long time, these relations were opposed to the detriment of nature. The realization that society and building culture are separate systems from nature has resulted in unsustainable built structures in a degraded living environment [26].

The lack of classifications, different interpretations of key terms, insufficient knowledge from biological science, and scarce evidence of benefits related to sustainability, circularity, resilience, and regeneration worsen the perception of designers about the possibilities of applying ecological parameters and bioclimatic principles in building design. Likewise, there is a need to develop evidence-based databases that could confirm the specific benefits of applied measures in the construction context. When the benefits of applying bioclimatic principles are justified by a sufficient number of realized cases, pre- and post-construction assessment systems can be developed, and their criteria and indicators determined. Considering the level of specialization that includes natural sciences with construction science, there is a need to promote the development of interdisciplinary research units, to improve experimental work, and to connect these laboratories with education and practice. This need is indicated by the already proven advantages of building, for example, energy-efficient buildings, and they refer to the fact that: 1) Funds invested in energy efficiency are returned in a period of 5-7 years; 2) By energy renovation of old houses and buildings, especially those built before 1980, it is possible to save about 60% in heat energy consumption; 3) Windows are the main source of heat loss, replacing windows is an opportunity to save up to 50% of energy; 4) The application of green roofs improves air quality, reduces city noise, and reduces the effect of heat islands; 5) Energy efficiency helps to control rising energy costs and affects the reduction of climate change. It is particularly useful to apply these measures to buildings built in the late 70s and early 80s, which in terms of usable area have higher CO^2 emissions than those built in the early 90s or later. [27] An energy-efficient building is a building that consumes the minimum amount of energy while providing the necessary comfort conditions (air, heat, light, and sound comfort).

5. CONCLUSION

Awareness of the outcomes of human activities is the basis for reducing environmental pollution and degradation. The type and scope of actions to reduce harmful effects on the environment depend on the field of action. Architecture is a field that has no future without sustainability because of the great influence it exerts through various fields of its application. In architectural design, knowledge of the ecological dimension is fundamental for defining technical, social, and economic measures. In this sense, this work establishes a platform of facts needed to understand the progressive anthropogenic impact on the environment, explains the genesis and development of ecologically correct objects in wider social conditions, and looks in detail at the segments that are currently the most developed. The paper deals with the main challenges in contemporary architectural design from the aspect of consumption of natural resources: water, land, energy, and materials, and at the same time elaborates possible scenarios of a resource-efficient future.

Economic development has caused greater production of construction materials, more intensive construction of residential, business, and industrial facilities, and at the same time, these activities have been reflected in a greater demand for construction land, and all of these activities have a negative impact on the global ecosystem. That is why it is extremely important to take responsibility for the impact that architecture has on the environment, so that future generations can realize their needs.

From the very beginning of construction, the building has an impact on the environment through various activities and processes (production of building materials, transport, construction, installation of materials, reconstruction, demolition, recycling, waste disposal). All these activities can cause environmental damage. Also, during the construction process itself, the construction site produces waste and noise, which also have a great impact on the environment. The impact that occurs even after the construction of the facility is not negligible because, during exploitation, there are also consequences for the ecosystem. It is very important to note that when a building loses its function (it is no longer in use or due to circumstances it was left unfinished and not brought to its intended purpose), its negative impact on the environment is extremely high. If such an object is not recycled (reconstruction or change of purpose or complete demolition and waste recycling), everything invested in the production, transportation, installation, and maintenance of such an object can be considered a loss and a constant negative impact on the environment. With a sustainable approach/design, and the consumption of non-renewable resources is reduced, the use of renewable energy sources is promoted, waste is reduced to a minimum, and a healthier and more rational living and working space is created. The principle of sustainable architecture implies the rational use of construction land, the use of ecological materials, the rational use of energy and water, the optimization of the process of functioning and maintenance of the building, as well as the improvement of conditions for living and working in the building and on a larger scale the design of compact cities.

The future of architecture depends on a responsible (sustainable) approach to the design, construction, and use of the building. Growing environmental problems lead to the realization that there is no future development of society (and therefore architecture) without harmonizing the relationship with nature. So this time attention is drawn to the importance of the ecological aspect in sustainable architecture and construction.

The emergence of ecological thinking is certainly the first step in improving the mutual relationship between humans and nature. As architecture has a significant impact on the environment, the impact of ecology is increasingly important in the approach to designing, building, and using buildings. In order to efficiently implement the impact of ecology, it is necessary to revise the building norms and rules, which slow down this process of environmental impact to a good extent.

Applying the principle of ecological correctness improves the performance of buildings, whether the design ambition concerns the design of a comfortable and functional architectural object with rational energy requirements or the achievement of sustainability standards such as a zero-energy or passive house. The choice of measures is ultimately a design choice on which the architectural quality and form expression of the building, as well as its function, will depend. And finally, regardless of the stated importance, although the climatic characteristics and ecological conditions of the local environment should be taken into account, the decision cannot be solely based on these items, due to the presence of many other parameters that are considered.

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submitted: 11.03.2024. *UDC : 628.31*
corrected: 24.04.2024. *Research scientific paper https://doi.org/10.62683/ZRGAF39.35-46*
accepted: 29.04.2024.

DECENTRALIZED WASTEWATER TREATMENT - A SUSTAINABLE SOLUTION FOR PROTECTING WATER RESOURCES FROM POLLUTION

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Abstract

In locations with low population density or constraints in technology, resources, and personnel, the use of centralized wastewater treatment systems is not be justified. In such areas, decentralized wastewater treatment systems offer several advantages over centralized systems. In these systems, the treatment and disposal of effluent is close to the source of waste water production, which reduces investments in a long sewage network and enables the application of other methods of wastewater transport, such as pressure sewerage and vacuum sewerage. A significant advantage of decentralized systems is their ability to be installed quickly, while also enabling local water reuse and implementation of the principles of circular economy, thereby enhancing productivity. In Serbia, according to the 2011 census, there are 449 settlements with more than 2,000 equivalent inhabitants whose wastewater should undergo at least secondary biological treatment. Given that approximately 80% of these settlements have populations ranging from 2,000 to 10,000, the implementation of decentralized wastewater treatment systems becomes imperative for sustainable water protection in Serbia.This paper provides a brief overview of decentralized wastewater treatment systems and, using the example of the municipality of Pirot, highlights the advantages and significance of implementing decentralized treatment to ensure a safe, reliable, economically justified, and ecologically sound solution for protecting water resources from pollution.

Key words: *Decentralized Wastewater Treatment, Sustainability, Protection of Water Resources from Pollution*

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1. INTRODUCTION

The main goal of wastewater treatment is to enable the removal of organic matter and other pollutants from water without endangering human health or polluting the natural environment [1]. The two main approaches to planning wastewater treatment and disposal systems are: centralized treatment, characterized by large facilities serving expansive municipal or regional areas, and decentralized treatment, which utilizes smaller facilities located near the point of water consumption and wastewater generation, with more localized areas of service.

In the field of wastewater treatment, the division between centralized and decentralized systems is currently a focal point of discussion and subject to intensive research. This global discussion has highlighted various economic, technological, environmental, and social barriers in the choice between centralization and decentralization, making it difficult to determine priorities and select one strategy over the other. Therefore, it is necessary to consider the specific conditions of each location and to analyze and address each case individually.

Centralized wastewater treatment systems have been the most widely applied approach to addressing wastewater issues in well-developed urban areas. These systems have been in use since the mid-1800s and have served society well. However, in recent years, it has become increasingly clear that reliance solely on such systems may not be optimal in terms of sustainable wastewater management [2]. Due to the population growth, rapid urbanization, the simultaneous increase in water usage, water scarcity, climate change, and the need for disaster mitigation, there is a growing need to develop more sustainable approaches to wastewater and water resource management [3].

Decentralized wastewater management is increasingly being considered as an alternative or supplement to large centralized collection and treatment systems. Decentralized solutions are being explored to meet the needs of new development zones within or on the outskirts of large cities (even if they already have centralized facilities). Therefore, decentralized systems are becoming a more universal approach to addressing wastewater issues for suburban living.

Small villages and rural communities in both developing and developed countries are also facing the same question: whether to prefer centralized or decentralized systems for effective wastewater management. In locations where population density is low or where there are limitations in technology, resources, and personnel, the implementation of centralized systems is not justified. In such locations, decentralized wastewater treatment systems have several advantages over centralized ones [4].

This paper provides a brief overview of decentralized wastewater treatment systems, using the example of the municipality of Pirot to demonstrate the advantages and importance of implementing decentralized treatment for ensuring a safe and reliable, economically and environmentally sustainable solution for protecting water resources from pollution.

2. WASTEWATER TREATMENT SUSTAINABILITY

Although the concept of sustainability is not explicitly mentioned in EU legislation, it is crucial for the implementation of sustainable wastewater collection, drainage, and treatment systems. The main goal of sanitary systems and wastewater treatment systems is to protect and improve human health by providing a clean environment and interrupting the cycle of diseases. For a system to be sustainable, it must be not only economically viable, socially acceptable, and technically and institutionally appropriate but also protect the environment and natural resources. When improving existing and/or designing new sanitary systems, sustainability criteria related to the following aspects should be considered [5]:

1. Health and hygiene: This includes the risk of exposure to pathogens and hazardous substances that could affect public health at all points of the sanitation system, from toilets, through collection and treatment systems, to the point of reuse or disposal and downstream populations.
2. Environment and natural resources: This includes the necessary energy, water, and other natural resources for construction, operation, and maintenance of the system, as well as the potential environmental emissions resulting from exploitation of the system. It also includes the degree of recycling and potential reuse and its effects (e.g., reuse of wastewater; returning nutrients and organic matter for agriculture) and the protection of other non-renewable resources (e.g., through the production of renewable energy sources, e.g., biogas).
3. Technology and operation: This encompasses the functionality and ease with which the entire system, including collection, transport, treatment, and reuse and/or final disposal of water, can be built, operated, and monitored by the local community and/or technical teams of local municipal enterprises. The system's robustness, its vulnerability to power outages, water shortages, floods, etc., and the flexibility and adaptability of its technical elements to existing infrastructure, demographic, and socio-economic development are important aspects to assess.
4. Financial and economic aspects: These relate to the households' and communities' capacities to pay for sanitation, including construction, operation, maintenance, and necessary reinvestments in the system.
5. Socio-cultural and institutional aspects: Assess the socio-cultural acceptance and appropriateness of the system, suitability, systemic perceptions, gender issues, and impacts on human dignity, compliance with the legal framework, and stable and efficient institutional arrangements.

3. CENTRALISED WASTEWATER TREATMENT

A centralized system is characterized by the collection and treatment of wastewater through a combination of centralized sewage and a centralized wastewater treatment plant, followed by disposal in controlled conditions [6]. Centralized system appear as more feasible solutions for densely populated regions that are already connected to a sewage system. By definition, these systems serve large and densely populated areas with a high number of apartments and households. One of the main advantages of centralized wastewater systems is the uniformity in meeting water demand while adhering to quality standards for a large urban area.

The introduction of centralized wastewater collection and treatment systems as a standard in urban areas has been a key factor in improving sanitation and wastewater systems. However, over the last 20 years, it has become evident that existing centralized wastewater treatment systems have several drawbacks and often fail to meet sustainability criteria:

1. Despite the existing wastewater treatment systems and undeniable improvements in public health and the environment, the quality of many

surface and groundwater bodies is still negatively impacted by nutrients, microorganisms, and hazardous substances from discharged wastewater.
2. There is a need to recover nutrients from wastewater, especially phosphate, as it is an endangered fossil resource. Today, many countries have recognized the calls for new concepts that enable the safe use of nutrients from wastewater.
3. Centralized management of sewage and wastewater treatment is not the right response to climate change adaptation as it requires a lot of energy and does not close local water cycles.
4. High investment and operational costs, consequential expenses, and their inflexibility make centralized systems inaccessible and difficult to manage.

Given these shortcomings, recommendations from the scientific, expert, and political communities suggest that sanitation systems must change to enable decentralization, potentially down to the level of a single household or group of households. Water cycles should be closed locally, and nutrients in households should be available for safe reuse in agriculture. The fundamental principles of innovative sanitation and wastewater treatment concepts are treatment at the source, recycling/reuse of water and nutrients, and the aspect of decentralization.

4. DECENTRALIZED WASTEWATER MANAGEMENT CONCEPT

Small/decentralized wastewater treatment systems can be used for individual houses, small communities, or groups of small communities where centralized sewerage is not justified. They are highly suitable for small communities, sparsely populated areas, and specific industries. In such locations, decentralized wastewater treatment systems have many advantages over centralized ones.

The significance of smaller/decentralized plants in water pollution protection plans has been underestimated in current practice, and their specificities have not been considered in the planning and design of such systems. It is unprofessional and unacceptable to argue that there is no room for the construction of smaller plants, insisting instead on building regional drainage systems with centralized wastewater treatment at all costs. Based on the on-site conditions and collected data, a detailed analysis should be conducted before choosing between a large central plant or several smaller/decentralized wastewater treatment plants (Figure 1).

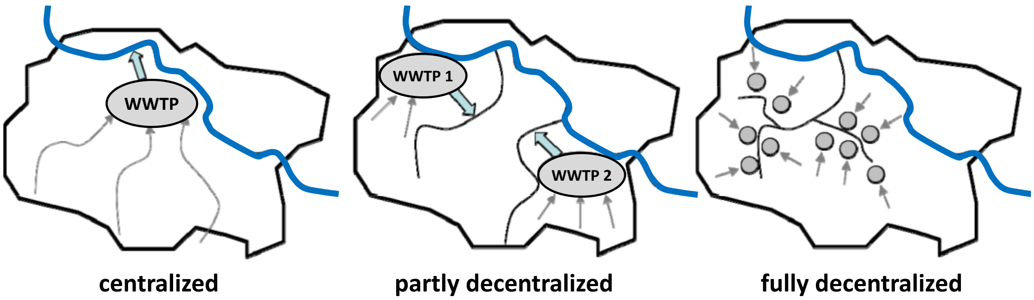

Figure 1. Centralized and decentralized wastewater treatment [7]

In decentralized systems, the treatment and disposal of effluent occur close to the source of wastewater production, resulting in a short wastewater transport network. This reduces the need for extensive investments in sewer networks and pumping stations. The small size of the network allows for the use of various wastewater transport methods in addition to gravity, such as pressurized sewer systems and vacuum sewers.

The implementation of small/decentralized plants typically does not result in savings in the construction of the facilities themselves. However, it is often a much cheaper option compared to a centralized system when considering the cost of the sewer system for collection and conveyance of wastewater. Small/decentralized wastewater treatment plants are easier to finance, simpler to plan, and quicker to implement because each project is much smaller than a conventional centralized system. A large percentage of the costs can be covered by private investments from direct users. A significant advantage of decentralized systems is that they can be installed quickly when needed.

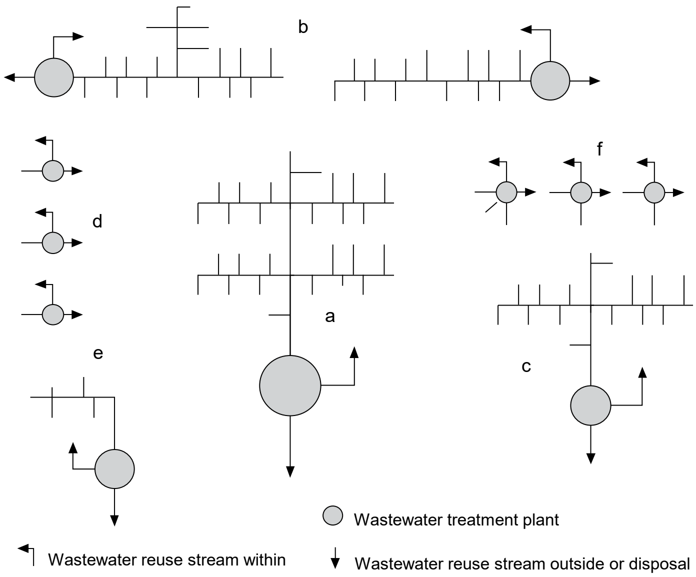

Figure 2. Schematic diagram of decentralized wastewater management concept for a small community [8]

a) Subsystem for residential and commercial centre, b) Subsystems for residential neighborhoods, c) Subsystems for industrial development, d) Subsystem for individual residences, e) Subsystem for new development, f) Subsystems for establishments or clusters of homes

Decentralized wastewater treatment systems enable local water reuse and the implementation of circular economy principles, thereby increasing productivity. Decentralized wastewater management involves managing wastewater as close to the potential reuse point as possible.

A decentralized wastewater management system for a small settlement or group of settlements can consist of several smaller subsystems for collection, treatment, and reuse. The size of each subsystem is determined by administrative and drainage boundaries, as well as other prevailing social and economic conditions. The smallest system can serve a single household [8]. Figure 2 provides a schematic representation of the decentralized wastewater management concept.

Decentralized management is flexible and can utilize a combination of cost-effective solutions and technologies [9] adapted to the prevailing conditions in different parts of the community. For example, conventional wastewater treatment systems can be applied to highly developed and densely populated commercial and residential centers within the community, while natural wastewater treatment systems or onsite systems can be applied to sparsely populated residential neighborhoods.

Decentralized wastewater treatment systems that are properly managed can be a cost-effective and sustainable option for achieving public health and water quality goals, especially for small suburban communities and rural areas.

4.1. Technologies for wastewater collection

Technologies for wastewater collection applicable in small communities or for transport of wastewater to decentralized treatment plants can be divided into two groups: greywater separation as an alternative management scheme for individual households and alternatives to conventional gravity sewerage [10].

4.1.1. Onsite Systems

The primary component of onsite wastewater collection is typically a septic tank; all wastewater generated in the house is collected in the septic tank, which provides flow equalization as well as initial wastewater treatment [10].

When it comes to wastewater collection, alternative management is possible if greywater and fecal waste are managed separately. This approach is attractive when disposal of wastewater into the ground is prohibited or when there is interest in reuse of greywater on the location, potentially along with treated fecal matter. However, some local regulations either prohibit or have unclear provisions for certain types of greywater disposal and separate fecal waste management.

The definition of greywater varies depending on the country. It is typically defined as used water that does not contain fecal matter, such as water from sinks, showers, dishwashers, or washing machines, although definitions may differ depending on local regulations. Greywater is wastewater with low solids content, with much lower concentrations of biochemical oxygen demand (BOD), nutrients, and pathogens compared to combined wastewater, and it does not require much treatment before disposal or reuse. Subsurface disposal of greywater is often possible without any treatment. Separate collection and disposal of greywater are particularly attractive if it can be reused for landscape irrigation after treatment.

4.1.2. Alternative Sewerage

Several alternatives to conventional gravity sewerage have been developed for wastewater collection applicable to small communities or for transport of wastewater to decentralized treatment plants, offering significant advantages for small and decentralized communities. The most common types of alternative solutions are: small-diameter sewers, pressurized sewers, or vacuum sewers. All of these alternatives use cheaper materials, typically polyvinyl chloride, because they can accommodate smaller diameter pipes. Additionally, they can utilize smaller gradients, allowing pipes to be installed at shallower depths compared to conventional gravity sewerage, resulting in significant savings in cost of construction (materials, excavation, and manholes). However, whether alternative sewerage can be built at a lower cost than conventional gravity sewerage depends on many other factors [10].

Construction of alternative sewerage is more favorable than conventional gravity sewerage for low-density residential areas because excavation and material costs are lower. In some areas, such as those with rocky terrain or high water tables, excavation to larger depths for conventional sewerage construction is undesirable, making construction of alternative sewerage a more cost-effective solution. Finally, alternative sewerage construction is more economical if the wastewater treatment plant is located at a similar or higher elevation than the households. Any of the alternatives can provide complete sewerage for the community or can be used in combination with conventional gravity sewerage as needed.

4.2. Wastewater treatment technologies

For individual households and small communities, a wide range of wastewater treatment technologies are available. At one end of the spectrum are highly mechanized technologies that use pumps to distribute wastewater, mechanical equipment for mixing, aeration, filtration, and other processes. Significant advancements in technology have emerged in this spectrum in recent years. At the other end of the spectrum are technologies that rely on gravity flow, have few or no moving parts, and rely on natural processes to achieve the required treatment. These technologies tend to have lower costs, minimal or no energy requirements, and require less maintenance. However, for wastewater treatment, they rely more on climatic conditions and environmental conditions, resulting in variations in treatment efficiency. Wastewater treatment technologies are generally known and will not be discussed separately in this paper. Below are only basic notes related to these technologies [10].

4.2.1. Onsite Wastewater Treatment

The most common configuration for onsite wastewater treatment systems consists of two components: a septic tank (ST) and a soil absorption system (SAS). Conventional ST-SAS systems are typically passive and operate entirely by gravity flow without the need for energy. The purpose of the septic tank is to provide removal of larger particles through sedimentation. Usually, a two-compartment or three-compartment septic tank is utilized. The mass of solid particles accumulating in the tank decreases over time due to anaerobic degradation. However, periodic removal of this sludge is necessary. Effluent from the septic tank is discharged into the soil absorption system, which aims to distribute wastewater into the soil, where it percolates through the unsaturated soil layer to the groundwater. During percolation, wastewater undergoes further purification through natural processes, primarily adsorption onto soil particles and biodegradation. An alternative to direct discharge into the soil absorption system is to provide additional treatment through intermittent filters. Typical filters use sand or fine gravel media, but synthetic media, which offer better performance compared to granular media, are increasingly being used [10].

Correctly designed ST-SAS systems should achieve sufficient wastewater treatment to prevent unacceptable contamination of groundwater, which ultimately receives the wastewater [10].

Alternative to ST-SAS systems are compact standalone wastewater treatment units. There are a large number of compact units available from different manufacturers. Most compact units use some form of biological treatment, which can be based on aerobic, anaerobic, or anoxic conditions and utilize attached or suspended organisms. Other processes such as membrane filtration and disinfection with chlorine, ultraviolet light, or ozone can also be incorporated into compact units. Some compact units are designed to provide water reuse and can produce extremely high-quality effluent [10].

4.2.2. Small and Decentralized Wastewater Treatment

Every intensive and extensive technology is applicable to decentralized wastewater treatment plants, as well as to large centralized plants, with the note that of course different technologies have their own advantages and disadvantages that need to be considered when choosing a technology [10].

As with centralized treatment plants, the conventional wastewater treatment process consists of a combination of physical, chemical and biological processes and operations for removal of solid pollutants, organic matter, and occasionally, nutrients from wastewater.

In wastewater treatment plants, intensive biological processes intensify the natural phenomena of degradation of organic matter and removal of nutrients. The most developed and advanced technologies are the activated sludge system with aeration, which requires a stable supply of electrical energy and skilled personnel for operation and maintenance, and trickling filters, which are well-known technologies and represent the standard in biological treatment.

Over the past few decades, there has been a growing focus on the need for more affordable, sustainable, and efficient wastewater treatment technologies, based on ecological principles and technologies based on natural wastewater treatment systems [9]. In natural systems, pollutants from wastewater are removed or transformed through natural processes. Natural treatment systems can be categorized into soil-based processes (including subsurface, slow-rate surface, rapid infiltration, overland flow) and aquatic-based processes (like wastewater stabilization ponds, wetlands, floating aquatic plants, and fish ponds...).

The main advantages of natural treatment systems are that they use little to no energy and chemicals, have lower construction and operational costs compared to mechanized systems, require less labor and maintenance, and have the ability to recover resources (water and nutrients) for reuse. The main drawbacks are the higher variability in effluent quality due to the dependence of treatment on climate factors and the need for large land areas. This often makes them impractical for large populations. Their application is recommended for communities with fewer than 5,000 inhabitants, but they can also be used for larger settlements with sufficient available land.

When selecting a wastewater treatment technology, several factors require careful study depending on the quality of the wastewater and the desired level of treatment, including reliability of operations and the ability of adaptation to changing loads, concentration of suspended and dissolved materials at the treatment plant outlet, noise and gas emissions, lifespan of facilities and equipment, energy consumption and use of other operational resources and chemicals, availability of equipment and spare parts in the domestic market [11].

Treatment processes cannot be directly copied and applied to every wastewater source or every location. It should be noted that small/decentralized plants should not simply be scaled-down versions of large treatment plants, nor should they rely on standard or off-the-shelf solutions, considering their specificities, such as: variations in the quantity and quality of influent are greater than in large urban plants, there are challenges in the treatment and disposal of sludge, which typically needs to be adapted for later use in agriculture, operational reliability should be prioritized over space and time savings, thus simpler yet more robust technologies and equipment are recommended [11].

It's important to note that regardless of the chosen wastewater treatment technology, the effluent discharged from the treatment plant must meet the established criteria and regulations for discharnging water into receiving water bodies, as defined by relevant legislation.

5. CASE STUDY – PIROT MUNICIPALITY

According to the 2011 census, there are 449 settlements with more than 2000 equivalent inhabitants (EI) in Serbia, whose wastewater should undergo at least secondary biological treatment, which accounts for 92.9% of the total number of settlements. Considering that around 80% of these settlements have a population between 2000 and 10,000 inhabitants, the implementation of decentralized wastewater treatment systems emerges as imperative for sustainable water protection in Serbia [11].

The municipality of Pirot is located in southeastern Serbia, in the Pirot Basin. The city of Pirot serves as the center of the Pirot municipality and Pirot district, functioning as an industrial, economic, cultural, and administrative center for the upper Ponišavlje region. Situated on the banks of the Nišava River, on the edge of the Pirot Basin, the city lies in an area characterized by fertile land suitable for agriculture. With a surface area of 1232 km², the Pirot municipality ranks third in Serbia in terms of area, while in terms of population, it ranks 26th, and it can be considered a representative municipality in terms of wastewater management [12].

On the territory of the Pirot municipality, according to the 2011 census, there were 72 settlements: 70 settlements with fewer than 2,000 inhabitants (constituting 97.2% of the total number of settlements) where 12,460 people lived (25.12% of the total population), and 2 settlements with more than 2,000 inhabitants, the city of Pirot and Gnjilan, with a total population of 37,141 inhabitants (74.88% of the total population), of which 34,942 residents live in Pirot and 2,199 in Gnjilan [12].

Based on the Directive on Urban Waste Water Treatment (91/271/EEC) [13], it is necessary to provide collection and secondary treatment of municipal wastewater for settlements larger than 2,000 Population Equivalents (PE), which, in the municipality of Pirot, are only the city of Pirot and the suburban settlement of Gnjilan. For other settlements in the Municipality of Pirot, according to the Directive, it is not necessary to provide collection and treatment of wastewater [12].

The city of Pirot and the suburban settlements of Novi Zavoj, Gradašnica, Berilovac, Gnjilan, Barje Čiflik, and Poljska Ržana have a sewer network built for collection of wastewater from the city and suburban areas. However, the sewage is discharged untreated into the Nišava River downstream of Pirot. To comply with the Directive, it is necessary to construct a centralized Wastewater Treatment Plant (WWTP) for the city of Pirot, where wastewater from the city and suburban settlements connected to the existing urban sewer network will be treated [12].

Due to the significance of the Nišava River for the city, one of the key issues receiving considerable attention in the municipality of Pirot is the protection of water from pollution.

The most favorable solution proposed by the General Sewerage Plan for wastewater from the villages of Poljska Ržana, Trnjana, Veliki Jovanovac, Mali Jovanovac, Veliko Selo, and Krupac in the Municipality of Pirot [14] is the construction of a regional sewerage system connected to the city's sewer network. This entails building sewerage networks within the villages and a main collector with three pumping stations to connect the villages to the regional system. Wastewater would then be directed towards the city's sewer network and central treatment plant.

In the study Analysis of the State of Wastewater Collection, Conveyance, and Disposal on the Territory of the Municipality of Pirot [15], an analysis of all settlements in the municipality of Pirot was conducted regarding the collection, conveyance, and disposal of wastewater, along with a proposed concept for water protection in the municipality's territory. For the city of Pirot and suburban settlements within the General plan area, it was proposed that wastewater treatment be carried out at the central municipal plant. For other settlements along the banks of the Nišava River upstream from Pirot, given their significant distance from the city, shared sewerage is not justified. Therefore, in accordance with modern principles and positive global experiences, the solution proposed is the collection and treatment of wastewater through small/decentralized plants for one or more settlements, depending on the conditions on the terrain. For all other settlements, it is suggested that the collection and disposal of wastewater be addressed individually through impermeable septic tanks and on-site technologies. The Municipality of Pirot has adopted the water protection concept proposed in the study (Figure 3).

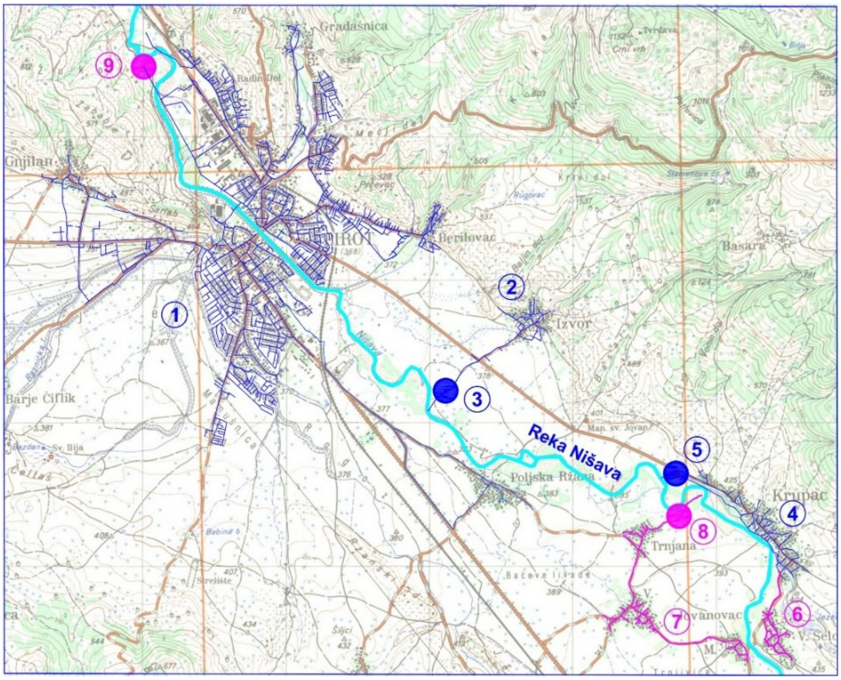

Figure 3. The concept of wastewater treatment in the municipality of Pirot

1- existing sewer system of the city of Pirot and suburban settlements, 2- existing sewer system of the village Izvor, 3- existing WWTP Izvor (1000 PE), 4- existing sewer system of the village of Krupac, 5-existing WWTP Krupac (2500 PE), 6- newly designed sewage network of Veliko Selo settlement, 7-newly designed joint sewage network for the settlements of Veliki and Mali Jovanovac and Trnjana, 8- newly designed joint decentralized WWTP Trnjana (900 PE) for the settlements Veliki and Mali Jovanovac and Trnjana, 9-central city WWTP Pirot (60000 PE)

In accordance with this concept, for the settlement of Krupac located on the right bank of the Nišava River with an established sewerage network, a compact decentralized WWTP (2500 PE) has been built. For the settlement of Izvor, also located on the right bank of the Nišava River, a sewerage network and a compact decentralized WWTP (1000 PE) have both been constructed. Furthermore, activities have been undertaken to develop technical documentation for the construction of a central urban WWTP (60000 PE), the construction of a sewerage network for the settlement of Veliko Selo to connect to the existing sewerage network and the existing compact decentralized WWTP (2500 PE) in the settlement of Krupac. Additionally, technical documentation is being prepared for the construction of a shared sewerage network and a compact decentralized WWTP (900 PE) for the settlements of Veliki Jovanovac, Mali Jovanovac, and Trnjana.

Considering that the construction of wastewater treatment plants represents an economic activity that requires significant resources to achieve an increase in services within a certain time frame, with the ultimate goal of meeting the needs of the population and environmental protection requirements, a Cost-benefit analysis of proposed variants of centralized and decentralized water protection systems in the municipality of Pirot was conducted. Based on the analysis, it was established that the adopted variant of the decentralized system is both financially and economically more viable than the variant of the centralized system.

The municipality of Pirot has undertaken a series of activities in accordance with modern principles and positive global experiences to ensure the most favorable solution for the collection and disposal of wastewater in the municipality. This creates conditions for sustainable and economically justified protection of water resources, primarily the Nišava River, in accordance with regulatory requirements.

6. CONCLUSION

Accelerated expansion of wastewater management services in small communities is of paramount importance for addressing concerns about water scarcity, pollution of water resources, and public health protection.

Planners and decision-makers often favor conventional centralized wastewater treatment systems, which are costly and water-intensive. However, introducing conventional centralized sewage systems in small communities is not sustainable and cannot be justified.

The development of wastewater management services requires improvement in the planning processes that tailor solutions to the social, cultural, ecological, and economic conditions in target areas. Solutions should be location-specific, sustainable, and cost-effective. Guidelines for selection and development of wastewater management systems in small communities greatly facilitate the decision-making process.

The basic principles that should be respected in the development of wastewater management services in small communities are that wastewater should be viewed as a resource that can and must be recovered and reused, and that wastewater should be managed as close as possible to its source and to the point where reuse is feasible. Applying these principles involves adoption of the concept of decentralized wastewater management, aiming to develop treatment systems that are more financially accessible, socially responsible, and environmentally sustainable than conventional centralized systems.

In Serbia, according to the 2011 census, there are 449 settlements with populations larger than 2000 Equivalent Inhabitants (EI) whose wastewater should undergo at least secondary biological treatment. Considering that around 80% of these settlements have populations ranging from 2000 to 10000 inhabitants, the implementation of decentralized wastewater treatment systems emerges as imperative for sustainable water protection in Serbia.

ACKNOWLEDGMENTS

The presented research was carried out as part of the scientific research work funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia according to the contract No. 451-03-65/2024-03/ 200095.

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submitted: 06.03.2024. *UDC : 728.1(=214.58)(497.11)*
corrected: 11.04.2024. *Research scientific paper* *https://doi.org/10.62683/ZRGAF39.47-58*
accepted: 16.04.2024.

CONCEPTUAL URBANISTIC-ARCHITECTURAL MODEL OF ROMANI HOUSING: CASE STUDY CRVENA ZVEZDA SETTLEMENT IN NIŠ

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Abstract

In Serbia, Roma people face various challenges, primarily expressed through discrimination in many fields, as well as difficulties in education, healthcare, and employment. The majority of Roma people in Serbia live in very poor housing conditions. Romani settlements are generally characterized by overcrowded areas, inadequate infrastructure, unplanned construction, lack of amenities in the surroundings and, often, a ghetto-oriented atmosphere. Housing of Roma people, which is the topic of this paper, is a complex topic having various social, economic, cultural and political aspects. The paper considers the Romani housing from a spatial point of view. Provision of housing for the Roma people is one of important ongoing problems that must be addressed by the state. The social and economic status of the Romani national minority could be improved by solving the housing problem. In an attempt to contribute to solving the abovementioned issue, the research deals with finding a sustainable housing model for the Romani population through the case study of the Romani settlement of Crvena Zvezda in the City of Niš: The paper presents an urbanistic-architectural conceptual model for the new Romani settlement on the location occupied by the existing settlement. The model for the new Romani settlement is the result of an architectural analysis of the location and the analysis of the relevant literature that gives a clear view of the state of the Romani population and their settlements in Serbia - their current situation, culture and tradition, habits and needs. The paper gives a proposal for the transformation of the settlement in the form of an experimental conceptual model. The aim of the paper is to contribute to finding an adequate housing model that would provide normal living conditions for the Roma people in a fast, cost-effective, and efficient way, thereby speeding up the process of their inclusion in the society. The modularity and flexibility of the presented conceptual model ensure its applicability in different locations and adaptability to various conditions, making it applicable in different spatial contexts.

Key words: *Romani, Housing, Housing Model, Case Study*

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1. INTRODUCTION

According to the latest census from 2022, the number of the Roma people living in Serbia is 131,936 [1], although many sources speculate that this number is much higher. The predominant characteristic of the Romani life in Serbia is poverty: the major part of the Romani population lives in very poor housing conditions, significantly worse than the majority population (small living space per person, poor construction, bad insulation etc.) [2]. Vuksanović-Macura Z. and Macura V. distinguish various types of impoverished areas where Roma people live, ranging them from *completely inhumane slums* to *relatively acceptable old urban neighborhoods*, and pointing out that regardless of their condition, the majority community typically holds an indifferent or repulsive attitude towards the Romani settlements, which results in the poor integration of Romani enclaves into the majority urban system [3].

Provision of housing for the Roma people ethnic group in Serbia is one of important ongoing problems that must be addressed by the state. The assumption is that by solving the housing issue, the social and economic status of the Romani people would significantly improve. This research deals with the issue of Roma people in Serbia through the prism of spatial organization of living environment with the aim to contribute to the development of a sustainable housing model that can meet the needs of the Romani population. The research is based on a case study of the existing Romani settlement Crvena Zvezda in the City of Nis, that proposes the conceptual urbanistic-architectural model for its transformation, i.e. the design of a new settlement in place of the existing one. The goal is to create a conceptual model that can provide adequate living conditions for the Romani population quickly, affordably, and efficiently, thereby facilitating their integration into society. The model's modularity and flexibility should make it suitable for different locations and adaptable to various conditions, rendering it applicable across different spatial contexts.

Hence, the main research is done using the so-called research by design approach, specific for the sciences such as architecture. According to Hauberg J.: "In many ways, the design process is similar to a research process, searching for new products or knowledge but working in the designer’s language, drawings and models, rather than the written word" [4]. "The most important way in which the architect achieves new cognition is through work with form and space: drawings, models and completed works" [4]. Other scientific methods applied in research are: observation, analysis, synthesis, description, comparison and modeling method. The paper is divided into two main parts – the explanation of conceptual proposal, with reference to the location analysis, and the discussion, which further lead to conclusions.

1.1. Short history of the Romani people on the territory of present-day Serbia

Sika P., Vidová J. and Rievajová E., refering to Sinaiová, A. and Ondriová I. [5], say that the origin of Roma people is most likely in India [6]. The Roma people's departure from India occurred over multiple centuries through migratory waves [6].

Despite this dispersion, they did not remain in individual countries for equal durations [6].

The Roma people arrived in the territory of present-day Serbia during the 15th and 16th centuries, during the time of the Turkish rule in these regions [3]. Mitrović A. writes: "In their long history, while moving from one country to another, the Romanies most often settled down close to urban settlements. Their attachment to towns was primarily related to their professions (crafts) that they could practice for the army they came along with and that mostly resided in towns. Coming together with the Turks to the Balkans, the Romanies also settled in Serbian towns as well as, to a small degree, in villages. The Turks had special regulations for ordering the Romanies' settling down. These regulations determined the places for building residential quarters for the Romanies; their quarters had to be on the periphery of the town or the city, separated from the Serbian houses. They came to be called *mahale* or *džemati*. Such a distribution, that is, location of the Romanies' settlements is almost the same even today in a greater part of Serbia. These are actually the settlements of the old type and they can easily be spotted and recognized. The houses are quite worn out and unstable; the hygiene is rather low; the streets show quite visible traces of the lack of sewage; here and there there can be a new house built; all in all, everything bespeaks that the Romany mahala in Serbia has preserved the same appearance described by the travellers as something "special"." [7] The socialist social order in the second half of the 20th century did not significantly contribute to improving the socio-economic status of Roma. The number of those provided with education, employment, or housing was very small. During the 1970s and 1980s, due to large migrations to cities caused by the industrialization of the country, a new type of illegal Roma settlements - slums, emerged. [3]

2. CONCEPTUAL URBANISTIC-ARCHITECTURAL PROPOSAL FOR THE ROMANI SETTLEMENT CRVENA ZVEZDA

2.1. Analysis of the location

The Crvena Zvezda settlement is an existing informal Romani settlement in the city of Niš (Serbia), classified by Grbić et al. as *slum*, an improvised, temporary shelter that eventually became a permanent settlement [8]. Its area, covering almost 2 hectares, is defined by Dušana Popovića Street to the north, Gabrovački put to the northeast, existing multi-family buildings to the west, and the dead-end of Đorđa Krstića Street to the south (Figure 1).

Figure 1. Location of Roma settlement Crvena Zvezda: (a) top view, (b) aerial view, source: https://www.google.com/maps/@43.3107052,21.9200624,294m/data=!3m1!1e3?entry=ttu, accessed 05.03.2024.

The location is built and inhabited by the Roma people. On-site inspection confirmed spontaneous construction without any plan or order and very poor housing conditions (Figure 2a). The structures are mainly made of solid materials, unfinished, and of questionable construction safety. They are mostly low, one- to two-story, buildings, with sloping roofs, placed very close to each other and randomly scattered across the site in a form of a spontaneously created groups (Figure 2b). This unusual spatial arrangement resulted in a creation of specific empty spaces that serve as areas for communication and gathering spots. Throughout the settlement there is no adequate infrastructure - paths are unpaved; the communications are of variable width, but very narrow for vehicles; many communications finish in dead ends. Since a large number of residents is engaged in collecting secondary raw materials, and there is no designated area in the settlement for their disposal, piles of waste can be found everywhere throughout the settlement, right next to residential units. The inadequate living conditions and the necessity to improve the quality of life at the location are evident, both for the people living there, which is primary, and for the people living in the surroundings. Having in mind that the location is close to the important urban facilities, it is also necessary to think of creation of more representative visual image of this part of the city, its safety and tidiness.

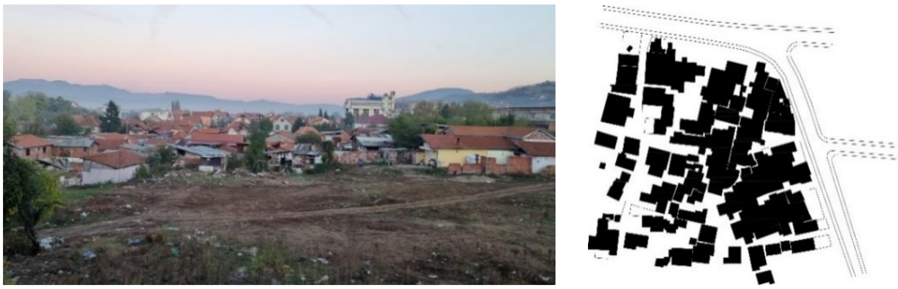

Figure 2. (a) View towards the settlement from the neighboring building, (b) Settlement scheme, source: authors

2.2. The explanation of the concept

2.2.1. Functional content

Conceptual urbanistic-architectural proposal for the new Romani settlement on the location of the existing one, envisions the construction of 50 residential units and the accompanying communal facilities (Figure 3). Each residential unit is capable of accommodating family consisting of five to eight members, hence the maximum population density the settlement could reach is 210 inhabitants per hectare. Communal facilities, which are scattered all around the Romani housing complex are intended for gatherings and socializing, cultural and educational purposes, as well as for relaxation, recreation and gardening: gathering center, recycle warehouse, playground, fruit and vegetable plantation and market place. There are also few groups of parking places for different vehicle types.

A communal gathering center is located in the southern part of the site and has a direct access from the newly designed street. It is envisioned as a multifunctional facility, which could host various educational sections for children, evening schools for adults, courses, celebrations (which are an essential part of the Romani culture

[9]), meetings, or perhaps the production of homemade food products out of harvested fruits and vegetables from the garden or other homemade crafts that could be further sold at the market. The communal facility is designed to be the formal center of the settlement, the main gathering and socializing place, and a hub for exchanging opinions and knowledge. The existence of such a functional content is of great importance for the sustainability of the settlement. In this case, these facilities are tailored to the general and specific habits of the social group for which the settlement is intended.

Figure 3. Proposal for the new Roma settlement Crvena Zvezda, Site plan, source: authors

Considering the fact that the local Romani population is often engaged in collecting secondary raw materials (packaging, metal scrap, old appliances), the recycling facility is planned at the outskirts of the settlement, where collected material could be stored, separated and further distributed for recycling.

In order to foster interactions with neighbours and other people outside the settlement, as well as to promote the home craftsmanship, along the main road, where the frequency of residents from the surrounding area and other passersby is the highest, i.e. at the place where the new Romani complex merges with the existing group of multi-family buildings, a small paved square with a market setup is envisioned. Here, the Romani people could sell their fresh garden products, thus generating additional income for their households.

For the purpose of relaxation and sport activities, playground that could be used for various sports with the smaller area for children's play is planned in the northwest part of the settlement. On the other hand, the southwest strip is intended for gardening, where the inhabitants could plant fruits and vegetables for themselves or for sale. This area is intentionally left undeveloped in order to create, together with upper relaxation area, green buffering zone at the transition between new Romani and the existing multi-family residential complexes.

2.2.2. Urban and architectural setup

The main design characteristics of the settlement are modularity and flexibility, i.e., adaptability to the current needs of the users. The concept is based on simultaneous individualization, so that each family has its own home, and communal living, achieved through a dense architectural carpet structure [10]. The rationalization of construction is achieved through the use of standardized elements, whose repetition forms a complex composition of the settlement (Figure 4). The residential unit is composed of three modular units, which, when combined, form the basic spatial and structural component of the residential part of the settlement. Two residential units are then grouped together, mirroring each other, in a way that one unit is laterally stuck to another. These attached houses are further multiplied, following an orthogonal grid that fits into the block's geometry, creating a dense structure of single-story buildings (Figure 4).

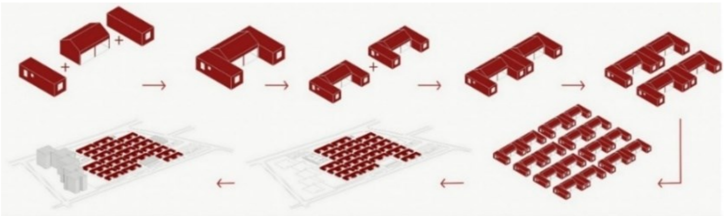

Figure 4. Modularity of Romani settlement Crvena Zvezda, source: authors

The spatial arrangement of the buildings is defined by clear pathways through the settlement. An orthogonal grid of paths creates spaces for easy pedestrian communication through the settlement and for vehicular access in a case of emergency or evacuation (Figure 5). Special attention is given to integration of greenery into the built structure. Greenery is present at multiple spatial levels (Figure 5): (1) within private courtyards, (2) as green strips along longitudinal and transverse communication routes (semi-private areas between buildings), which serve as mini buffer zones between the public and private spheres, or transitional spaces between pathways and courtyards, and (3) around the perimeter of the complex - a buffer layer towards the surrounding streets on the eastern, northern, and southern sides and towards the adjacent group of buildings to the west.

The design of the settlement promotes pedestrian and bicycle traffic. The settlement is entirely free of motor traffic, with access for motor vehicles only possible along the perimeter (Figure 5). Two parking zones are planned - one along the newly designed southern street, which has the least traffic, and one in the form of a parking group accessed from Gabrovački put. There is a total of 51 parking spaces, meeting the criterion of 1 parking space per residential unit. Bicycle parking is located inside the small green park at the crossroad, as well as next to the recycling warehouse.

Figure 5. Constructed area (up left), Green areas (up right), Pedestrian paths and parking areas (down left), Evacuation ways (down right), source: authors

In functional terms, the residential unit is organized to accommodate multi-generational composition of Roma family of characteristic habits (Figure 6a). The space is divided into three structural-functional units: the central unit (largest unit, representing the main, daily, part of the building), and two side units (housing sleeping areas and accompanying facilities - entrance, hygiene facilities, and household maintenance spaces). The main area/functional zone of the housing unit is organized according to the principles of the open space concept and combines a space for food preparation (single-track kitchen), a dining area with a table seating eight, and a living room with a large sectional sofa. This area serves as the focal center of the residential unit where family activities take place. The interior space of the main area seamlessly extends to the garden terrace on the south side, which serves as an extension of the living space. With movable glass panels, the interior and exterior spaces are integrated not only visually but also physically, becoming one unit that functions as an expanded living room during favorable weather. There is also the option to create a winter garden in the part of a courtyard with additional glass panels, thus increasing the usable daily space during winter months and improving thermal comfort of the building by creating an additional thermal envelope. The night zone is located in the side wings of the house and is deliberately divided into two parts for generational separation. It is characteristic of Roma families that multiple generations live in the same household. Roma often marry at a young age, forming new, young families, so it is not uncommon for children to live with their parents and grandparents (extended family) in the same home. According to Grbić M. and Nikezić A. [9] three-generational structure is the most frequent household organization in Romani settlements in Belgrade. A primary Romani family, that has five members consisting of a husband, wife and three underage children, after the marriage of children (sons) expands, being then comprised of a husband, wife, their sons and daughters-in-law and their children [9]. The division of the night zone follows the idea of separating parents with children from elderly parents. Thus, one part of the night zone includes a parental and children's room with an external bathroom used by all household members, while the other part includes a double room for elderly parents with a toilet, also available to all household members. The dimensions of bedrooms are minimal, for rational space utilization, but sufficient for optimal functional organization. Due to changes in family structure or the increase of household members, by replacing a regular bed with a bunk bed, the children's room initially designed for one child can become a sleeping space for two children, or parents can give their room to the children and use the living room for sleeping in a case of more children. Accordingly, the living room is designed as a multifunctional space (Grbić M. et al. emphasize the necessity of enabling the permanent transition of the living room into a multipurpose room [11]). The bathroom is envisioned to be shared by all users for the sake of economy. As an additional hygiene space, due to possible crowding in the house, there is a toilet, near the entrance, accessed through the laundry room. The number of sanitary facilities is determined following the example of the regulations that apply when designing residential buildings and apartments [12]. Given that the residential units are designed as houses, the entrance area is designed as a vestibule or buffer zone between indoor and outdoor spaces. The building is fully enclosed to the north and opens towards the south and the semi-atrium courtyard. The entrances of adjacent units are placed right next to each other and recessed relative to the northern facade plane to create covered areas as a protection from the weather.

The net area of the residential unit is almost 85m^2 with an additional garden area of almost 40m^2, approximately half the area of the house. The main space of the house is oriented toward the south, and large transparent surfaces blur the boundary between indoor and outdoor spaces, uniting them into a whole that functions as one large extended house. The southern orientation also plays a role in passive heat absorption, particularly important for winter months when the daytime area of the house is additionally heated by sunlight. During the summer months, overheating of indoor space is prevented by the awning and the use of opaque curtains (a cost-effective sun protection solution).

Figure 6. (a) Floor plan – attached housing units, (b) 3D model - view from the pedestrian pathway to the south garden of housing unit, source: authors

2.2.3. Architectural shape

A typical housing unit is of very simple shape. As mentioned, the housing unit, spatially organized as semi-atrium structure, consists of three volumes. Three volumes/wings are positioned around the central yard that opens to the south and the pedestrian street. The side wings are designed as container structures with flat roofs, while the central volume has a gable roof (Figures 6b, 7a). The gable roof of the central part serves a dual purpose: (1) the southern slope of the roof is used for collecting solar energy through solar panels, which is then used to heat water in the household; (2) the gable roof form, adopted from the existing settlement, corresponds to the design habits of Romani residents.

Figure 7. 3D model: – (a) repetition of housing units across the complex, (b) entrances to the housing units, source: authors

Due to the uniformity of the buildings, i.e., the repetition of the same shape, there is a potential problem of a monotonous visual atmosphere in the settlement. However, the assumption is that the residents themselves will give their homes a personal touch (e.g., by installing curtains of different colors, decorating their gardens differently, introducing or not introducing winter gardens, etc.). Each unit is numbered with a large house number at the entrance (Figure 7b), which also contributes to recognition.

3. DISCUSSION

Although the primary idea of the new settlement concept stemmed from the analysis of the location, which was conducted before the start of the design process, without prior detailed theoretical background on the topic, it turned out that independent pre-design analysis led to the same or similar conclusions as those reached by experts researching the Roma housing in Serbia. Engaging with the topic of improving spatial organization of housing in Roma settlements in Belgrade, Grbić M. in her doctoral dissertation starts from the standpoint that there exists a relationship between the spatial and social levels in Roma settlements that needs to be recognized, harmonized, and presented [13]. When designing residential space for Roma families, special attention should be paid to the characteristics of the Roma society, primarily in terms of culture, customs, traditions, neighborhood connections, and the like. The conceptual proposal, presented in the previous chapter, took into account the following aspects: (1) Roma families are multi-generational, with often several generations of one family residing in the same household, thus the functional organization of residential units was developed accordingly; (2) Roma families are not isolated; there is a dominant social interaction among neighbors, so the spatial arrangement intertwines spaces of different degrees of privacy within the settlement, ranging from private to semi-private/semi-public to public or communal; (3) Roma families spend a significant amount of time outdoors (especially children, who enjoy being outside with other children), so the settlement intertwines open and enclosed spaces inside of which the life equally takes place during the day - the categories of interior and exterior are more interconnected and overlap each other than in housing the majority people in Serbia are used to.

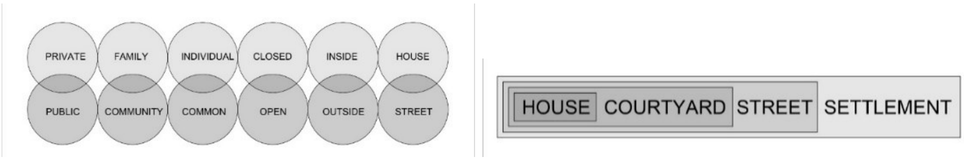

Figure 8. Diagrams of the overlapping of social-spatial categories in Romani everyday life inside of the settlement, source: authors

Observing the Romani lifestyle, one could conclude that the relations between certain social and spatial domains are much stronger than in the lifestyle of the majority population (Figure 8 left). The everyday life of Romanies is intertwined with the constant interactions between opposite social-spatial categories such are: family and community, individual and common, private and public, closed and open, inside and outside, house and street. Those social-spatial categories are of great importance for understanding the spatial needs of the Romanies, because they overlap each other, creating a layered space inside of which inhabitants dwell. Urb-architectural elements: house, courtyard, street and settlement are not strictly separated from each other, but they complement each other, creating a more homogeneous structure of the settlement that functions as a single whole. House imperceptibly expands to the courtyard, which further expands to the street, which further expands to the settlement (Figure 8 right). There are no clear boundaries – the life equally takes place inside and outside those elements, which enhances the gradation of space in terms of privacy, making the spatial scale richer (private/semi-private/semi-public/public).

Some of the basic structural elements of Roma settlements, highlighted by Vuksanović-Macura Z. and Macura V. [3], are: settlement center, residential zone, workspaces, street network, infrastructure, and greenery in the settlement. According to them, the settlement center and public facilities are of vital importance for the internal integration of residents. Although the majority of existing Roma settlements lack a central gathering point, it does not mean that there are not places for gathering, where children play, and where young people hang out: elements such are crossroads, auxiliary buildings or someone's yards spontaneously become places of social life [3]. According to Grbić M. et al. [8]: “Streets in Romani settlements have a complex character with a significantly pronounced degree of integration of users. Streets in slums are areas of communication, connecting elements of courtyard building groups, but they are also spaces that the daily rhythm of residents initiates into gathering spaces”.

Following the habits of Roma population, the conceptual design of the new Crvena Zvezda settlement aimed to satisfy all the needs of the residents. The main and largest zone in the settlement is residential, while other zones - work, recreational, green (buffer zone towards surrounding roads and other neighboring facilities), and socializing and gathering zones - are arranged around the perimeter.

Vuksanović-Macura Z. and Macura V. also emphasize another important fact, namely that Roma people live in family houses with their own yards, and that this type of housing should be maintained as dominant because it stems from the cultural habits of Roma families, i.e., family relationships [3]. Since the same conclusion was made after analyzing the existing Crvena Zvezda settlement, the single-family houses were chosen as housing typology for the new settlement.

The presented conceptual proposal of the settlement relies on the idea of ensuring the optimal use of space, improving housing conditions, and providing accessibility to key resources such are water, electricity, and sanitation. The design of the settlement promotes social interaction and communal activities, as well as integration with the surrounding urban context. The design involves simultaneous individualization, where each family has its own home, but also a sense of community achieved through dense architectural structure. Construction is rationalized through repetitive typical elements, creating a complex composition of the settlement. Aesthetic aspects are also included in the concept to ensure harmony and aesthetic value of the settlement, which would contribute to improving the quality of life and the community identity. The design takes into account traditional forms of Romani houses and their habits, such as gabled roofs, ground-level structures, the need for social life, and outdoor living. One of the goals of the concept is to be sustainable at ecological, economic, and social levels, which means it should encourage the use of renewable energy sources, support the local economy, and promote social inclusion through education, employment, and social support programs.

4. CONCLUSION

The general description of Roma settlements is often associated with inadequate, unplanned, and ghetto-oriented spaces. Research on the housing of the Roma people in Serbia in this paper emphasizes that housing for this ethnic group is an extremely important issue. The research was conducted through design, namely through urbanistic-architectural proposal for a new Roma settlement on the location of an existing Roma settlement. The aim of this experimental urban-architectural project, or the case study that focuses on the Crvena Zvezda Romani settlement in Niš, which was chosen as the example, is to contribute to finding appropriate housing model that would help in providing normal living conditions for the Roma population in a fast, inexpensive, and efficient manner. The assumption is that by improving living conditions through housing, the process of social integration of Roma people, which is also one of the most significant issues, could be accelerated. The conceptual urbanistic-architectural proposal for the Crvena Zvezda Roma settlement encompasses a series of elements based on the community's needs and characteristics, as well as sustainability, flexibility, modularity, inclusivity, and aesthetics principles.

This research, within a theoretical framework, represents an experiment that utilizes architectural tools to address the housing issue of an ethnic group whose quality of housing, and, consequently, their overall quality of life, is at a very low level. Considering that this concerns a not insignificant number of people, or families, whose daily life is becoming increasingly difficult, the necessity of addressing this topic is evident. The issue of the Roma population can be viewed from various angles and aspects, as the problem is complex. Since the problems are interconnected, solving one could significantly impact the solution to other. However, on the other hand, to completely solve one problem, it is necessary to address other problems as well. Improving housing conditions would be a significant step forward; however, if parallel efforts are not made in other areas (primarily education, raising awareness about ecology, health, and increasing employment rates), the problem could soon resurface. Addressing the issue of Roma housing, even in theory, represents progress in solving the problem. Certainly, it is crucial for the solution to be implemented in practice, which would open up new obstacles and discussions.

Inevitably, the involvement of the state in addressing the housing issue of the Roma is crucial. Although this problem has existed for decades (or even century), it has only recently begun to be considered, and concrete measures have been taken to address it. However, progress in practice is not as fast as desired, but any advancement, even theoretical, is significant. Based on the research of Roma settlements, one conclusion that can be drawn is the proposal that successful solution of the housing issue of Roma population requires state support in the form of certain subsidies to facilitate access to healthy homes for Roma families. Although this issue can be categorized as part of the broader social housing problem, the approach to addressing Romani housing, due to its specificities (closely linked to Romani culture, tradition, and customs), should be unique and independent. Just as the Regulation on standards and norms for planning, designing, construction, and conditions for use and maintenance of social housing [14] was adopted for the design of social housing, the proposal is to adopt a similar regulation aimed at addressing housing for Roma people. This regulation would clearly define standards for the design of housing in Roma settlements, while adapting the norms to the specific needs of users. Furthermore, if the construction of settlements were to be under the directive of the state, the proposal is to emphasize energy efficiency in construction, as it is the key to sustainability. Njegić T., Manić B. and Lojanica V., speaking about sustainable social housing, state: "Given that social housing is under the direct responsibility of the public sector, it can be a testing ground for promoting energy-efficient solutions and encouraging local market development in the field of energy-efficient construction techniques and technologies" [15].

ACKNOWLEDGMENTS

The research is financially supported by Ministry of Science, Technological Development and Innovation (Agreement on the realization and financing of the scientific research work of Scientific research organization (University of Niš, Faculty of Civil Engineering and Architecture) in 2024, registration number: 451-03-65/2024-03/200095).

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submitted: 10.04.2024. *UDC : 624.074.4:621.383.51*
corrected: 26.04.2024. *Preliminary communication* *https://doi.org/10.62683/ZRGAF39.59-66*
accepted: 30.04.2024.

EXPLORATION OF THE SUITABLE TENSIONED MEMBRANE PROPERTIES FOR THE PHOTOVOLTAICS INTEGRATION

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Elena Lucchi[3]

Abstract

The possibilities for the integration of tensioned membrane structures and photovoltaics have been researched intensively in the past decade. This integration has huge potential and is intended to bring benefits to both of these individual systems. This paper presents a preliminary communication of the research that is intended to facilitate the PV/membrane integration. Upon reviewing the current body of knowledge in the field, it is concluded that the mechanical properties of PV are known, some integration already occurred, both of the systems are still being perfected, however, it is not clear what properties a membrane structure needs to have in order to be suitable for the PV integration. Therefore, the goal of this research is to find out the relation between some of the structural parameters and the strains of the membrane, which are already determined as critical for the photovoltaics efficiency. The methodology of the research is laid out in this paper. A numerical simulation will be conducted in order to achieve membrane strains lower than the critical. For this, a set of variable parameters are selected and altered. The results should help the designers in choosing the values of the structural parameters, with the goal of designing tensioned membrane structures suitable for the integrations with photovoltaics.

Key words: *Tensioned Membrane, Membrane Structure, Photovoltaics, Numerical Simulation, Membrane Strain, PV/Membrane Integration*

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1. INTRODUCTION

Both tensioned membrane structures and photovoltaics are highly advanced systems and both are still being perfected. Tensile membranes are extremely efficient when it comes to the amount of self-weight compared to the area being covered. This is a result of their thinness and the optimal shape they take for each of the given boundaries. In addition, they are esthetically very pleasing, which is a great benefit, as this attracts much attention and visits (Figure 1). On the other hand, photovoltaics are seen as a way to solving the energy crisis. Transforming the solar energy into electrical energy is expected to provide enough power supplies so that most of the buildings become independent from the external network. For this to be achieved, two strategies are currently deployed – reducing the energy consumption in buildings, and increasing the efficiency of photovoltaics. Once the efficiency of the PV achieves high levels, there will be less need to continue working on the reduction of energy consumption. Until then, the amount of area covered by the PV will still be of high importance. Therefore, the idea of integrating photovoltaics into tensile membranes arose. Membranes provide large areas for possible PV integration and are often used to cover open spaces. However, due to their lightweight nature, their coupling with heavy panels is not optimal, which is why organic PV cells (OPV) technology is currently the best option for membrane integration. This integration calls for additional research and this paper is dedicated to the exploration of suitable membrane properties for the PV integration.

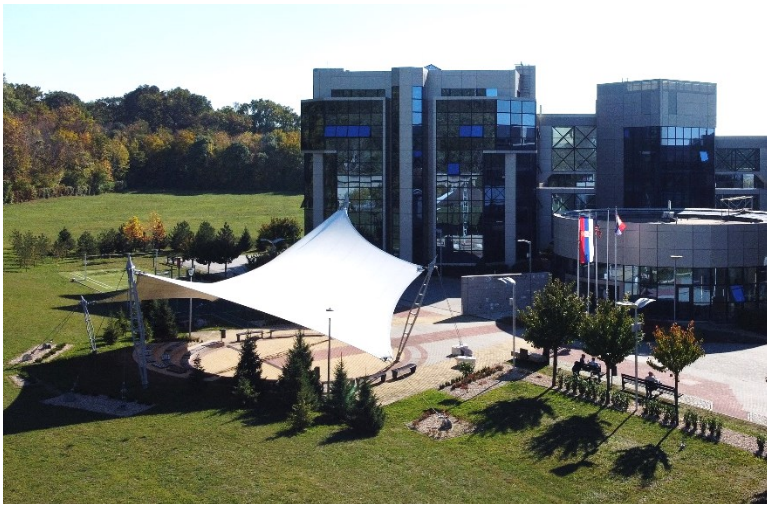

Figure 1. Tensioned membrane at the Science and Technology Park Belgrade, by Artech (courtesy of www.artech.rs)

Fan et al. provided a major contribution to this field of research [1]. They conducted experimental investigation of the mechanical robustness of the OPV module and membrane-printed functional layers for flexible solar cells. Review of the membrane integrated PV has already been presented [2,3]. Irradiation analysis of membrane structures for the purpose of covering with photovoltaics has also been presented [4]. Membrane stresses and deflections under external loads have been analyzed on hypar [5] and barrel-vault shaped membranes [6,7]. Different aspects of integration of PV onto ETFE cushions have been explored [8], including structural [9] and electrical, thermal and mechanical properties [10]. Mechanical properties of membranes have also been experimentally tested [11]. One study has been done on the life cycle assessment and life cycle cost analysis of a pneumatic ETFE membrane incorporating PV cells [12]. Another article has analyzed a case study to assess the feasibility of textile envelope in different parts of Europe [13].

The goal of this research is to investigate what properties a tensile membrane would need to have to be suitable for the integration with the photovoltaics. This paper does not present the results of the research, but rather provides a discussion and explanation of the methodology used for the research. Once the research is complete, the results will be published, and it is expected that they will give clear guidance for the designers of tensile membranes on how to design or modify their designs in order to incorporate the PV on architectural membranes. This should help in wider application of the PV-integrated membrane structures, which will as a result lead to a greener and more sustainable future.

2. RESEARCH BASIS AND MOTIVATION

Currently, three different membrane materials are most frequently used. These are two fabric coated materials and one foil material. Polyvinylchloride (PVC) coated polyester fabric and polytetrafluoroethylene (PTFE) coated glass fabrics are woven materials, while ethylene-tetrafluoroethylene copolymer (ETFE) is a foil. There are some important differences between them. Foil is much thinner and can be transparent, while woven membrane materials are translucent and can cover larger spans. Due to the latter difference, ETFE is most commonly used for pneumatic structures. Therefore, this research will focus more on the fabric membranes as it is interested in covering larger areas. Even among the fabric-based membranes there are some significant differences. PTFE materials in general have better mechanical properties and a longer life span, while PVC membranes are cheaper. Both of these material types are further classified according to their properties. The appropriate material for each designed tensioned membrane structure is selected according to the mechanical and other important properties of the material.

Mechanical properties of the membrane material can be regarded as a link between the photovoltaics and the membrane, while, at the same time, mechanical properties of the PV are the limiting factor for their integration. The main problem is that PV cells still cannot withstand large strains which are specific for tensioned membranes and do not occur in structures made from traditional building materials. This became one of the major obstacles in incorporating PV onto membranes. Research about the strains of OPV was conducted by Fan et al. [1] and it became the base point for the research presented in this paper. Starting from the results obtained by Fan et al. this research aims to find out what properties a tensioned membrane structure needs to have, in order to allow for the integration with the OPV, regarding the strain limitation of photovoltaic cells.

Three existing strategies are explained in the paper [1] for PV/membrane integration. These are the mechanical integration, lamination, and direct printing of OPV modules on the substrate. The research goes on to experimentally investigate the commercial OPV module and the new, membrane printed OPV modules. For the latter type, several different options were examined in order to compare them. Stability, mechanical and electrical characterization tests were conducted on the commercial OPV module. A nominal stress-strain curve is shown and a failure mechanism of different layers is described. However, this information does not give data about the actual efficiency of the module under strain. Therefore, strain is given in relation to the normalized efficiency and the electrode 1 conductance. Based on previous research, a 20% drop compared to the initial efficiency is used as a limit. According to the experiment, it correlates to the strain of 1.8%, which is then considered as the critical strain. For the printed OPV the results show the relation between the strain and the normalized conductance. A critical strain level has not been defined, but the results show that these printed modules show much larger strains compared to the commercial ones, tested in the first part of the experiment. Scotta et al. did a research [14] on membranes with embedded flexible photovoltaic cells. They reported that after the stress of 22 N/mm the power production decreases significantly for the tested samples.

The mentioned results motivated research to find out what the properties of a tensioned membrane structure would be, that can respond to the limitations set by the photovoltaic cells, or more specifically, have strains lower than the set critical strains for the OPV. Therefore, a research methodology has been set and presented in this paper. The research deals with the properties of the membranes and does not further explore the photovoltaic part of the integrated system.

3. METHODOLOGY

There were several important aspects to be consider while setting up this research. Once the topic and the scope were defined, it was necessary to plan the methodology of the simulation. For this, parameters to be analyzed had to be selected. Since the strains under load are examined, the appropriate loads were defined. Finally, the result analysis methodology needed to be adopted. To all of the mentioned topics, a separate subchapter is devoted.

3.1. Simulation

The strain analysis of the tensioned membrane structures will be conducted as a simulation. In the first phase of the research, the simulation will be done as a numerical simulation. Due to the complex behavior of membranes, some simplifications need to be made in this case. There are now many different methodologies on how to numerically test tensioned membranes. Commonly used software apply different methods for this. Finite element analysis software Sofistik was already used for many numerical simulations of membranes [15]. It does not account for the nonlinear material behavior of membranes. Therefore, the results will not be the same as in physical testing, but behavior and trends can be observed and general conclusions will be obtained. This will allow for more precise setting of the physical experiment which will happen in the second phase of the research. Further details about this phase will be given once phase one is completed.

3.2. Parameters

The selection of parameters to be analyzed is the essential for this research. Having in mind the goal of the research, the search for the properties of membrane structures that can facilitate the integration with the photovoltaic cells, it is important to define structural parameters that need to be fixed during testing, and the ones that will be varied. In this way, the research will produce conclusions in the form of recommendations on how to select the values of the variable parameters in order to be able to incorporate photovoltaics onto membrane structures.

The first constant parameter of the membrane structure is the membrane form. For this research a hypar shaped membrane is selected. The membrane will have four edges and four corners. Corners will alternately be positioned as low and high, in order to get the hypar shape of the membrane. Other usual forms of membranes are cone and barrel-vault, however, hypar is selected for the testing as the most frequently used one. The base of the structure will be square-shaped. Variations to the shape of the base are possible, but in order to limit the number of variables, only square is considered.

The thickness of the membrane is fixed at 1 mm during the entire testing. Despite slightly different thicknesses of different analyzed materials, the change of this parameter will not have an important impact on the results, due to the low weight of the membrane with regards to the covered area. The properties of the steel cables used as edge cables will also remain the same throughout the study. The cables will have a diameter of 12 mm and the elastic modulus of 205 kN/mm^2. The size of the finite element of the membrane will be approximately 0.1x0.1 m. This size was selected in accordance with the applied loads.

As for the variable parameters, a list of six parameters is defined. These are the membrane material, the size of the base, the height of the model, the patterning direction, the type of edge supports, and the intensity of the prestress. A similar list of variable parameters was used in a different study that dealt with the deflections of membranes [16]. Here, not only the research topic is different, but also the testing process is different, as now a limit value for the strains is defined, and the appropriate parameter values have to be found. Therefore, it would not make sense to try to define the analyzed values in advance. Instead, the initial testing will start with the parameters that are expected to have a larger influence, based on the previous experience with testing membrane structures. These are the size and the height of the model and the membrane material properties. Afterwards, other parameters will be analyzed. The results will confirm whether the assumption about the significance of influence of these parameters was correct.

Six parameters selected for analysis essentially define the tensioned membrane structure. The size of the base is directed by the span, and is usually given as a requirement to the designer, although sometimes there is a possibility to divide the structure into several smaller ones [17]. The height of the structure, in relation to the size of the base, defines the curvature of the membrane, which is known to have a large impact on the behavior of the membrane under load. The type of membrane edges has a subtle effect on the form of the membrane, but straight membrane edges usually mean more massive and heavy supports. The patterning direction of the membrane impacts the visual appearance of the structure, but it also has structural implications. Intensity of the prestress and membrane material are closely related. They are usually the last parameters to be defined, and are used for structural adjustments to the structure, when the designer is already satisfied with the appearance of the design.

3.3. Loads

Three types of loads have been selected for simulation. These are the loads that are known to have large impact on the strain of the membrane. The first one is snow load. Although snowfalls do not occur at all locations, it is a very common load for most of the structures. The second applied load is the wind load that is often the dominant load in the structural calculation of membranes. The third load is the concentrated load that occurs mostly from the weight of people on the membrane. This load is specific, because in case that it produces unfavorable results, the recommendation to forbid access to the membrane can be given, which is not the case with the two other analyzed loads. In this case, all maintenance, inspection and repair have to be done using cranes or other devices to allow workers to approach the upper side of the membrane without standing on it.

Loads acting on the structure, as well as some of the structural properties, have to be simplified in the testing. For snow load this is of lesser importance, since its action is not very complex. Most importantly it will be assumed that the load acts with the same intensity across the entire membrane, which is not the case in reality. For wind load simplifications are much more significant, as wind is a dynamic action that will be applied as a static load in this testing. Load from humans walking on the membrane also has a dynamic component that will be ignored during the analysis. The exact load values and parameters will be selected with regard to the previous studies done on membrane stresses and deflections.

3.4. Results analysis

The testing will start by applying each of the loads individually to the initial model of the tensile membrane structure. The maximal strain results will be monitored. Based on the obtained results, the parameters will be varied in order to find the sets of parameters that define different membrane structures that are suitable for the application of PV cells on them. One variable parameter will be varied at a time. For each new set of parameters, a new numerical model will be built. Once the dependency of the strain on the parameter value is established and the strains are lower than the defined critical strains, the variation of the next parameter starts. The procedure will be continued until all parameters are analyzed.

There is a risk that strains lower than the critical cannot be achieved. In this case, a change in the results analysis should be made. Instead of monitoring maximal strains, all strains of the membrane will be analyzed. The goal of this is to find parts of the membrane suitable for PV integration, since the most strained parts are unsuitable for this. In this case, conclusions will have to include this aspect of the analysis, so that recommendations will be given to designers even for the membranes that are not entirely suitable for integration.

4. CONCLUDING REMARKS

This paper presents the methodological set up for a research dealing with finding the appropriate parameters of tensioned membrane structures to make them suitable for integration with photovoltaic cells. It is intended as an introduction to the research, whose results will be presented in the articles to follow. In the paper, a brief overview of the existing literature in the field is given. Based on the state-of-the-art, the research question is formed and the motivation for the research is elaborated. Then, the methodology of the research is discussed and presented. The significance of analyzed variables and their role in defining a tensioned membrane structure is given. The testing process is presented, as well as the results analysis, that will have an impact on the testing methodology.

It is expected that the results of this study will provide an understanding of the relation between the six analyzed parameters and the membrane strains under load. This knowledge will be useful even when the photovoltaic cells advance and no longer have the same critical strains as defined in this study. Therefore, the results will be of help to designers of membrane structures when the integration of PV cells is intended. The novelty of this research is in providing values for structural parameters, compared to existing research where individual cells or parts of the membranes are tested. Once the production of transparent flexible photovoltaic cells begins, they may become an integral part of every membrane, as soon as cost effectiveness is achieved. It can be concluded that we are still at the beginning of the road towards membrane integrated photovoltaics, and that this research is a small step towards future developments that are likely to make humanity more energy independent.

ACKNOWLEDGMENTS

This research is financially supported by the Ministry of science, technological development and innovations of the Republic of Serbia, under the grant 451-03-65/2024-03/200095.

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submitted: 13.03.2024.
corrected: 05.04.2024.
accepted: 10.04.2024.

Review paper

UDC : 72:061.231(497.11))
711.3(497.11)
https://doi.org/10.62683/ZRGAF39.67-78

LANDSCAPE PAINTED WITH TEA: ARCHITECTURAL COLONY IN KLINCI VILLAGE (LUSTICA)

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Abstract

This paper reflects on the outcomes and implications of an architectural colony conducted in the village of Klinci, Montenegro. The colony aimed to address rural development challenges through innovative architectural solutions while fostering collaboration among students, professionals, and local stakeholders. Drawing upon the experiences and discussions from the colony, this paper examines the successes, challenges, and lessons learned.

The results indicate a remarkable quantity and quality of proposed solutions despite the extended timeframe. However, organizational shortcomings, participant motivation, and resource constraints emerged as significant challenges. Suggestions for improvement include the involvement of external support, such as investors and funds, and the implementation of photogrammetric methods for comprehensive terrain analysis.

Moreover, the paper highlights the educational value of such colonies for architecture students. Through collaborative teamwork, students develop essential skills in communication, problem-solving, and critical thinking. The colony serves as a platform for experiential learning and the cultivation of a sustainable mindset among future architects.

In conclusion, the paper emphasizes the importance of sustained efforts in promoting rural development through architecture. By addressing the identified challenges and leveraging the lessons learned, future iterations of architectural colonies can contribute more effectively to sustainable rural development initiatives.

Key words: *Architectural Colony, Workshop, Klinci, Luštica*

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1. INTRODUCTION

Considering the profound themes and complex patterns explored in the novel "Landscape Painted with Tea," the name of the architectural colony carries an implicit association with mysterious destinies and invisible connections among people, characteristic of Pavić's literary oeuvre. While there may not be an apparent connection between the colony's name and the themes of the novel at first glance, it certainly invites reflection on the intrinsic meaning and symbolism that may be linked to the subject of architectural research.

Furthermore, the name of the architectural colony as "Landscape Painted with Tea" can serve as an inspirational framework that fosters imagination and creativity both in the design process itself and in the experience of visitors or residents of the colony. This association with Milorad Pavić's literary work can add depth and complexity to the perception of space and architectural solutions, providing an additional layer of meaning that transcends the mere physical aspect of architecture.

The term "colony" is predominantly associated with painting or art in general. The oldest art colony in the Balkans and within the former Yugoslavia is an institution known as Sićevo. It was established on July 30, 1905, 16 kilometers east of Niš, in the village of Sićevo, upon the initiative of the Serbian painter Nadežda Petrović. [1]. This colony continues to exist today, albeit with a hiatus of 59 years due to the period of wartime destruction in the country. Since 1991, it has had an international character and serves as a model for many art colonies established in the Balkans. During the transition period, following the change of the political system in Serbia in 1999, the term "colony" often transformed into the name "workshop," following the practice of Western countries. Following the example of painting colonies, architects organized their own gatherings for collaboration under various names (summer schools of architecture, architectural workshops). The term "workshop" seems to correspond better to the nature of architectural research, although both terms refer to a form of collaboration among specific groups of professionals. Due to the flexible nature of workshops and colonies, it is not coincidental that such platforms enable the exchange of ideas and collaboration among students from different faculties and universities. Architectural workshops constitute a vital part of the educational process, providing young architects with an opportunity to develop their skills and creativity in a real-world environment. [2-5].

In Montenegro, the notable activities of the non-governmental organization known as Expeditio are well recognized. Since 1997, this association has implemented a considerable number of projects, including architectural workshops in Perast, Zagora, Podgorica, and Godinje [6]. It can also be noted that the realization of international workshops in Perast in 1997 and 1998 spurred the author of this paper to organize similar events. The workshop "Revitalization of the City of Perast," based on gathered data, enabled students to contribute their ideas for the revitalization of Perast. The outcomes of this research workshop are documented in the publication "Three Hundred Years of Solitude" [7], alongside exhibitions and a documentary film.

In Serbia, there are several architectural workshops and events specifically designed for architecture students [8-11]. In Niš, at the Faculty of Civil Engineering and Architecture of the University of Niš, several workshops for architecture students have been held. The "Turres Architectural Workshop" was organized by the Niš faculty at the Museum of Ponišavlje in Pirot in 2013 [12]. The "Summer School of

Architecture," organized by the Balkan-Architrave association from Dimitrovgrad and the Niš faculty, has been held annually since 2014 in the villages of Poganovo and Senokos, as well as in Veliko Trnovo in Bulgaria [13]. The architectural colony "Luštica: A Landscape Painted with Tea," organized by the Faculty of Civil Engineering and Architecture of the University of Niš, the village of Klinci, and A Production from Belgrade, was conducted in 2022 in the village of Klinci, Montenegro [14,15]. The workshop titled "15x100" was carried out in 2023 under the auspices of the Niš Society of Architects, the Faculty of Civil Engineering and Architecture, and the Urban Planning Cluster [16]. In a series of workshops for students, the Faculty of Civil Engineering and Architecture and the Institute for the Protection of Cultural Monuments collaborated this year under the title "Preservation of Architectural Heritage: The Old Bazaar of Vlasotince" [17]. Besides the colony in the village of Klinci in Montenegro and the workshops in Vlasotince, the products of architectural collaborations have not been publicly presented. Additionally, according to the author's knowledge, the documentation of these events has not been published in scholarly literature, requiring researchers in this field to analyze newspaper archives and social media posts. To establish a research foundation for architectural workshops in Niš, the aim of this paper is to comprehensively present the colony in the village of Klinci. To achieve a scholarly format, the position of this colony in academia has been examined in relation to relevant literature. Furthermore, improvements for future gatherings and the enhancement of the Klinci village concept according to scientific and professional guidelines comprising the topic of diffuse hotels in literature have been proposed.

The concept of a diffuse or scattered hotel first emerged in Italy in the early 1980s, specifically in the Friuli region following an earthquake, as an innovative idea during the phase of reconstruction and revitalization. The project was later implemented in 1989 in the municipality of San Leo in Montefeltro. The primary objective of such a tourist offering was to emphasize hospitality, encourage short stays, promote cultural experiences, and provide guests with a better opportunity to immerse themselves in the local culture [21]. A diffuse hotel differs from traditional hotels in that guests have the option to stay in individual accommodation units. Each of these units can have its unique design and characteristics, making them distinct from one another. However, the hotel's common reception area serves as a central hub for managing all accommodation units. Currently, there are about 60 diffuse hotels operating in Italy [22,23] and while this topic was relevant during the pandemic, the issue of the carbon footprint for hotels is now emerging [24]. It is evident that from an environmental standpoint, it is better not to build at all if we only consider the impact of construction on the surroundings. However, if construction is necessary, it should be done using local and natural resources to create buildings with low energy demands over their lifecycle [25]. While the criteria for sustainable architecture are known in literature, sustainable business faces challenges if it does not determine the extent and manner in which hotel capacities should be developed [26]. It has been shown that hotels should be built in an environmentally friendly manner [27], because guests positively recognize the hotels' environmental commitment, significantly influencing satisfaction and loyalty. Moreover, staying at green hotels leads guests to develop specific loyalty toward hotels implementing green practices. It can be said that attention to nature conservation is quite decent, unlike the period before the pandemic [25] and the crisis in Ukraine.

2. METHODOLOGY

This paper presents the architectural colony "Luštica: A Landscape Painted with Tea," which took place in the village of Klinci in Montenegro. The aim of the paper is to document the outcomes of the colony, beginning with an overview of its organization. Subsequently, specific solutions within the scope of the project's three components are depicted and described. These results are analyzed in accordance with contemporary theory and practice in sustainable architecture. Through a comparative analysis of specific examples from literature relevant to this topic, the proposed solutions are evaluated. Based on the conclusions drawn during the discussion phase, measures for improving architectural colonies are proposed, emphasizing the significance of architectural colonies or workshops in the education of young architects.

3. RESULTS

The call for participation in this architectural workshop was published on October 11, 2022. An announcement was posted on the faculty's website, directing individuals to the colony's website [18]. The landing page prominently featured the organizers of the colony: the Faculty of Civil Engineering and Architecture, A Production from Belgrade, and Klinci Village Resort, with the latter serving as the host. All final-year students of the Faculty of Civil Engineering and Architecture at the University of Niš were invited to participate in this colony. The names of the application selectors were disclosed: Dr. Mirko Stanimirović from the Faculty of Civil Engineering and Architecture, and Dr. Vladan Zdravković from A Production in Belgrade. The application portal remained open until November 1, 2022. Applicants were required to submit a brief biography and a maximum of 5 architectural works illustrating their competence in architectural design. A total of six students applied for participation, and upon review of their drawings, all candidates were accepted as participants in the colony. The initiator and author of the colony, also the author of this paper, designed the website and visual identity of the colony. Additionally, the author drafted a memorandum of cooperation among the mentioned institutions, which remains unsigned to this day due to missing institutional data in the header. However, this technical issue did not affect the realization of the colony, and the first phase took place from November 17th to 21st, 2022, as announced to the public through the faculty's portal [19]. Besides the author, two students, Nemanja Ranđelović and Vukašin Vasić, participated in the residency program during this period. It was agreed during the preparatory phase that the participants of the colony would not develop conceptual designs during their stay due to issues with computers and software. While visiting the host, participants engaged in the construction of the project task, drone and camera terrain mapping, and the formation of initial architectural concepts. The host set the program very liberally, only requesting that participants "think outside the box", without providing precise instructions that might influence the solutions. The aim was to obtain fresh ideas without being burdened by funding or legal constraints on construction. During the first phase, the old structures in the area were mapped, and measurements of certain newer structures were taken. To better understand the slope of the entire area, the host prepared a cadastral plan of the area around the main threshing floor. The choice of filming location itself highlighted the imperative to preserve traditional architectural values in the Bay of Kotor region and Montenegro as a whole.

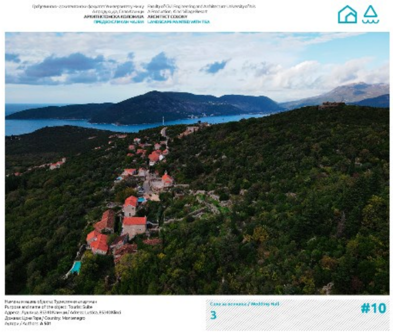


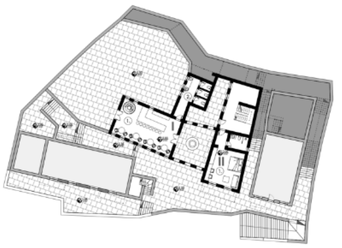
Figure 1. Part of the poster with the visual identity of the colony

Following the visit to the village of Klinci, the development of conceptual designs was organized in cabinet 501, the Drawing Studio at the Faculty of Civil Engineering and Architecture in Niš (second phase). The team name (A501) was chosen based on the name of the studio, comprising Dr. Mirko Stanimirović, an associate professor, and students Nemanja Ranđelović, Vukašin Vasić, Boris Rančev, Mihajlo Petrović, Vukašin Stefanović, and Anđela Stevčić. Although it was expected that the conceptual designs would be presented in the following months, due to difficulties in terrain reconstruction, the team surpassed all agreed deadlines, and it was not until October 20, 2023, that 24 panels were installed on the colony's and the faculty's website [20]. As of the writing of this paper, the exhibition of these works (third phase) has not yet been organized, likely due to the very late submission of conceptual designs. Additionally, the second iteration of the colony did not take place, as the development of solutions from the first iteration extended over more than a year. This significantly hindered the traditional maintenance of the colony in the village of Klinci.

The project scope within the framework of the first iteration of the colony's solutions is divided into three parts. The first part includes, in addition to existing structures, a new reception area, spa center, new apartment buildings, and a wedding hall. The second part examines the development of the village towards the north, with variously shaped new apartments (ranging from completely new structures to renovated and expanded old ones). The third part is entirely dedicated to the wedding hall, which is accessed from the north.

A total of 24 posters displayed multiple solutions for the same functions. Two distinct concepts for the wedding hall within the third section were proposed. A completely new concept for a multifunctional hall was suggested at the southernmost part of the area, in direct proximity to the existing structures within the first section. In the heart of the current settlement, reception, spa center, and two variations of apartment units were proposed on the foundations of older structures. New and reconstructed buildings were redesigned, considering the traditional roof concept as a better solution compared to discordant terraces. Within this section, two discreet methods for covering the threshing floor, used as a platform for weddings, were proposed. The second section represents a logical progression of the settlement towards the north, as ascending towards the top of the hill improves the sea view. In case of continued development from the southern side, new facilities would entirely lose desirable vistas due to the slight slope of the terrain. Apartments in the second section were designed in three different ways, each with two to three variations within a distinct group of solutions. Interior designs of the first group of solutions were particularly emphasized, presented in the form of hyper-realistic renders.


Figure 2. Situation - three parts (sectors)   *Figure 3. Interior of the Apartment: part 2*



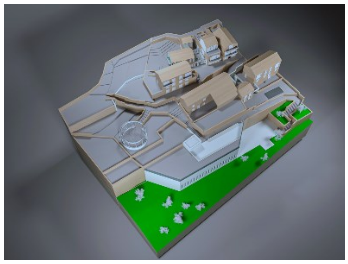


Figure 4. Reception Area: part 1

Figure 5. Wedding hall in the southern part of the settlement: part 1

4. DISCUSSION

The dispersed hotel in the village of Klinci is inspired by the pioneering Italian concept known as "albergo diffuso," which involves integrating a full hotel into various buildings of a largely abandoned village. Most old villages in Montenegro suffer from depopulation as residents move to larger cities in search of employment. This is the same issue that has inspired many Italian villages to sell houses at symbolic prices. Enterprising hoteliers have taken over these deserted villages and transformed them into often luxurious accommodations, where guests can stay in their own buildings, then dine in a restaurant or perhaps visit a spa located in another part of the village [29]. During the pandemic, many tourists preferred accommodation that offered the possibility of physical distancing. This is where dispersed hotels come into play. If we add the condition of preserving rural areas [30] and sustainable construction, we get new forms of dispersed hotels [31-33]. The situation in the village of Klinci is interesting for another reason. Its clientele consists of foreigners, wealthy businessmen, and celebrities who are looking for hidden experiences. Klinci village is located on a hill above the sea, and the beach is accessible by car or taxi. Therefore, there are no typical coastal crowds, allowing clients to peacefully stay in old cottages dressed in modern comfort. The road to the village is unremarkable, so anyone who wanders may think they are lost. This minimizes the problem of uninvited guests, which of course also suits the clients who value guaranteed privacy.

Some exemplary enhancement solutions for the village of Klinci include La Colombe d'Or Hotel and Restaurant (located at the threshold of the village of Saint-Paul de Vence; France) [34], Reschio Estate (Perugia, Italia) [35], San Canzian Hotel & Residences (Mužolini Gornji, Croatia) [36]. These examples represent highly exclusive tourist destinations with tastefully appointed cottages, both inside and out. Achieving such a goal is certainly feasible for the village of Klinci, considering its already exclusive status and reputation for its exceptional local cuisine, which relies on healthy and locally sourced food such as pomegranates, oranges, and olives. Additionally, Klinci village boasts the lowest carbon footprint, utilizing smart heat pumps for heating and cooling, as well as wood biomass for heating sourced from the estate. It can be said that the path taken by the hotel in this village in Montenegro aligns with contemporary trends. This is in line with a study that provides a bibliometric analysis of smart hotel research to examine scholarly trends and developments in this dynamic field. Smart hotels, characterized by the integration of advanced technologies such as AI, IoT, cloud computing, and big data, aim to redefine customer experiences and operational efficiency [37]. In the era of sustainable tourism, guests are no longer passive consumers but active participants in sustainable practices who value transparency and authentic experiences. From the same study, it follows that smart hotels that combine technology and sustainability will shape the future of the tourism industry.

Smart hotels are modern forms of accommodation that integrate advanced technologies to enhance guest experiences and streamline property management. These features of smart hotels provide guests with a more enjoyable stay while helping hotels improve operational efficiency and deliver better service [38], [39]. Some of the key features of smart hotels include automation (smart lighting and various types of sensors), smart rooms (utilizing devices that enable personalized experiences for each guest), and sustainability (smart hotels often employ technologies that help reduce energy and water consumption, as well as waste, contributing to more sustainable operations).

The mentioned characteristics of modern technology do not inherently influence the form of buildings, as they are typically installed similar to electrical wiring, within structures. However, in the case of utilizing heat pumps, solar panels, and collectors, such external installations must be integrated into the architectural composition. Only in the case of district heating and cooling, installation blocks are not located in the immediate vicinity of buildings and therefore do not affect their form. Conversely, a solar farm would undoubtedly alter the environment, which may be protected by laws preserving nature and inherited architecture. For these reasons, in protected areas, reducing carbon footprint is achievable by utilizing green energy derived from facilities located outside the protected area and from renewable sources such as solar, wind, or hydro energy.

The integration of these renewable energy sources requires careful planning and design to achieve harmony between technology and the environment. For example, solar panels can be incorporated into urban spaces, while wind turbines can be integrated into rural landscapes. In protected areas, special attention should be paid to preserving natural beauty and historical value, but this does not preclude the use of green energy. On the contrary, proper planning and the use of renewable energy sources can contribute to the preservation of nature and cultural heritage while simultaneously reducing the ecological footprint.

In the literature, sustainable development has been proposed for protected areas in Montenegro [40] and globally [41,42]. Without delving into potential issues related to fire protection [43] or internal insulation [44], let us focus on the architectural composition problem, as additional insulation for rural buildings has been shown to be necessary [45]. The specific form of a stone house with a gable roof, covered with stone or clay tiles, does not align with the installation of solar panels over the roof covering. Another unresolved issue is the additional insulation of stone houses, which is directly linked to green construction and the energy required for heating and cooling. Without added insulation, the desired thermal comfort is not achieved, and this layer needs to be covered externally with a new stone wall, thereby increasing the carbon footprint. An attempt to reconcile these two conditions is illustrated in a study dedicated to the Karuč house [40]. Sun rays are utilized in the winter for passive heating, while during the summer, glass surfaces of the roofs and walls are covered with horizontal slats. While such a method of shaping the house may be questionable, it can be concluded that the internal organization is well-resolved, as carefully positioned openings contribute to natural ventilation within the house.

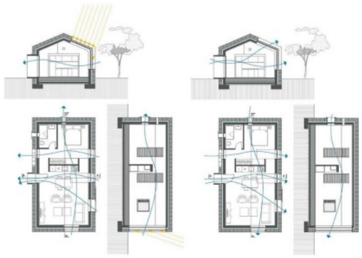
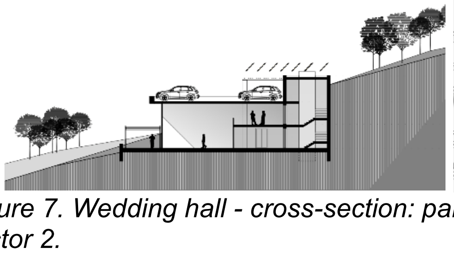


Figure 6. Karuč house - Summer day and night impact analysis [40]

The unresolved issue of additional insulation is also present in the village of Klinci. However, conceptual solutions are aligned with the need for sustainable development in specific cases. The terrain slope and surroundings favor the concealment of external units of heat pumps, while the presence of solar panels is justified only in the case of the upper wedding hall. Specifically, access to the parking area is from the upper side, and guests descend to the hall through vertical communication from the parking lot. If the panels are installed above a section of the parking area and the building on the parking lot, they will not dominate the architectural composition.



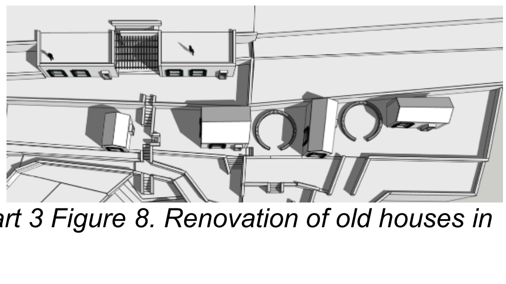


Figure 7. Wedding hall - cross-section: part 3 Figure 8. Renovation of old houses in sector 2.

The idea of protecting the rural landscape is also supported by the unobtrusive integration of new apartments into the terrain, with green flat roofs used as accessible terraces offering open views towards the sea. Furthermore, the renovation of derelict houses in sector 2 and their connection via terraced platforms and stairs to the center of the old settlement aligns with the concept of a diffuse and sustainable hotel. This approach also highlights the historical value of the circular walls comprising the threshing floor, as their platforms serve as shared open spaces between individual and authentic buildings transformed into modern apartments. According to this conclusion, the conceptual solution in sector 2, spanning from the church to the wedding hall (Fig. 2), should fully adhere to the goal of sustainable rural development. This entails the transformation of both newer and existing buildings (Fig. 9) towards the architectural form outlined earlier in this paper.

Figure 9. Village Klinci - Sector 1 and 2

Based on verbal feedback from the host Bogdan Kaludjerović, among all the solutions proposed during this architectural workshop, the wedding hall structure on the southern side below the old part of the village has attracted the most attention (Fig. 5). This concept is justified by the client access from the southern side, as the terrain below the village has a gentler slope compared to the northern part. On the other hand, the green flat roofs and the tree-filled surroundings will aid in integrating this structure into the landscape, but only to a certain extent. In fact, tackling the issue of vehicular access in such rugged terrain is quite challenging. This is linked to the positioning of the new structures, which are justified in terms of the needs of this diffuse hotel, but their complete rural integration is unfeasible due to their size. This conclusion also represents the main theme for future iterations, as further consideration is needed on how to form a large hall within the confines of small stone houses with gable roofs.

5. CONCLUSION

If we were to measure the success of the colony based on the time taken to propose solutions, we would obtain a negative value. On the other hand, if we were to measure the quantity and quality of solutions, we would achieve outstanding results. There is no need to delve into precise accounting (project costs, residency program costs, etc.) because the idea of the colony transcends material expenses. From the presented solutions and discussions, conclusions can be drawn to enhance future iterations.

Firstly, the "one-man organization show" is unsustainable, and the initiator of the colony needs assistance in terms of organization. Secondly, participant motivation is crucial, and feedback from students on what would help enhance their engagement should be obtained. Thirdly, the host's resources are finite, so involving investors and funds in planning further collaboration is necessary. Fourthly, the terrain should be surveyed using photogrammetric methods in its entirety to enable the reconstruction of an optimized 3D model. The significance of this tool in research is immense, especially when drawings are realized outside the Klinci village. Only in that case will participants be able to obtain all necessary information about constructed objects and their surroundings (slope, vegetation, elevation points, etc.). Lastly, future research topics should be exclusively linked to sustainable rural development.

Furthermore, it is important to emphasize that maintaining an architectural colony or workshop is highly beneficial for architecture students. This investment in knowledge and skills of young individuals will make them more competent and competitive in the dynamic market in the future. During their participation in the colony, students become acquainted with the benefits of teamwork, achieved through good communication, coordination, and combining different perspectives to reach more efficient solutions to set tasks. Activities that connect the team include sharing responsibilities, a common purpose of action, and a focus on finding the best solution. Additionally, teamwork stimulates individual learning within the group and strengthens interpersonal relationships. Simultaneously, this approach fosters creative and critical thinking, as workshops are creative and challenging environments that encourage students to develop their problem-solving skills.

The author extends gratitude to the Faculty of Civil Engineering and Architecture, A Production, and Klinci Village Resort for their support in organizing and funding the architectural colony, which is the subject of this research.

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submitted: 09.04.2024.
corrected: 11.04.2024.
accepted: 16.04.2024.
Review paper
UDC : 624.012.45:625.725(497.16)
https://doi.org/10.62683/ZRGAF39.79-90

DESIGN OF RC STRUCTURES OF MEDIUM-RISE APARTMENT COMPLEX ON SIGNIFICANTLY SLOPED TERRAIN IN MONTENEGRO

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Nenad Stojković[3]

Abstract

Design of structures in medium or extremely sloped terrains is a demanding and challenging engineering task. Depending on the depth of foundations of the future buildings, different methods of securing foundation pit sides are used. Extremely high vertical excavations cannot utilize the standard methods of securing ground stability (use of "L" segments) so somewhat more complicated and demanding solutions must be found. This paper shows the method of temporary securing of the vertical excavation during the building construction, using the prestressed geotechnical anchors in combination with the RC frame, on the example of the Apartment complex in Montenegro.

Key words: *Reinforced-Concrete Structure, Prestressed Anchors, Foundation Pit Support Structure, Retaining Walls*

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1. INTRODUCTION

The anchor bolt is widely used in support engineering because of its advantages of speedy installation and applicability to most types of rocks [1-4]. With the development and implementation of underground engineering, the characteristics of high ground stress, extremely broken surrounding rock and extra-large sections are becoming increasingly common, and the support of surrounding rock is also facing severe challenges [5-7]. Currently, prestressed anchor bolts are widely used as critical active support systems in different types of building structures involving high stresses and fractured surrounding rocks [8].

The stability of slopes of soil and rocks is important for designing and construction of various types of buildings: cuts and embankments of roads, hydraulic engineering buildings, landslide stabilization and other engineering buildings. At the moments when the shear stresses along the sliding plane reach or exceed the shear strength of the soil, there can occur the shear failure of the ground and large displacements of the ground mass above the sliding surface, i.e. the collapse of the slope. Practical consequences of the slope collapse can vary greatly, from the catastrophic ones (loss of human life and extensive material damage) to marginal. The causes of slope instability can be different in characters: a) excessively steep ground mass contours, b) high pore pressures, c) loads of surrounding structures, d) seismic inertial forces or e) high loads on the traffic infrastructure. In order to provide the slope stability various analytical and numerical methods are used, which guarantee sufficient security measures - safety factor. Calculation methods can mostly be divided into two groups: a) method of limit equilibrium – on whose basis the safety factor F_s is determined, which is used to assess the slope stability; b) Stress-strain analyses – where the stresses and strains in the slopes are calculated using numerical methods (finite element method) base on which the slope stability is evaluated.

According to Eurocode 7 when the slope stability analysis is conducted, it must be verified that the effects of the load E_d are lower than the resistance R_d. Calculated values of parameters are used. They are obtained by increasing the loads and soil parameter are reduced through implementation of the corresponding partial safety factors. Instead of the global safety factor F_s, Eurocode 7 introduces the implementation of partial safety factors and in this way the unreliability of input parameters is compensated. According to the National annex of Eurocode 7 (SRPS EN 1997-1) the design approach 3 is used as the proof of limit state in the slope stability.

Depending on the case which may occur in practice, different types of slope or vertical excavations stabilizations can be used: a) supporting structures, b) piles, c) passive measures, d) soil treatment in combination with drainage measures and others. In order to find appropriate solutions, main reasons for the predicted or observed instability must be identified so that the technical design would be economical and safe.

This paper presents the method of temporary securing of the vertical excavation during the building construction using prestressed geotechnical anchors in combination with the RC frame. Geotechnical anchors 5xØ15.7 (f_{pk}=1860N/mm^2) 20m and 22m long, and RC frame composed of vertical beams having cross-section 70/60cm and horizontal beams having cross-section 50/50cm were also used. Based on the obtained results, the vertical excavation satisfied the safety factor criterion.

The paper is divided in four sections: the first shows the introduction to the paper; general description of the apartment complex is shown in the second; the third deals with the implementation of securing of vertical excavations using prestressed geotechnical anchors, while the fourth section is the conclusion and discussion of the obtained results.

2. APARTMENT COMPLEX IN BEČIĆI – MONTENEGRO

Architectonic design of the apartment complex in Bečići was made by the company „Urbanist Projekt“ doo Budva, authored by the architect Uroš Urošević Bachelor with honors in architecture, hired by the investment fund „R.E.C.“ Limited Liability Company doo Budva.

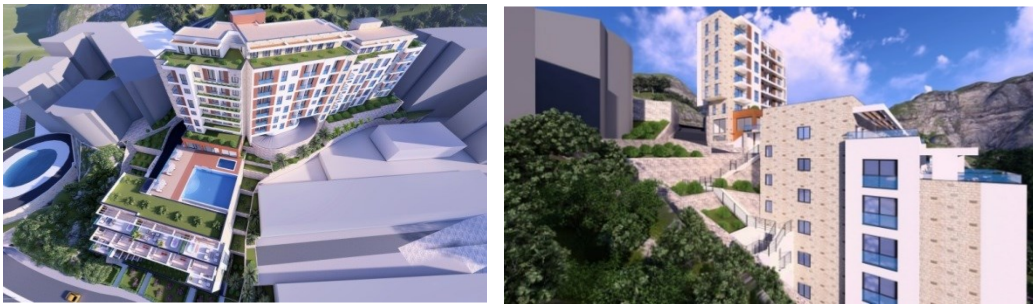

Figure 1. Apartment complex in Bečići - Montenegro

Apartment complex was design in the town planning block 105A, UP 105.1, on the cadastral lot 451/1, 453/7 and 453/8, cadastral municipality Bečići, DUP Bečići, Municipality of Budva. The complex consists of the buildings A, B, C and the garage G of the total surface area of around 22000,0 m^2. Buildings A, B and C have 9 and 10 floors, including the underground levels. Garage G has 4 floors with a swimming pool on the roof level (which can be clearly seen in figure 1). Building A is situated next to the principal road, seen frontally in figure 2. Immediately behind it (towards the rising side of the lot) the Garage G building was designed. Since the A building is dug almost 6 levels into the terrain on the rear side, it was necessary to provide the design to secure the side of the foundation pit for the 16m high vertical excavation.

The design of the supporting RC structure of apartment buildings was produced by the authors of this paper in cooperation with other engineers. In addition to the authors of the paper, Dragan Danilović, Bachelor with honors in Civil Engineering and Nikola Nikolić Bachelor with honors in Civil Engineering participated in the design of the support structure. The support structure consists of a vertical RC frame around 16 m high with prestressed anchors in the part of the lot behind the structure A. On the lateral sides, a system of perpendicular retaining walls was built (figure 1) which are not addressed in this paper. In addition to the previously mentioned support structures, on the top side of the apartment complex buildings B and C a support structure was designed, consisting of RC piles connected with the capping beam.

Figure 2. Apartment complex in Bečići – view from the highway

The focus of this paper is the use of prestressed anchors in the system with the RC frame for securing the vertical excavations, on the case study of the apartment complex in Bečići, Montenegro.

3. SECURING OF VERTICAL EXCAVATION USING PRESTRESSED ANCHORS

For the needs of the first phase of construction of apartment building – Building A, a staged excavation was planned, along with formation of multiple foundation pits for foundations designed buildings. Considering the spatial limitations imposed by the lot boundaries and existing infrastructural constructions, the foundation pit had to be constructed with verticals sides which, at extreme points were over 16m high.

The foundation pit is horizontal at the elevation of 10.80m and its approximate layout dimensions are 35x23m. The excavation is performed on a slope with a steady inclination between 31° and 35°, and the elevation from which the excavation starts is approximately 27.30mnm.

It is in agreement with the required dimensions of the foundation pit, defined contours of sides and geological conditions, the excavation of the foundation pit is secured with vertical RC beams having cross section of 70x60cm at an axial distance of 4m with three rows of horizontal beams having cross section of 50x50cm.

It is planned to construct prestressed geotechnical anchors at the locations where horizontal and vertical beams intersect. Anchors are arranged as beams in three rows with the following characteristics:

- Anchors at elevation 11.86asl (lowest level) 5xØ15.7mm, long 20m, with anchoring zone 10m long and anchoring zone cross section is 72mm;
- Anchors at elevations 19.11asl and 26.36asl (medium and upper level) 5xØ15.7mm, 22m long, with anchoring zone 10m long and anchoring zone cross section is 72mm;

The technical design of excavation and securing plans for the excavation in phases and securing of the foundation pit in the following phases:

- **Phase 1**:

In this phase the surface layer is removed from the entire slope, which, according to the available archeological data, is a potentially unstable wash. Simultaneously with the removal of this material, the decomposed diabase is excavated to the level 26.50asl, which is also the level from which the vertical excavation of the foundation pit starts. The slope in the decomposed diabase is constructed in the inclination 1:1. The design provides for the permanent geotechnical supervision, ground notch mapping and comparison of the rock mass with the parameters from the geological report on whose basis the stability analyses were conducted. In case of the considerable departure of the field working conditions, it was planned to attenuate the final slope using the jet grouting in a layer of 10cm reinforced with the single wire mesh Q188 and with the sporadic securing of potentially instable parts of the slope using rigid SN anchors made of reinforcement steel B500 B, having diameter Ø10mm and length 4m. The arrangement of the anchors is determined in situ, depending on the results of the IG mapping.

- **Phase 2**:

The second phase of construction provides for the excavation of the first level of the foundation pit to the elevation of 22.90asl, i.e. excavation 3.60m high. Excavation in this phase is performed in phases which prevents sudden unloading of the slope. After each stage of excavation in this phase, RC beams are cast and prestressed anchors are built in. Anchors are pretensioned to the force of 50kN. The geotechnical supervision defines all necessary parameters. In the case worse geotechnical conditions than those defined in the geological data are registered, it is necessary to secure the cut between the beams using the jet grouting 10cm thick and rigid SN anchors made of reinforcement iron B500 B, having diameter Ø10mm and length 4m.

- **Phase 3**:

After all the works of the second phase are finished, the third phase starts. As in the previous phase, the construction is performed in stages. The excavation is carried out to the elevation of the medium beams, beams are cast and anchors are installed. After formation of the entire vertical beam and installation of both anchors, the anchors are tensioned to the maximum force of 600kN.

- **Phase 4**:

This is the last phase, where in accordance with the planned phase work, the excavation in stages is performed along with securing the slope to the designed elevation of the future foundation pit of the building A. Figure 3 shows the schematic display of the final phase of securing the vertical excavation.

As shown in figure 3, during the excavation of phases 3 and 4, not all material is removed from the berm, but a part of the material is left as an additional ballast to secure the stability of the slope. This part of the ground is removed only after finishing all the excavation and securing works of the current excavation stage.

For the analysis of stability and for defining of securing measures, data from the previously executed site investigations were used. In terms of morphology a wider area of exploratory activities is the slope extending to the sea, immediately above the "Jadranska magistrala" principal road. The slope has a uniform inclination, to 300m, flat in extension. The elevation above sea level of the terrain which is being investigated is from 14.5asl at the level of the principal road below the location to around 45asl at the street above the location. In the geological composition of a wider area are present various sediments dated back to Triassic, Jurassic, Cretaceous and Cretaceous-Eocene and Quaternary times. A wider area of the location, in geological terms, is built of igneous-sedimentary series composed of igneous rocks, then tuff and tuffite, marlstone, sandstone and mostly of plate-like limestone. The location itself exclusively consists of igneous rocks, represented by porphyries and diabase, of massive textures, over which is a thin layer of sedimentary cover made of clayey and dusty debris.

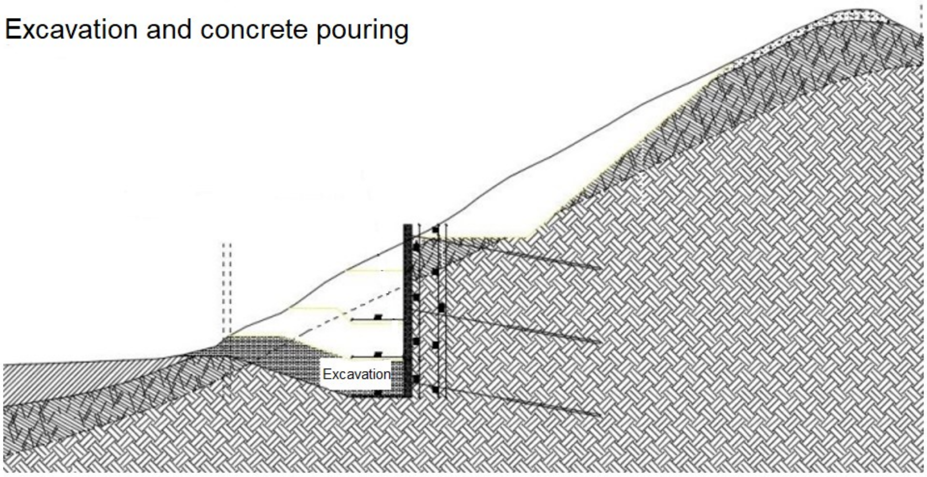

Figure 3. Final phase of excavation and securing of foundation pit sides

Table 1- Physico-mechanical properties of rock mass

Physico-mechanical properties	Sample			
	U-1	U-2	U-3	U-4
Lithological properties	Igneous-sedimentary formation			
Density (gr/cm^3)	2.440	2.444	2.455	2.512
Compressive strength (Mpa)	53.14	43.71	7.10	7.10
Shear strength (Mpa)	4.84	5.46	1.01	1.01

Hydrogeologic properties of terrain are in the function of the lithological composition of excavated ground. In, general, those are low water permeable and impermeable sediments. In the low water permeable rocks, is present fine and coarse detritus with a variable content of red clay, of sedimentary origin, having inter-granular porosity. Impermeable rocks feature igneous sedimentary series rocks such as: diabase and porphyry, tuff and tuffite, marlstone, sandstone and plate-like limestone.

The design of the slope stability and required security measures were done using the software package PHASE 2. Analyses were performed on a 2D model, based on the results of earlier survey – geomechanical report. The calculation of the slope stability was performed using the finite element method (FEM) and using the method based on the reduction of shear strength (Shear Strength Reduction - SSR).

Table 2- Physico-mechanical properties of separated medium

Medium	Parameter			
	γ (kN/m³)	φ (°)	C (Mpa)	D (Mpa)
Degraded igneous – sedimentary formation (medium 2)	22-24	22-27	0.05-0.10	50-100
Medium	Parameter			
	γ (kN/m³)	φ (°)	γ (kN/m³)	D (Mpa)
Igneous-sedimentary formation (medium 3)	23-25	30-40	0.30-0.60	300-500

The goal of SSR is to demonstrate what is the load bearing reserve of the rock. Shear strength reduction method makes it possible to determine the rock mass safety factor using the finite element method and appropriate material model.

- The procedure for determining the safety factor consists of:
- Reduction of failure envelope using the factor F,
- Determining material constants corresponding to the reduced envelope,
- New calculation with the same model of finite elements using the newly obtained estimated parameters,
- Safety factor is the lowest value of the reduction factor F for which the result is an instable slope.

The situation when the numerical calculation cannot converge to the solution is taken as the instability criterion (occurrence of failure).

The Mohr-Coulomb material model was applied

$$\tau = \sigma \cdot tg\varphi + c \tag{1}$$

If F is the shear strength reduction factor, the upper equation can be written in the following way:

$$\tau/_F = {}^{\sigma \cdot tg\varphi}/_F + {}^{c}/_F \tag{2}$$

$$\tau_{red} = {}^{\tau}/_F \tag{3}$$

$$c_{red} = {}^{c}/_F \tag{4}$$

$${}^{tg\varphi}/_F = tg\varphi_{red} \tag{5}$$

where c_{red} and φ_{red} are cohesions and the internal friction angle of the reduced failure envelope. Analogously, the value of the factor F at which the failure occurs, is assumed to be the global slope safety factor.

Analyses of the slope stability and calculation of securing measures were performed for the most critical cross – section, terrain profile at the middle of the slope where additional geological surveys were carried out, and for which there were the most reliable data on the terrain composition. The design profile was analyzed from the initial state.

Calculation of the stability was conducted for the following phases:

1. Initial state – natural slope,

2. Removal of the top layer of sediment and excavation of the first and second stage (sediment removal) to the elevation 26.50asl and formation of the slope with the inclination 1:1,

3. Excavation to the elevation 22.90mnm (phase 3 of the works),

4. Excavation to the bottom of the foundation pit.

The first calculation model was made as a case of the vertical excavation without additional elements of securing the slope stability (figure 4 left).

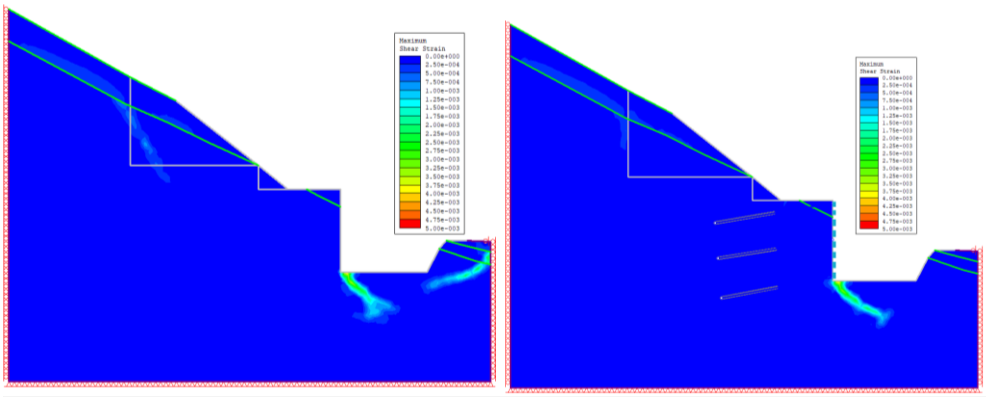

Figure 4. Left: Slope security factor without securing measures Fs=0.99<1.20; Right: Slope security factor with securing measures Fs=1.24>1.20

Considering that the slope safety factor is lower than the required one for the temporary slope (adopted $F_{s,min}$=1.20), further calculation of the slope was performed with the slope securing measures, assumed in the following way:

1. Prestressed anchors with prestressing force F=600kN,

2. AB vertical beams having cross-section 70x60cm,

3. If necessary, slope with the inclination 1:1 is secured using jet grouting 10cm thick reinforced with the reinforcement mesh Q188 and rigid SN anchors of reinforcement steel B500C Ø20 4 meter long.

Final excavation phase and support structure are shown in figure 4 right.

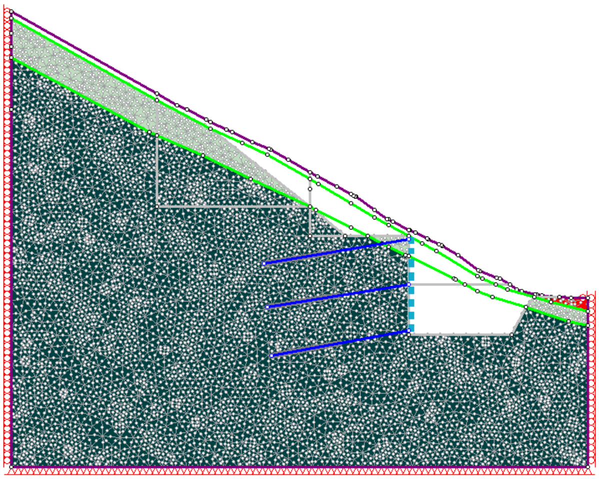

Figure 5. Final excavation phase and support structure

Based on the conducted calculation and analyses, for the vertical securing of the excavation, the use of the following anchors was planned:

- Geotechnical anchor 5xØ15.7 (f_{pk}=1860N/mm^2)

Based on the calculation of the required length of anchor (shear on the contact of steel and rock) the obtained lengths are 7.40m and 7.85m. The final adopted length of the anchoring zone is Ø72mm, L=10m.

The free length of the anchors on two upper levels is 12 meters, and of anchors on the lower level is 10 meters, so the total lengths of the anchors are L_1=22m and L_2=20m.

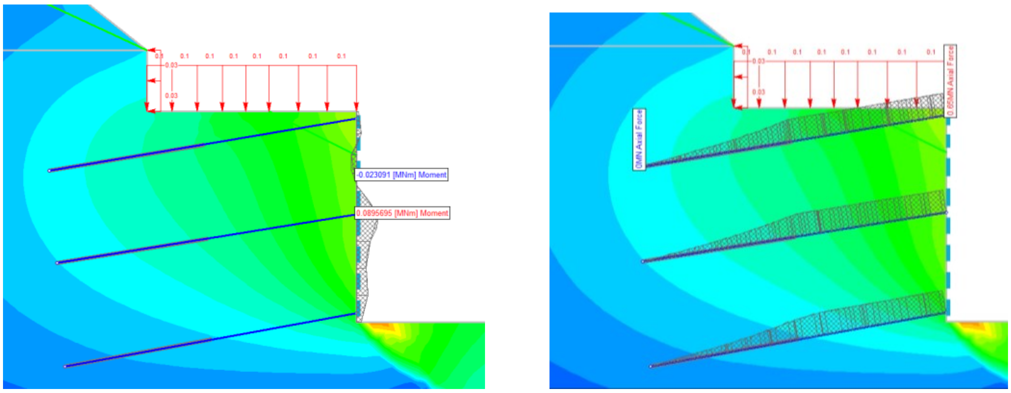

Figure 6. Left: Bending in the beam; Right: Maximum forces in anchors

After introducing the securing structure of the vertical excavation (anchors and RC frame), the safety factor obtained is higher than the minimum Fs=1.24>1.20 (figure 4 right). By calculating the maximum ground displacement, concentration at the bottom of the vertical excavation is obtained (figure 7). The value of maximum displacement is 7.0e-3 meters. In figure 6 right are shown the results of the obtained maximum forces in the anchors, on whose bases they were designed. While in the figure 6 left the obtained bending moments are necessary for designing RC vertical beams. Apart from the analyses shown in figure 5-7, models in the software package Tower were made, for two different phases. First phase in which vertical and horizontal beams are modeled for one characteristic span, and figures 12 and 13 where the modeling concept for the entire RC frame was implemented.

The securing structure, in addition to the prestressed anchors is composed of the RC frame designed from vertical and horizontal beams. Horizontal beams are mutually spaced 4m, while the horizontal beams were set in three levels at a distance of 0.5m, 8.25m and 15.5 meters from the top elevation of the ground. The support structure calculation was performed for the second and third phase of excavation. The static design was done in the Tower software package based on the finite element method (using linear finite elements). The adopted concrete class is C25/30 and reinforcement steel B500 B.

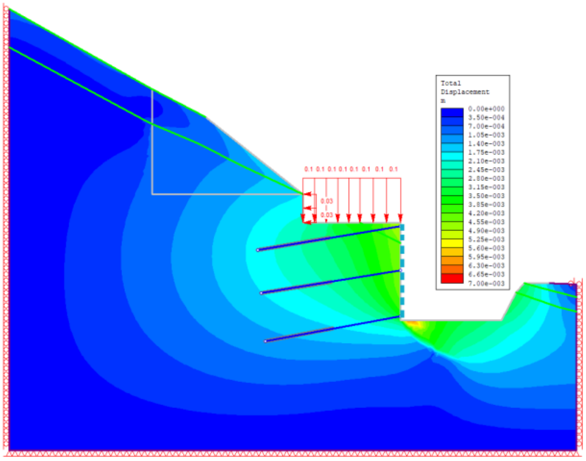

Figure 7. Total ground displacement

RC structure consisting of vertical and horizontal beams is analyzed in two phases. The first phase comprises one characteristic grid segment (two vertical and two horizontal beams), while the second phase comprises entire protective structure. In the first phase, beams have supports in anchor locations, while the load is equal to the reactive load of the rock of maximum force in anchors of 600 kN.

In the second phase the static structural system is the frame composed of vertical and horizontal beams in the entire volume. Beams in the places of anchors loaded with reactive load of 600kN, or 63.20kN/m. In addition, on the side of the safety, an incident load was considered, corresponding to the situation when the maximum permissible force in the anchor of 840kN is reached. In this case, the corresponding reactive load is 88.40kN/m.

Based on the analyzed phases of construction and design positions, the final reinforcement in the RC frame composed of vertical and horizontal beams was adopted. The results shown in figure 8 clearly demonstrate that the maximum required reinforcement in the beam grid is relevant for the first phase of construction, while above the support the maximum impact is recorded in the second phase of construction when the entire designed frame is formed.

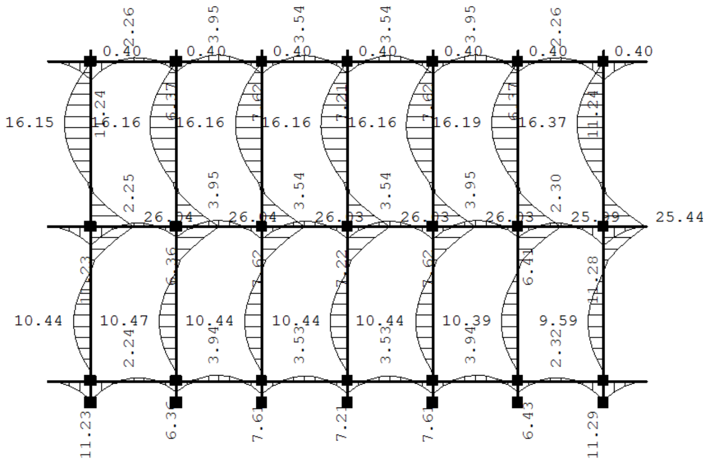

Figure 8. Required calculated reinforcement A_{a1}/A_{a2}

4. CONCLUSION

Designing of high-rise buildings on the lots with medium or high inclination require use of certain systems for securing foundation pit sides. Such systems can be made of “classical” RC tubs having walls 20-30cm thick walls and the foundation slab, which is a system for securing a maximum of two floors. However, if it is necessary to secure the vertical excavation for multiple floors it is necessary to construct somewhat more complex securing systems. It is usual to use the systems with piles and RC beams capping the piles. In the presented paper all the mentioned systems could not be used because of the excessive height of the vertical excavation (around 16m above ground). For these reasons, it was necessary to find such a solution to provide a safe stability of the vertical excavation but also to be economical The approach based on the use of prestressed geotechnical anchors 5xØ15.7 (f_{pk}=1860N/mm^2) in combination with RC frames made of vertical (70/60cm) and horizontal beams was used (50/50cm) was implemented.

In the first phase of the analysis, the case of a vertical excavation without any security measures was considered. The obtained slope safety factor was 0.99 which is lower than the recommended permissible safety factor of 1.20. After that, the slope stability was analyzed after the implementation of geotechnical anchors and RC frames. The conducted analysis demonstrated a higher safety factor than the minimum recommended one of 1.24>1.20, which provided the proof of slope stability.

The calculation of the RC frame was performed by analyzing two characteristic phases during the works execution. The first phase is when only one segment consisting of two vertical and horizontal RC beams and four geotechnical anchors are installed. The obtained results in this model were relevant for adopting the reinforcement in vertical beams in the grid segments. In the next phase, the entire RC frame was analyzed with all the installed geotechnical anchors in which the force in the anchor was: a) 600kN and b) 840kN. The other model provided relevant impacts above the support points.

The design presented in this paper was successfully implemented on the designed location. The presented design can be applied in relatively rocky areas. Considering the height of the vertical excavation, the design is extremely economical, relatively simple to construct and provides unobstructed construction of newly designed buildings

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submitted: 01.03.2024. *UDC : 72(450+497.11+560)*
corrected: 17.04.2024. *Review paper* *https://doi.org/10.62683/ZRGAF39.91-102*
accepted: 22.04.2024.

ASSESSMENT OF PROTECTIVE STRUCTURES FOR ARCHITECTURAL HERITAGE: CASE STUDY OF POMPEII, LEPENSKI VIR AND GOBEKLI TEPE

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Abstract

The protection of archaeological sites is crucial for preserving their authenticity and historical significance. This study evaluates the effectiveness of protective structures implemented at three different sites: Villa dei Misteri in Pompeii, Lepenski Vir in Serbia, and GT1 Göbekli Tepe in Turkey. Our focus extends to iconic landmarks where different types of protective structures and different types of protection were used. Each structure is assessed based on criteria such as preservation of authenticity, physical protection, accessibility and presentation, sustainability, and aesthetic impact.

The protective structures at all three sites demonstrate varying degrees of success in the selected criteria. Each structure has its advantages and disadvantages, highlighting the importance of careful design and maintenance to ensure the long-term sustainability of archaeological sites.

This study seeks to improve our understanding of the key role played by geometric design, material selection and technological application in the preservation and presentation of cultural heritage on a global scale. By providing insight into successful strategies and potential challenges, the primary goal of this research is to extract valuable knowledge from global practice, for later use on concrete examples.

Key words: *Protective Structures, Cultural Heritage, Preservation of Authenticity, Lepenski Vir, Pompeii,* Göbekli Tepe

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1. INTRODUCTION

Preserving architectural heritage is a key challenge in the contemporary context, where we face dynamic cultural, ecological, and technical changes [1]. There are three main approaches to protecting the remains of historic buildings. The first refers to remains that have been buried underground for centuries and involves re-covering them with earth. Another way is to undertake conservation efforts in the form of conservation and reconstruction. The third approach is the installation of a protective structure over the site [2].

Although covering is not a mandatory requirement for the protection of architectural heritage, if a decision is made to envisage a protective structure, there are numerous challenges and requirements that need to be met [3]. Protective structures can be completely closed or partially closed in the form of canopies [4].

This paper provides an analysis of various examples of protection used in the preservation of cultural heritage, focusing on three specific cases: Pompeii in Italy, Lepenski Vir in Serbia, and Göbekli Tepe in Turkey. Through a study of these cases, we explore the impact of modern approaches to designing protective structures on the preservation, presentation, and authenticity of architectural masterpieces. Emphasis is placed first on different types of protection, and then on different types of protective structures.

This research aims to enhance our understanding of the key role of geometric design, material selection, and technological applications in the preservation and presentation of cultural heritage worldwide. Through case study analysis, we uncover the complexities, challenges, and achievements arising from various types of protective interventions.

The selected examples, Lepenski Vir, Pompeii, and Göbekli Tepe, share some similarities but also differ in key aspects. All these sites have significant historical value and require protection from atmospheric conditions, human activities, and other potentially harmful factors to preserve the authenticity and integrity of archaeological remains [5]. The public nature of each selected site provides visitors with an opportunity to experience cultural heritage and gain education.

Pompeii, as a Roman-era site with diverse locations [6], Lepenski Vir, a prehistoric settlement with stone sculptures [7], and Göbekli Tepe, an early Neolithic settlement [8], represent different periods and civilizations. Artifacts and cultural influences associated with these sites reflect the diversity of cultural heritage.

While all these sites share a common purpose of preserving cultural heritage, their specificities require tailored approaches to protection and presentation. Each locality is a case in itself, determined by its geographical location and local influences. Therefore, an important contribution to the topic of protection is made by the analysis and assessment of different examples around the world [4]. Through a comprehensive analysis, this research aims to provide a basis for practical and sustainable solutions for the protection of architectural heritage around the world.

2. CRITERIA FOR THE ASSESSMENT OF PROTECTIVE STRUCTURES

Analysis of protective interventions in the context of cultural heritage preservation involves establishing clear criteria for evaluating their success [9]. When assessing the effectiveness of protective structures, several key criteria need consideration [4]. With the aim of providing a holistic overview of their functionality and contribution to the preservation of architectural masterpieces, this study will evaluate selected examples based on the following criteria: preservation of authenticity, physical protection, accessibility and presentation, sustainability, and aesthetic impact.

The fundamental criterion for evaluating the success of protective structures is their ability to preserve the authenticity of cultural monuments. Questions arising from this criterion include the extent to which a structure retains original architectural features and how observers perceive the authenticity of the site through the protective structure [10].

The efficiency of a structure in providing physical protection against weather conditions and potential hazards is of paramount importance. It is necessary to analyze the extent to which a protective structure prevents damage caused by precipitation, solar radiation, wind, and human activities that could impact the preservation of archaeological or historical elements [11].

Aspects related to access and visual presentation of cultural monuments are crucial for the overall visitor experience. A protective structure can either facilitate or restrict public access and influence the visual perception of an archaeological site.

The long-term sustainability of a structure is essential for ecological balance and the enduring protection of monuments. A protective structure also contributes aesthetically to the overall environment and cultural landscape, enhancing the overall visual experience. Integration with the surroundings is key to preserving harmony and the authentic spirit of the place.

The analysis of these criteria, set from the aspect of architecture, lays the foundation for subsequent sections of the research where these criteria will be applied in the context of specific examples: Pompeii, Lepenski Vir, and Göbekli Tepe.

3. CASE STUDIES

After archaeological excavations, the remains of historical buildings that have been buried for centuries must be physically protected, given their high sensitivity to various environmental influences. There are different approaches to preservation. One of them is to cover them again with soil. Another option is to leave them uncovered, preserve them, and regularly repeat this process with continuous monitoring, while the third strategy involves conservation and covering the location with a protective structure. The decision to build a protective structure must be carefully made, taking into account many factors. In this process, the analysis of the location and the perception of the value of the historical structure play a crucial role [2].

If the choice is to build a protective structure, even designing a small canopy poses a challenge in achieving protection, especially for fragile ruins. Causes of damage include: rain; wind; solar radiation; ultraviolet rays; rapid cycles of evaporation/condensation; and their combination [3].

3.1. Pompeii, Italy

The archaeological site of Pompeii, located near Naples, is significant as an ancient Roman city that was largely destroyed and buried during the eruption of Mount Vesuvius in 79 CE. Following archaeological excavations that began in the second half of the 18th century, Pompeii is now a UNESCO World Heritage Site and one of the most visited archaeological sites in the world [12].

Preserving archaeological sites, especially in locations like Pompeii, where the ruins cover vast areas, poses a challenge due to weather impacts. In Pompeii, during earlier excavations, several homes were restored, including roof renovations, serving a dual purpose: protection from weather conditions and restoration to their ancient appearance.

Villa dei Misteri, one of the most famous villas in Pompeii, stands out for its frescoes depicting mysterious rites. Its history dates back to the 2nd century BCE, with significant construction phases documented over different periods. Discovered in 1909, the villa now draws visitors eager to experience the unique atmosphere of ancient Roman times (Fig. 1) [13].

Figure 1. A suburban villa located next to the main archaeological area of Pompeii - Villa dei Misteri, source https://www.nomenclatorbooks.com/villapage.html (18.03.2024.)

During the 1960s and 1970s, most of the roof structures in the villa were replaced with heavy reinforced concrete frames or flat roofs with mixed reinforced concrete beams and hollow brick floors. Later, due to concerns about the load on the ancient masonry, these types of constructions were abandoned in favor of wooden structures (Fig. 2) [12].

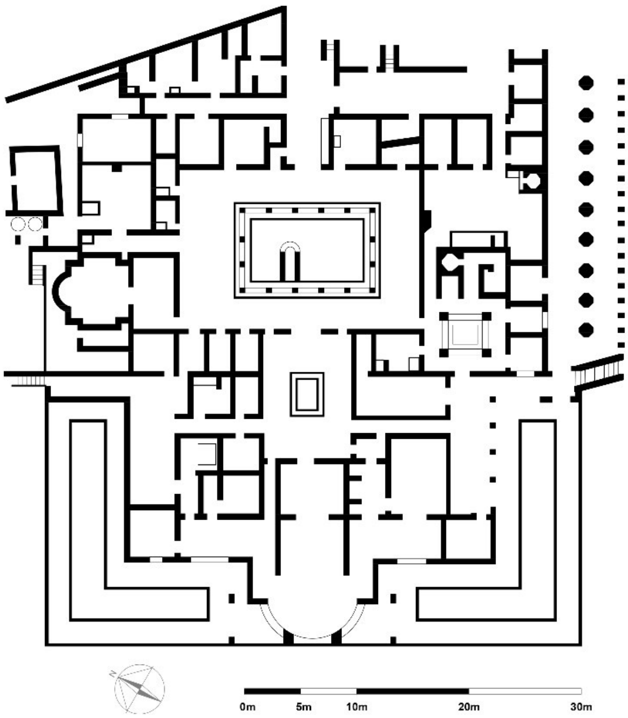

Figure 2. Technical presentation of the base of Villa dei Misteri, author N. Kocic according to [12]

Although such a construction revives the former appearance of the object, the use of heavy structural elements can lead to overloading of the existing walls, endangering the cultural heritage itself, as well as visitors. This is evidenced by the collapse of the wooden beam of the Peristylium in 2012, which was subsequently closed to the public.

Due to concerns about the safety of the monument, the Archaeological Park of Pompeii and ENEA implemented a conservation project that involved a multidisciplinary approach, including historical and archaeological analysis, geometric and structural research, damage assessment, drone surveys and vibration analysis for seismic safety [12].

3.2. Lepenski Vir, Serbia

The prehistoric settlement of Lepenski Vir enjoys the status of a cultural monument of exceptional importance (Službeni glasnik SRS 1979/14). This settlement holds particular significance as the oldest known sedentary prehistoric site in Europe. Numerous remains of sacral and residential architecture, totaling 136 structures, were unearthed through research conducted between 1965 and 1970. Residential structures included simple constructions, such as one-room pit-houses and huts, often shaped in basis like truncated circular segments obtained by cutting circles at angles of 30 or 60 degrees [14].

To preserve it from submersion due to the construction of the "Đerdap" Hydroelectric Power Plant, the site was relocated to a higher elevation before the power plant became operational. Subsequently, in 2011, a new protective structure was built, providing a permanent solution to shield the site from external influences and making Lepenski Vir more accessible to visitors. This structure facilitates the preservation and study of the rich heritage of this significant archaeological site. 4

The protective structure is in the form of a cascading greenhouse, with a steel structural frame and semi-transparent panels (Fig. 3) [14].

Figure 3. Section of the steel-grid construction over the archaeological remains, author N. Kocic according to [13]

The construction of the protective structure has also improved the accessibility of the site. Considering that within the structure, in addition to the covered site, there are also accompanying auxiliary rooms, controlled access is provided to visitors, with the possibility of guided tours and interactive engagement.

It also plays a significant role in its visual presentation. The installation of transparent glass panels to allow for increased insolation draws a parallel with the organization of houses in the fishing settlement, as the former housing units were oriented towards the south with their wider side (Fig. 4).

Figure 4. View from the inside of the building, source https://www.politika.rs/sr/clanak/456203/Ugrozeno-arheolosko-nalaziste-Lepenski-vir (26.02.2024.)

3.3. Göbekli Tepe, Turkey

Structure GT1 covers a part of the archaeological site of Göbekli Tepe, which was first discovered in 1963, but archaeological excavations did not begin until 1995 [8].

The main idea of the protective structure project is to provide adequate protection to archaeological remains while allowing researchers and visitors to explore and experience this archaeological treasure. The protective structure is open, elliptical in shape at the base, with a roof membrane in the form of a hyperbolic paraboloid (Fig. 5). The choice of such a construction is a response to the criteria set by the location itself. The shape of the structure is resistant to local strong winds, with a minimal number of supports and overcoming a large span, leaving the interior space column-free [15].

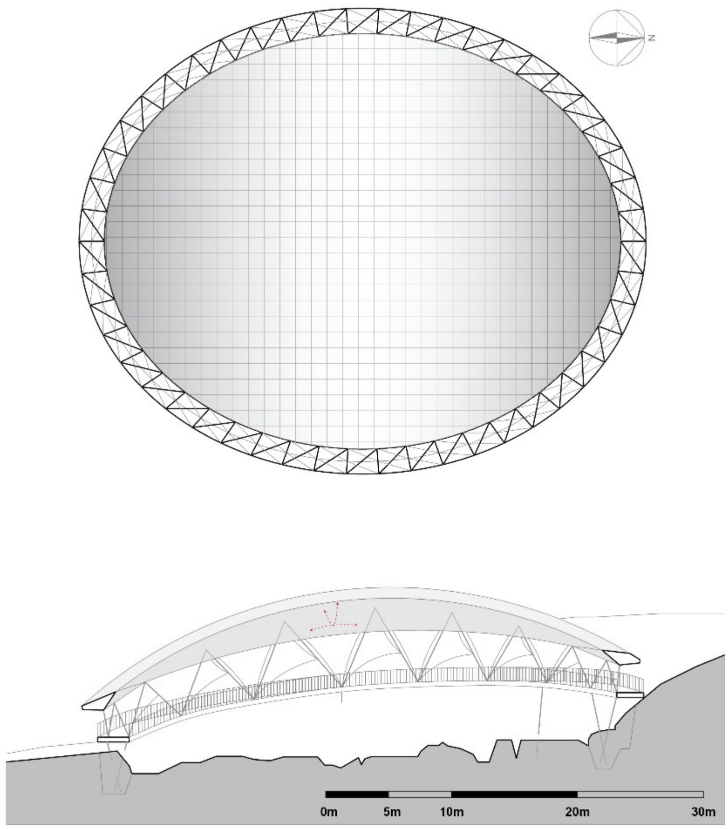

Figure 5. Technical presentation of the base and section of GT1 structure, author N. Kocic according to [15]

The steel skeleton of the roof structure forms the shape of a hyperbolic paraboloid, with all vertical structural elements located on the outside. The membrane is semi-transparent, allowing daylight to pass through, enhancing the visual comfort of visitors (Fig. 6) [16].

Figure 6. View of the protective structure from the east side, source http://www.transtinsaat.com/proje-detay/29/sanliurfa-gobeklitepe.html (27.02.2024.)

A wooden pathway is placed around the perimeter of the structure with four platforms, offering visitors a view of the archaeological remains, as well as enabling the work of archaeologists and conservators (Fig. 7) [17].

Figure 7. View from the inside showing the wooden pedestrian pathway, source https://eisat.de/en/projekte/schutzdach-1-fuer-die-ausgrabungen-am-goebekli-tepe-tuerkei (27.02.2024.)

4. RESULTS AND DISCUSSION

Selected examples differ in design approach, used materials, construction systems, location characteristics. In examining each case, a table mentioning their general characteristics is presented.

Table 1. Technical specifications of selected structures

Technical characteristics	Villa dei Misteri, Pompeii, Italy	Lepenski Vir, Serbia	GT1 Göbekli Tepe, Turkey
Material	concrete frames, roof tiles, wooden beams	steel-grid construction, transparent glass panels	steel construction, PTFE Mesh membrane roofing, timber
Shape	pitched roofs covering the existing structure	structure with rounded edges following the slope	hyperbolic paraboloid
Dimensions	up to 30m	cca 33m	37x45m
Visual effect	closed space	transparency	open design
Access	controlled	controlled	free

Villa dei Misteri, Pompeii, Italy

Advantages. Placing a protective structure directly on the existing construction of the Villa dei Misteri in Pompeii aims to restore its original appearance, which contributes to the preservation of its historical value and authenticity. The installation of roofs provides permanent protection from external influences, at the same time enabling visitors to visit the site regardless of weather conditions.

Disadvantages. Adding loads to an existing object must include both static and dynamic analysis. In addition, it is very important to implement adequate maintenance in order to avoid damage of protective layers, appearance of vegetation on the roof covering, occurrence of rust - which happened at the Villa in Pompeii.

Lepenski Vir, Serbia

Advantages. A permanent protective structure, such as an enclosed building, primarily provides long-term protection from weather conditions, such as rainfall, sunlight, wind and temperature – offering continuous and consistent protection, protecting archaeological remains from the direct effects of humans and wildlife. It also allows for constant surveillance and monitoring of the archaeological site with controlled access.

Disadvantages. The biggest problem of a closed structure with glass panels is the appearance of the greenhouse effect. Given the large volume of internal air, the existing HVAC system struggles to regulate its temperature, which results in overheating during the summer.

GT1 Göbekli Tepe, Turkey

Advantages. By using a structure that is not enclosed on all sides, the creation of artificial indoor climate is avoided. It facilitates natural ventilation under the shelter, providing thermal comfort.

Disadvantages. An open structure does not provide complete protection against external influences, necessitating regular maintenance and increased control. This type of construction is exposed to direct weather impacts, which over time can cause gradual wear and degradation of archaeological remains. Maintenance is, therefore, crucial to ensure long-term functionality and preservation of the visual appearance. Additionally, an open structure may be susceptible to unwanted human activities, including vandalism or careless behavior by visitors, emphasizing the need for careful management and supervision.

4.1. Assessment of protective structures

Villa dei Misteri, Pompeii, Italy

Preservation of authenticity. The construction successfully preserves the authenticity of the archaeological site, allowing visitors to experience and understand the historical context.

Physical protection. Provides solid physical protection against weathering and potential damage, but there are some maintenance challenges.

Accessibility and presentation. The construction allows easy access for visitors, providing an educational experience.

Sustainability. The construction is functional, but there is room for improvement in terms of environmental sustainability.

Aesthetic impact. Contributes to the aesthetic experience of the visitors, it fits into the environment, but some elements could be improved for better aesthetics.

Lepenski Vir, Serbia

Preservation of authenticity. The construction aims to preserve the authenticity of the archaeological site, but the potential for improving the solution is recognized.

Physical protection. Ensures complete long-term protection of archaeological remains.

Accessibility and presentation. Access is controlled, but opportunities for interactive presentation and education are limited.

Sustainability. Improvement is needed to reduce the impact on the environment.

Aesthetic impact. Tries to fit into the natural landscape.

GT1 Göbekli Tepe, Turkey

Preservation of authenticity. The construction is designed to preserve the authenticity of the archaeological site as much as possible, giving visitors the opportunity to experience and understand the historical significance of this place.

Physical protection. Regular maintenance is necessary to ensure long-term protection.

Accessibility and presentation. Easy access to visitors, in addition to the presentation of archaeological remains, provides an educational experience with an insight into the work of conservators and archaeologists on site.

Sustainability. Designed using materials and technology that support environmental sustainability.

Aesthetic impact. It harmoniously fits into the natural environment and at the same time highlighting the cultural heritage.

The analysis of the mentioned criteria was translated into numerical grades (1 - poor, 5 - good) and shown in Table 2 and represents the view of the author, from the aspect of architecture.

Table 2. Assessment of protective structures shown with points from 1 to 5

Assessment criteria	Villa dei Misteri, Pompeii, Italy	Lepenski Vir, Serbia	GT1 Göbekli Tepe, Turkey
Preservation of authenticity	5	4	5
Physical protection	4	5	4
Accessibility and presentation	5	3	5
Sustainability	3	4	4
Aesthetic impact	4	4	5
Overall score	4.2	4.0	4.6

4. CONCLUSION

The protection of architectural heritage is essential for the preservation of cultural heritage, historical significance and community identity. It also contributes to tourist attractiveness, education, artistic and aesthetic richness, and supports long-term sustainability. Without adequate protection, architectural works can be exposed to various threats, which emphasizes the importance of taking measures to preserve and prevent loss, whether it is the reconstruction of the building or the construction of new protective structures.

This study has evaluated the effectiveness of protective structures implemented at three diverse archaeological sites: Villa dei Misteri in Pompeii, Lepenski Vir in Serbia, and GT1 Göbekli Tepe in Turkey. Through the assessment of various criteria such as preservation of authenticity, physical protection, accessibility and presentation, sustainability, and aesthetic impact, we have gained insight into the strengths and weaknesses of each protective structure.

The analysis emphasize the importance of careful design and maintenance to ensure the long-term sustainability of archaeological sites. While some structures excel in certain criteria, others may face challenges that need to be addressed for optimal preservation and presentation of cultural heritage.

This research contributes to our understanding of the significance of geometric design, material selection, and technological application in the protection and presentation of cultural heritage on a global scale. By examining different types of protective structures, we aim to draw valuable positive and negative experiences in order to lay the foundation for practical and sustainable solutions for protective constructions of architectural heritage.

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submitted: 10.02.2024.
corrected: 08.05.2024.
accepted: 13.05.2024.
Review paper
UDC : 711.4:728
https://doi.org/10.62683/ZRGAF39.103-113

THE MIX-MESH CONCEPT OF LOW-RISE HIGH-DENSITY HOUSING – ADVANTAGES AND POSSIBILITIES OF APPLICATION IN LOCAL CONTEXT

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Abstract

The increased demand for residential space is in constant conflict with available spatial resources. Utilization of unbuilt urban land for residential purpose is faced with two opposing extremes – development of single-family housing in peripheral urban areas, on one hand, and the insertion of multi-family housing as infill in central urban zones, on the other. A contemporary approach to housing development turns towards the application of low-rise high-density model – as an alternative solution, that tent to achieve the best of both extremes.

The research deals with the possibilities of applying a modular system, symbolically named Mix-Mesh, which, through various combinations of the basic module (dimensions 4.2x5.0m) would enable the development of a wide range of residential units – grouped within various typological forms: from two or three-story single-family row houses; combined models of single-family and multi-family housing; to multi-family buildings, which can be developed in the form of gallery or corridor solutions (depending on the shape, dimensions and plot orientation). One of the main advantages of low-rise high-density housing, which is reflected in the presence of significant private open areas, is also present in this model. A specific advantage of this modular solution is reflected in its easy adaptability to different urban parameters and conditions present on a plot, which is obtained through various combination types.

Key words: *Low-Rise High-Density Housing, Design Principles, Typology, Private Open Areas, Modular Construction*

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1. INTRODUCTION

The urbanization of cities leads to significant changes in the built urban fabric, especially noticeable in areas and structures designated for residential purposes. The increased demand for housing is in constant struggle with available spatial resources. As a result of such circumstances, two opposing extremes are evident in residential developments: the construction of family housing in peripheral urban areas, on one hand; and the insertion of multi-family housing into central urban zones on the other [1]. The desire to own a family house, as an oasis providing such needing privacy, and a private yard, as one's own piece of land that brings the user closer to nature, is entirely understandable [2-5]. However, the contemporary way of life increasingly imposes the imperative of proximity and accessibility to amenities in relation to the place of residence [2]. It is not surprising that a significant number of households seek to meet these needs by living in the central city core.

In both cases, there is a severe degradation of the urban functional [2]. The construction of single-family housing in peripheral areas lead to uncontrolled urban sprawl, which results in nonfunctional urban areas, inefficient use of service and infrastructure facilities caused by physical remoteness from the city center, and significant reduction in the quality of living. On the other hand, densification of the central urban fabric degrades the micro environment of the area, burdens the existing service infrastructure, creating enormous pressure on these zones and resulting in the collapse of functional quality within the central urban area.

1.1. Low-rise, high-density housing as a possible response to emerging urban problems

As an alternative solution, a contemporary approach to residential development turns to the application of the low-rise, high-density housing (in further text LRHD housing). This concept represents a compromise solution, aiming to mitigate the differences between single-family and multi-family housing, utilizing the qualities of both of these prevalent types [6-9].

Several studies highlight four main characteristics of LRHD housing [6,7]:

- Density ranging from 350-550 inhabitants/ha, with buildings planned up to 5 above-ground floors.
- Strong sense of individuality, achieved through clear differentiation of individual elements - whenever possible, direct access to units is provided from the ground level.
- Avoidance of development of spaces that lack clear territorial differentiation – in particular, privatization of most of the outside space, by relating them directly to residential units.
- Integration of housing with accompanying functions, without clear differentiation, in order to create continuity of the construction by a system of built fabric, with overlapping residential units.

A large number of developed countries have implemented LRHD housing into urban planning regulation and have made recommendations related to the construction of this type [10-16]. Unfortunately, in the Republic of Serbia, this residential form has not yet been clearly recognized. These circumstances are precisely the reason for conducting the research regarding the development of modular LRHD housing model, which could be applied within local contexts.

2. URBAN PLANNING AND ARCHITECTURAL METHODOLOGICAL APPROACH IN THE DEVELOPMENT OF LRHD HOUSING

Depending on the region, there are slight differences in the methodological approach for the development of LRHD housing. However, there are certain common characteristics, mainly in the domain of economic and social sustainability, primarily involving the application of various forms of public-private partnerships, through the implementation of mix typology, as well as the improvement of open spaces treatment.

2.1. Applied typology

Since LRHD housing requires a density ranging from 350-550 inhabitants/ha [6][7], considering the average household size, the number of housing units per hectare should range between 100 and 150. Given that this model implies low-rise buildings, the application of higher plot occupancy rates is expected. Such prerequisites necessitate that LRHD housing can only be developed through the application of certain housing typologies.

In terms of spatial layout of residential blocks intended for single-family housing, detached and semi-detached houses do not meet the requirements regarding the necessary densities [10]. The required urban parameters can only be achieved by forming linear or grid-like construction patterns, which involve planning row and/or courtyard houses [10]. To achieve higher densities, undeveloped areas are reduced to a minimum, resulting in a reduction of the usual unbuilt plot area in single-family housing – which in this type implies provision of a small front yard (which takes on the role of a buffer zone and softens the interface between private and public domain) and a rear yard of modest dimensions (Figure 1) [11,12]. The total area of such plots often does not exceed 120m². The application of this typology provides a higher occupancy rate, which in such formation ranges from 50-70%, and reach density of 85-100 housing units/ha (300-350 inhabitants/ha) [13].

Figure 1. The City Houses, Islands Brygge, Copenhagen / Vandkunsten Architects (Source: https://vandkunsten.com/en/projects/city-houses-islands-brygge)

As a more economical solution, the transitional typology model is applied, which in appearance and its advantages strongly resembles single-family housing, obtained through the multiplication of units, by connecting, stacking and overlapping them, to form complex, hybrid types (Figure 2.) [10-12]. In most cases, all units have access from the ground, either directly or via individual open staircases. Private open areas strongly resemble yards of single-family house – the ground floor units gain a part of the terrain; while the ones on higher floors possess larger roof terraces, as an alternative to yards, This type obtains most benefits of single-family housing while increasing the density, which in this case ranges from 100-120 housing units/ha (350-420 inhabitants/ha).

Figure 2. The Residences at Sandford Lodge, Ireland / Shay Cleary Architects (Source: https://archello.com/news/shay-cleary-architects-completes-irelands-first-low-rise-high-density-residential-development)

The typology that provides the highest densities of LRHD housing is the construction of multi-family housing in the form of garden-apartments [11,12]. This type of housing can be developed in the form of an open or enclosed block, with up to five above-ground floors, and a density up to 150 residential units per hectare (550inhabitants/ha). Part of the terrain is attached to the units on the ground floor, giving them private open area resembling gardens, hence the name of this typology. Units on higher floors often have large associated open areas in the form of balconies or loggias. Often, these buildings feature setbacks on the top floors, allowing the development of larger roof terraces, providing units on higher floors with a suitable alternative to the ground-floor gardens.

Figure 3. CPO AMSTELWIJCK, Amsterdam / Blauw Architecten Source:https://www.blauw-architecten.com/projects/woongebouw-zuidelijke-wandelwe

2.2. Private open areas

As a residential form that aims to reduce the differences between single-family and multi-family housing, LRHD housing should provide a suitable alternative to a single-family home. The yard, as one of the main advantages of single-family housing, must find an adequate replacement in this typological form. Therefore, one of the main characteristics of LRHD housing is the presence of significant private open areas, which serve as an alternative to the yards of single-family homes. This space, in terms of its position, spatial layout and dimensions, should serve as an outdoor extension of the living room area and should support everyday activities such as dining, children's play, leisure activities, socializing with guests and more [4,5,8].

Table 1. Design standards for private outdoor areas

	Private garden	Balconies and loggias	Rooftop terrace
Housing design quality and standards - Supplementary planning guidance [14][15] UK	A minimum of 20m² of private outside space in a form of a private garden should be provided for two person dwellings and an extra 5m² for each additional occupant. The minimum depth and width of all private gardens is 500cm. Space for children's play equpment, table and chairs, storage and an area for dry washing.	A minimum of 5m² of private outside space should be provided for one-to-two person dwellings and an extra 1m² should be provided for each additional occupant. The minimum depth and width of all balconies and other private external spaces is 150cm. These minimum areas and dimensions provide sufficient space for either a meal around a small table, clothes drying, or for a family to sit outside with visitors.	A minimum of 5m² of private outside space should be provided for one-to-two person dwellings and an extra 1m² should be provided for each additional occupant. The minimum depth and width of all balconies and other private external spaces is 150cm. These minimum areas and dimensions provide sufficient space for either a meal around a small table, clothes drying, or for a family to sit outside with visitors.
Apartment Design Guidelines for Victoria [11][12]. Australia	An area of 25m², with a minimum dimension of 3m at natural ground floor level and convenient access from a living room, or An area of 15m², with a minimum dimension of 3m at a podium or other similar base and convenient access from a living room.	A balcony with an specified area and dimensions, and convenient access from a living room. Stud./ 1bdr. – 8m² /1.8 2bdr. – 8m² / 2m 3bdr – 12 m²/2.4m	A roof-top area of 10m² with a minimum dimension of 2m.
Residential and Mixed Use Overla yDevelopment Code [16]. US	Each single-family row-house or courtyard unit shall be provided with a yard of at least 300sq.ft. with a minimum dimension of 15ft. Each ground floor apartment unit shall be provided with a usable, outdoor yard with an area of at least 100sg.ft. with a minimum dimension of 10ft.	Balconies and loggias of upper floor units shall have usable, private open space with an area of at least 60sq.ft. with a minimum dimension of 5/6 ft.	Roof deck shall have usable, private open space with an area of at least 60sq.ft. with a minimum dimension of 5/6 ft.

LRHD housing is characterized by variety in terms of private open areas - from private gardens, in units located on the ground floor; over spacious loggias and balconies; to the roof terraces on the last floors [8]. The design of these spaces is primarily based on the principle of space hierarchy and spatial continuity, in order to create a connection between different open spaces [8].

In most developed countries, the treatment of private open spaces is defined by regulations or other documents that define residential developments. A comparative presentation of defined values in certain developed countries is presented In Table.1.

3. MIX-MESH DESIGN CONCEPT OF MODULAR LRHD HOUSING

3.1. Design strategy

The proposed modular concept, which could be used in the development of LRHD housing, is based on theoretical data presented in the introduction of this research. The basic module, with dimensions of 4.2x5.0m, was chosen as the most efficient one due to its ability to accommodate various functions: from parking (either underground or at ground level), to living rooms and double-bedroom areas, but also for accompanying services, since its dimensions support the grouping (combination) of certain functions, such as: communication and toilet, communication and kitchen, kitchen and dining room, two single bedrooms and etc.

Figure 4. Variation of units' spatial layout in Mix-Mesh model of LRHD housing
Source: author

Varieties of spatial layouts, as an effect of different module combination, provide the opportunity to develop a wide range of residential units: from studio apartments, through one-bedroom to multi-bedroom apartments, with the possibility of their arrangement in a form of single or multi-story dwelling (Figure 4).

Two and three-story residential units can be adapted to a form of single-family row house. By combining a larger number of residential units, it is possible to form multi-family housing units, with up to 5 above-ground floors (Figure 5.) which, depending on the number of combined units, can be organized as freestanding, single access buildings, or in a form of a row structure, with multi-access points. Such building can be organized either as gallery or corridor-access type. Particularly high-quality solutions for multi-family housing are those where the larger ground-floor units have direct access from the surrounding terrain through the associated yard. In this way, some residential units in multi-family housing complexes acquire the characteristics of urban single-family homes.

Figure 5. One of the possible combination of units, in a form of multi-family dwelling
Source: author

One of the dominant characteristics accompanying LRHD housing, reflected in the development of significant private open areas, is also in the core of the Mix-Mesh concept. All ground-floor units are provided with associated terrain in the form of private gardens, whose surface ranges from 21 to 50m2. Part of these surfaces is planned with paving, while the rest is greened. Units on higher floors are provided with private open areas in the form of balconies or loggias, ranging in size from 8.5 to 17m². Larger balconies or loggias are also provided with planters for medium-height greenery. Units on the top floors are set back from the facade plane, allowing the development of larger private open areas in the form of roof terraces.

3.2. Possibilities and results of the application of the concept

Regarding the manner of units' spatial organization, mutual combination and vertical assembling, residential blocks of different typologies and densities can be developed. Some of those possibilities will be presented in the continuation of the paper, along with achieved urban parameters regarding densities (Figure 6).

Case 1 – residential block of family housing. In this case, up to six single-family residential units, larger in structures and suitable for multi-member households, are grouped together in the form of row houses. Units in such block can be two to three story high. A network of 4.2m profile pedestrian footpaths are provided within the area. Each residential unit is accessed through a small front garden, 2.0m deep (with area of 8m²). All units have modest rear garden, with dimensions 5.0x4.2m (an area of 21m²). Application of such typology can provide density of 98 residential units per hectare, i.e., around 330 inhabitants/ha.

Case 2 – mixed residential block, combining single-family and multi-family housing. In this type of block, one part of the residential units is arranged in the form of row houses, while the other part is grouped within multi-family housing building. Row houses typically have two to three floors, while the number of floors in multi-family building can vary from three to five. All residential units at ground level (regardless the applied typology) have private front gardens with a depth of 2.0m, providing access to the units, and rear gardens with dimensions of 4.2x5.0m. This way, a large number of residential units acquire the characteristics of single-family houses. Regarding density, achieved values heavily depend on the proportion of single-family row houses. In the case of an even representation of both housing types, with the construction of multi-family dwelling as a corridor structure of five floors, it is possible to build around 140 housing units per hectare, achieving a density of around 450 inhabitants/ha.

Case 3 – residential block of multi-family housing. In this case, only multi-family housing buildings are applied, with the number of floors depending on defined urban planning parameters. Depending on the specific conditions corridor or gallery layouts can be applied. Significant private open areas, as the main feature of LRHD housing, are evident in this case as well. The units on the ground level, as in previous cases, have private gardens. All units on higher floors have accompanying balconies or loggias. By withdrawing the façade levels on the top floor, significant roof terraces are developed, serving as alternatives to ground floor gardens. The achieved density depends on the defined urban planning parameters and applied typology. As a maximum, in the case of application of the corridor layout an five floors buildings, it is possible to build up to 200 housing units per hectare, achieving a density of around 600 inhabitants/ha.

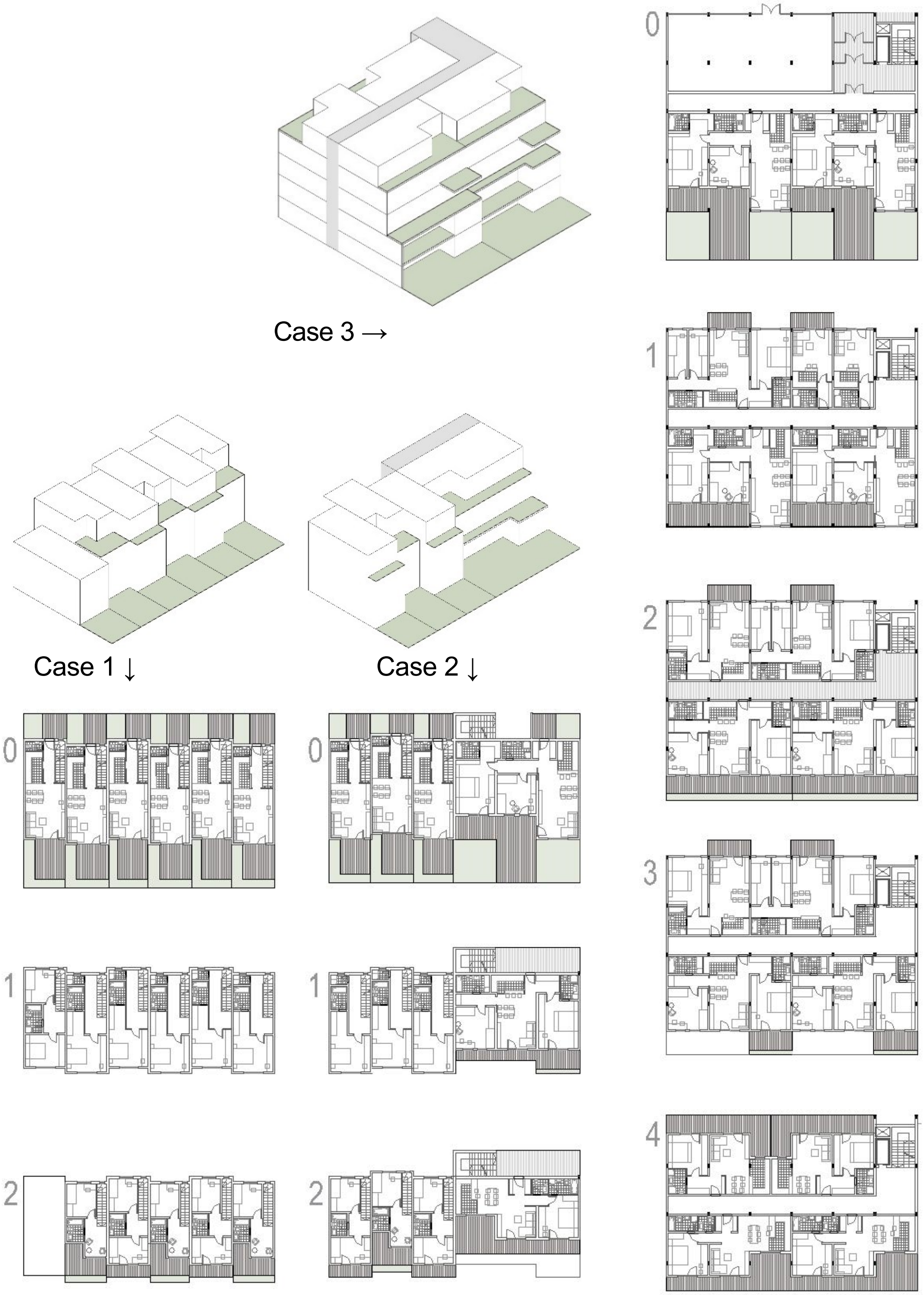

Figure 6. Different typologies obtained by MIX-MESH concept
Source: author

4. CONCLUSION

Contemporary theoretical and practical research points to the sustainability of LRHD housing [17]. Rational use of spatial resources, better infrastructural equipment, a higher level of embeddedness and the multiplication of housing units, positively affect the compactness of the construction and provide many benefits. However, LRHD housing will be successful only if high quality living is obtained, which is reflected in the relationships with the surrounding area in terms of connectivity, scale and integration.

The proposed Mix-Mesh concept has a large number of the mentioned advantages. A special value, considering the local context and accompanying housing issues, is certainly the more significant greening. The variability of units' structures and residential typologies makes this concept easily applicable in various locations. Nevertheless, this type of housing model is best developed on larger urban blocks, rather than on individual plots as infill in urban fabric, which unfortunately is the dominant practice in housing construction in Serbia. By introducing the LRHD housing into planning regulation and more thoughtful urban planning, it is possible to create conditions for the development of such housing model and utilize the benefits provided by the application of proposed typology.

ACKNOWLEDGMENTS

The research is financially supported by Ministry of Science, Technological Development and Innovation (Agreement on the realization and financing of the scientific research work of Scientific research organization (University of Niš, Faculty of Civil Engineering and Architecture) in 2024, registration number: 451-03-65/2024-03/200095).

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

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Vasov. - 2003, br. 19- . - Niš : Građevinsko-arhitektonski fakultet Univerziteta u Nišu, 2003- (Niš : Grafika Galeb). - 24 cm

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