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PREFACE

We are delighted to present the latest issue of the Journal of the Faculty of Civil Engineering and Architecture, as we continue the tradition of publishing high-quality research in its 45th year, with 40 volumes to date. Building on the developments initiated in previous years, we are proud to note that the journal is steadily progressing toward greater international visibility and scientific recognition. According to the Serbian national classification, the journal was awarded the M54 category for the 2024 volume, and we believe this year will be even more successful.

This volume features a diverse range of peer-reviewed papers addressing contemporary challenges in architecture and civil engineering. Several papers focus on sustainable design and bioclimatic principles, including an analysis of contemporary family housing in Krašići, Montenegro, and a case study on the application of brise-soleil systems in residential neighborhoods. Redevelopment strategies for public open spaces within multi-family housing estates in the post-socialist Czech Republic are critically examined, highlighting both challenges and opportunities. Urban development themes continue with an exploration of the multipurpose character of shopping centers and their future directions. From an engineering perspective, the volume includes a probabilistic estimation of life-cycle chloride-induced corrosion, a methodology for determining the load-bearing capacity of high-profile sheets through experimental methods, and an analysis of surface deformations during small overburden tunnel excavations in poor rock masses. Additionally, the costs and benefits of water protection projects in Pirot are assessed, while specific technical challenges related to heat transfer in deep-freeze storage facilities are also discussed. The volume also includes a study on the geomorphological, geological, and hydrogeological features of the immediate surroundings of Sarajevo, Bosnia and Herzegovina.

The authors contributing to this volume come from China, Italy, Bosnia and Herzegovina, and Serbia, reflecting the journal's growing international reach. We sincerely thank all authors for choosing our journal to present their research and for their contribution to the advancement of knowledge in civil engineering and architecture. The peer-review process was supported by experts from a wide geographical range, including Poland, Romania, Slovenia, Indonesia, Malaysia, Bosnia and Herzegovina, North Macedonia, Montenegro, and Serbia. We are deeply grateful to all reviewers for their dedicated work, which ensures the high quality and scientific rigor of the published papers. Finally, we invite researchers to consider our journal for disseminating their research, and we pledge to continue working on increasing the journal's visibility and scientific impact.

Editor-in-Chief,
Prof. Dr. Miomir Vasov, M.Arch.
Dean,
Prof. Dr. Slaviša Trajković, M.Eng.

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PROBABILISTIC ESTIMATION OF LIFE-CYCLE CHLORIDE-INDUCED CORROSION

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Abstract

Coastal bridges constitute critical components for the transportation in offshore areas, and thus their serviceability and safety against hazard such as earthquakes need to be ensured in a life-cycle perspective. However, coastal bridges are confronted with significant corrosion that results in degradation effects mainly on concrete piers. This can make the resistance property of bridge diverse from the initially designed state. Hence, it is vital to predict the residual performance of coastal bridges throughout its life-cycle period. Prior studies described the corrosion evolvement using mostly deterministic methods, whereas the uncertainty was neglected in terms of both the corrosion environment and concrete performance. In this study, the corrosion developed of bridge pier was investigated probabilistically. A convolutional formula was proposed to account for the correlation between the initial corrosion time and the remained time to the expected lifetime. The proposed approach was validated using a prototype bridge in China, where the corrosion environment was captured by historical chloride data, the uncertainty in other parameters was reflected using random variables. The results showed that the proposed method can well apply to predicting the corrosion state in the bridge life-cycle period, where the initial corrosion time approaches closely to skewed distribution. The selected bridge exhibited notable corrosion likelihood at the end of lifetime. It was found that the probability of corrosion absence is approximately 30% while the maximum loss mass ratio reaches around 45% for the lifespan of 100 yrs. The proposed method can be further used to determine the degraded performance for bridge analysis under other impacts such as earthquakes and waves.

Key words: *Chloride-induced corrosion; Coastal bridge; Life-cycle; Probabilistic.*

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1. INTRODUCTION

Coastal bridges were built to connect the districts separated by bays, leading to their great importance in the transportation of community and resources. Whereas, these structures were threatened by a number of unfavorable effects, among which earthquakes can bring about direct load impact while the corrosion action can give rise to the declined capacity. Chloride-ion is the main cause of corrosion in oceanic environment. The combined effects of both events pose significant threats to coastal bridges, and the risk develops as the service time expands [1]. Hence, it is vital to predict the corrosion state so as to supply guidance for repairing and retrofitting.

The corrosion process consists of two phases including the initiation of corrosion and the development of corrosion effects [2]. For the reinforcement-concrete (RC) bridge, the corrosion initiation depends on the chloride-ion that penetrates concrete cover and erodes the strengthened reinforcement [3]. Many studies have been conducted to predict this parameter given environmental conditions.

Tuutti [4] suggested to describe the process of ion penetration using the second Fick's law. Kassir [5] studied the influence of chloride-induced corrosion on the reinforced-concrete bridge decks, in which a closed-form formula was proposed to predict the corrosion initiation time using the ion accumulation data from measurements. Their results showed that the constant concentration can cause underestimation towards the imitation time. Lin [6] proposed a dynamic corrosion rate model based on Bulter–Volmer kinetics, with a rust expansion model also developed based on Faraday's law. A comparison between their model and experimental results validated the accuracy and reliability of the mathematical method. Khan [7] conducted a review research upon the estimation method of the initial corrosion time. Reviewing prior researches shows that, the initiation time is affected by multiple factors that are all highly uncertain within the life-cycle period of bridges. Therefore, using the probabilistic method to describe such process is more suitable comparing to the deterministic method.

Precedent studies have implied that corrosion can affect the bridge performance mainly by undermining the rebar resistance [8], while some have also addressed their influence on the concrete material and the bonding effects between concrete and rebar [9]. In this study, the corrosion effect was reflected with emphasis on the rebar component. Enright [10] studied the degraded resistance of reinforced concrete bridge beam subjected to chloride-induced corrosion. The flexure strength loss in a concrete bridge was addressed in their study, with various factors considered to compare the effects on the remain effective steel area and beam performance. Ghosh [11] investigated the time-varying fragility of a bridge under the joint effects of earthquake and corrosion-induced degradation. The formulation was developed to consider the time-dependent feature, with the distinct degradation rate in various bridge components also considered to reflect the realistic situations. Dizaj [12] inspected the vulnerability of corroded RC frames within their service life. The pitting corrosion effects were highlighted in their research, showing that the variability of pitting corrosion has insignificant influences on the global failure of bridge. Liu [13] conducted an experimental research to examine the remained materials after major corrosion effects, showing that phases of steel rust in the atmospheric zone were lepidocrocite and goethite, while lepidocrocite and maghemite dominate in the tidal zone. Tian [14] conducted research to analyze the steel corrosion using historical data obtained from natural environments. Their research focused on the corrosion rate, microstructure at the steel-concrete interface, rust composition and properties. And the analysis indicated that the natural corrosion rate of steel tends to decrease over time in long terms. It is then evident that the eroded materials can undermine the rebar performance in terms of both the section area and strength property.

The coastal bridges in seismic-prone areas, such as the west coast of USA, and Japan, are also exposed to the high seismic risk. Historical post-hazard survey has shown that bridges piers were significantly damaged or even collapsed during strong ground motions [15][16]. And this can be further escalated by the joint actions of both hazards due to the declined capacity.

The literature review shows that the corrosion influence was characterized from deterministically to probabilistically by accounting for the uncertainty in the chloride-ion environment. However, existing research often adopted a simulation method to obtain the corrosion uncertainty after certain service time, in which the initiation time and the corrosion state were sampled according to the corrosion environment. Such method requires to run the sampling operation for each corrosion period, leading to poor efficiency for a life-cycle investigation. To this end, the probabilistic estimation of corrosion was highlighted in this study. An analytical method was presented to anticipate the corrosion degree at arbitrary time, so as to improve the efficiency for other analysis. A case study was performed to validate the proposed method, where the historical data was employed to capture the chloride uncertainty. The analysis results showed good applicability of the proposed method in predicting the corrosion as per the service time. It was found that there exists both upper and lower bounds for the corrosion state, and they were prone to rise with increasing rate as the service time becomes longer.

The primary contents of this study were structured as follows: 1) the analytical model for corrosion prediction was developed in Section 2, where the initiation time and corrosion influence were illustrated; 2) a case study was demonstrated in the third section, where the prototype bridge and the site-specific data were employed. Besides, a reliability analysis was conducted to obtain the failure probability of the bridge subjected to the design acceleration; 3) the conclusion remarks were drawn in the final section.

2. PROBABILISTIC LIFE-CYCLE CORROSION ESTIMATION

2.1. Initiation corrosion time and corrosion effects

Estimating the initiation corrosion time is crucial because it determines the time left for the corrosion development. The initiation time is affected by multiple factors including the ion concentration, cover depth, critical concentration for the corrosion onset, and concrete properties. On this basis, the erosion process starts when the ion concentration at the cover depth reaches the critical value, as shown in **Fig. 1**. And the initiation time can be estimated by the following equation when the primitive chloride concentration is negligible [17],

$$T_{init} = \left\{ \frac{d_c^{\,2}}{4k_e k_t k_c D_0 \left(t_0\right)^n} \left[erf^{-1}\left(\frac{C_s - C_{cr}}{C_s} \right) \right]^{-2} \right\}^{1/(1-n)} \quad (1)$$

in which d_c is cover depth, D_0 is the diffusion rate of ion penetration, and t_0 is the curing time of concrete material. k_e, k_t, k_c are factors employed to reflect concrete properties, which corresponds to the influences of environment, temperature and the curing condition. C_s and C_{cr} are the ion concentration near the bridge pier and the critical value, respectively. Besides, n is the age factor that reflects the declined corrosion rate with time.

Reviewing existing research showed that the chloride-induced corrosion primarily results in the loss of section area and strength for steel reinforcements. The influence on concrete is also associated with the strength decline in the rebar as it further leads to the lowered confinement to concrete [18]. In this study, the rebar corrosion was highlighted because of its dominant influences on the flexure behavior of bridge piers [10].

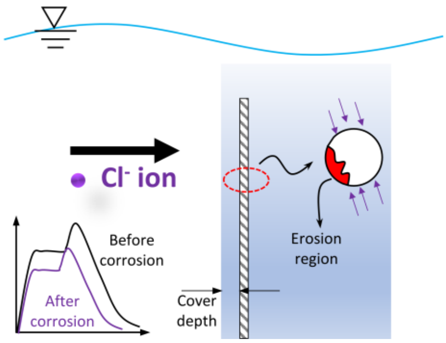


Figure 1. Diagram of corrosion initiation and progression

Many researches have implied the correlation between corrosion rates and the current density due to the corrosion process. And the time-varying diameter of rebar can be expressed in the following form [11]:

$$d_s(t) = \begin{cases} d_{s0},\, t \le T_{init} \\ d_{s0} - 2\int_{T_{init}}^{t} \lambda(t)\,dt,\, T_{init} < t \le T_f \\ 0,\, t > T_f \end{cases} \quad (2)$$

Note that d_{s0} is initial rebar diameter, t is the time since the corrosion onset, and T_f refers to the time when the rebar is completely eroded. In addition, $\lambda(t)$ is the corrosion rate affected by the current density, which takes the form as follows:

$$\begin{cases} i_{corr}(t) = 0.85 i_{corr,0} \left(t - T_{init}\right)^{-0.29},\, t \ge T_{init} \\ i_{corr,0} = \dfrac{37.5\left(1 - w/c\right)^{-1.64}}{d_c} \mu A / cm^2 \end{cases} \quad (3)$$

in which $i_{corr,0}$ is the current density at the initial stage, w/c is cement-water ratio, while other parameters are defined in alignment with Eq. (1). Accordingly, the mass reduction ratio (Q_{corr}) can be calculated using the below formula:

$$Q_{corr}(t) = 1 - \left(d_s(t)/d_{s0}\right)^2 \tag{4}$$

Prior research suggested that corrosion can also give rise to the reduced strength of steel rebar, and the reduction was correlated to the mass loss via the equation as follows:

$$f_y = \left(1 - \alpha_y Q_{corr}\right) f_{y0} \tag{5}$$

in which f_{y0} is the yielding strength at the initial stage, while α_y is the decrease rate of rebar strength. And it is taken as 4.9×10^{-3} in the current research.

2.2. Proposal of lifetime corrosion model

To improve the efficiency of corrosion analysis throughout the life-cycle period of bridges, an approximate lifetime corrosion model was proposed in the current work. To begin with, the uncertainty in the initiation time can be characterized by a random distribution $f_{T_{init}}(t)$ by fitting the data from Monte Carlo modeling in accordance to **Eq. (1).** Besides, the corrosion degree can be also determined for the residual time depending on the designed lifetime or the inspected operation time. Consequently, the erosion progress can be characterised by the following equation in according to the whole probability theory:

$$P_{CR}\left(CR{=}cr_i\right) {=} \sum P_{CR}\left[CR = cr_i \middle| T = T_i, T_L = t_l\right] \cdot P\left(T = T_i\right) \tag{6}$$

where $P(T = T_i)$ represents the likelihood that the corrosion starts at T_i, and P_{CR} is the probability of corrosion state $CR = cr_i$ conditional on a design lifetime of T_L. Such equation can be further modified into the following form when the initiation time is continuous as:

$$\begin{cases} f_{CR}(cr) = \int_0^{T_L} f_{CR}\left(cr \middle| T_R\right) \cdot f_T(t)\,dt \\ F_{CR}(cr) = \int_0^{T_L} F_{CR}\left(cr \middle| T_R\right) \cdot f_T(t)\,dt + \int_{T_L}^{+\infty} f_T(t)\,dt \end{cases} \tag{7}$$

in which f_{CR} is the probability density function of corrosion state given the residual corrosion time $T_R = T_L - t$, and f_T signifies the probability density of the initiation time and is equal to $f_{T_{init}}(t)$ derived from regression analysis. In addition, the last term of integral from TL to infinite is used to reflect the absence of corrosion within the bridge lifespan. The above equation accounts for overall possible initiation time throughout the life time T_L in the upper integral limit, as illustrated in Fig. 2.

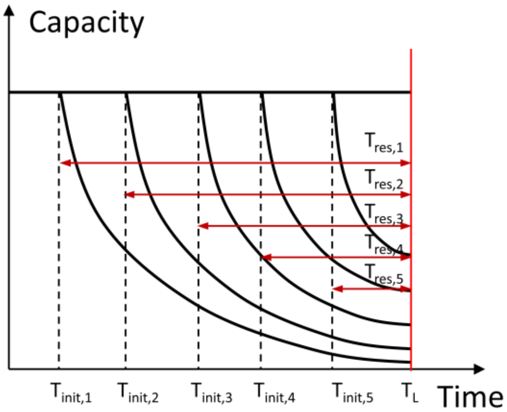


Figure 2. Relationship of initiation and residual time in lifetime model.

On this basis, the probability function of corrosion state can be deducted by only calculating the corrosion development in the specified residual time by separating the design life time into multiple intervals. And the corrosion at other residual time can be approximately obtained by correlating the density function with time-dependent factors as follows:

$$\begin{cases} f_{CR}\left(cr \mid T_R\right) = f_{CR}\left(cr \mid T_R\left(t\right); \alpha_1\left(T_L - t\right), \alpha_2\left(T_L - t\right), \cdots, \alpha_n\left(T_L - t\right)\right) \\ F_{CR}\left(cr \mid T_R\right) = F_{CR}\left(cr \mid T_R\left(t\right); \alpha_1\left(T_L - t\right), \alpha_2\left(T_L - t\right), \cdots, \alpha_n\left(T_L - t\right)\right) \end{cases} \quad (8)$$

where $\alpha_1\left(T_L - t\right) \sim \alpha_n\left(T_L - t\right)$ are the corrosion density function within the residual corrosion time $\left(T_L - t\right)$. Furthermore, the uncertain corrosion distribution at arbitrary time of the bridge lifetime can be computed using the integral formula in **Eq. (7)**.

3. CASE STUDY

3.1. Information of prototype bridge

To validate the effectiveness of the proposed method above, a case study was carried out to demonstrate the corrosion analysis. Besides, a reliability analysis was also conducted to inspect the time-varying security of degraded bridges. A prototype bridge in China coastal area was chosen for this purpose, whose designed lifespan is 100 yrs. **Fig. 3** shows the geometry setups of the selected bridge, which consists of two spans with equal length at 30 m. The girder employs a box-shape section, with length and height equal to 12 m and 2.6 m, respectively.

More detailed configuration of the girder component can be found in this figure. The bridge pier is designed as single column with circular section, where the diameter is set to 1.6 m. The reinforcement configuration inside the pier section (40Φ25), and the pier height is set identically at 10.5 m for each span. The bridge girder is supported by the bent-cap (2.5 m height and 1.9 m width) casted on the pier top. The girder component was connected to the bent using high-strength bearings alongside adequate constrainers to ensure the force delivered between super- and sub-structures. As a result, the shear and flexure failure modes at the pier bottom dominate in contrast to the possible joint flexure failure for a rigid-frame bridge. All the bridge components are constructed using C35 concrete and HRB400 rebar, where the compressive and yielding strengths are 35 MPa and 400 MPa, respectively. Further, the cover depth of bridge piers is expanded to 80 mm to resist against the high-diffusion environment.

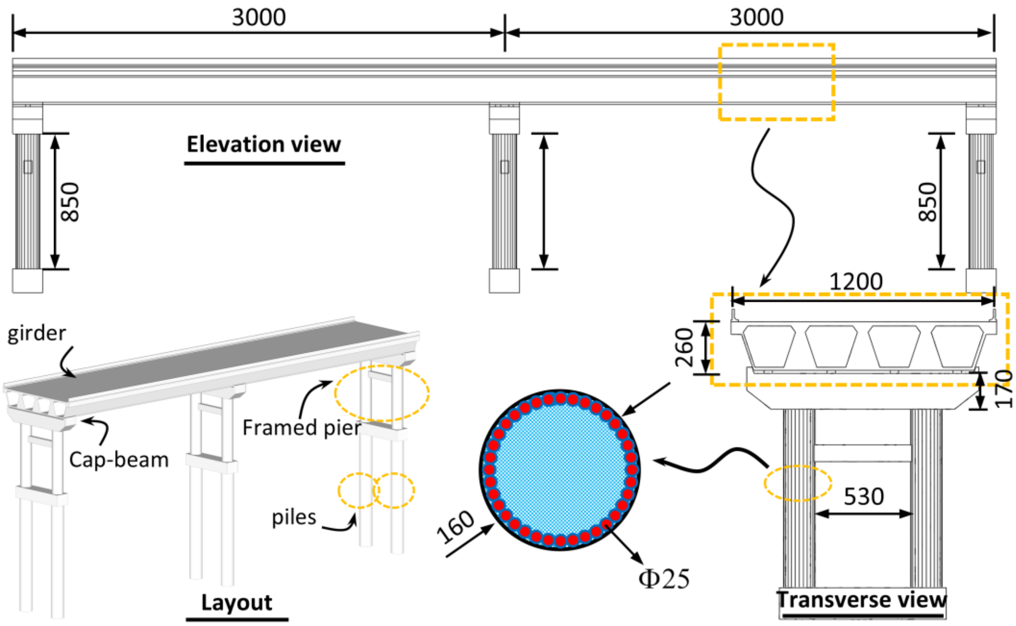


Figure 3. Configuration of prototype bridge (unit = cm).

3.2. Corrosion analysis

The chloride-ion environment is required to perform corrosion analysis according to **Eq. (1)**. To this regard, the concentration in sea water was collected from the Chinese Ocean Science Data (COSC) platform, and the observation data from 1986 to 2016 (30 yrs) was adopted for our analysis. **Fig.4** indicates the monthly variation of the ion concentration. It can be found that the concentration value reaches the maximum in November, and continue to remain high in adjacent months including December and January. In contrast, the ion concentration turns lower at the middle of the year, from June to August.

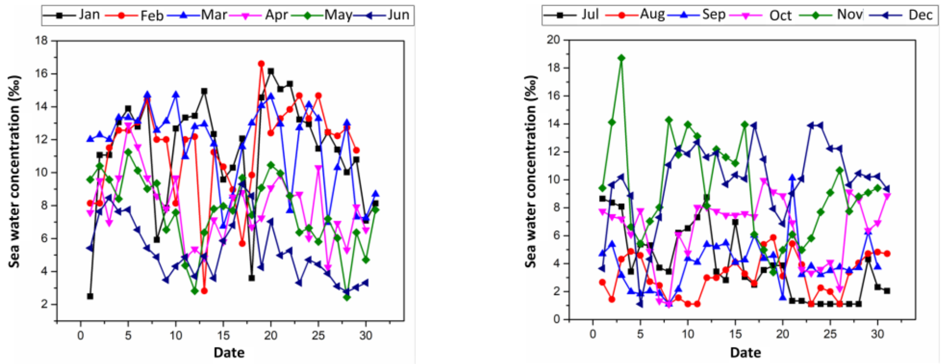


Figure 4. Monthly ion concentration in sea water near selected bridge (1996): (a) Jan. – Jun.; (b) Jul. – Nov.

Using the historical concentration data, the statistic analysis was demonstrated to describe the uncertainty in chloride-ion condition. **Fig. 5(a)** presents the histogram of ion concentration, along with the empirical cumulative probability (ECDF). On this basis, the ion concentration was hypothesized to approach normal distribution, and the distribution parameter can be attained using the regression analysis, as indicated in **Fig. 5(b)**. Moreover, the concentration of chloride-ion can be calculated using a ratio relationship, see **Eq. (9)**. Note that $S\text{‰}$ and $Cl\text{‰}$ are the concentration of overall ion and chloride only, respectively. This leads to the normal distribution of chloride ion with $\mu = 4.23$ and $\sigma = 2.22$.

$$S\text{‰} = 1.80655\, Cl\text{‰} \tag{9}$$

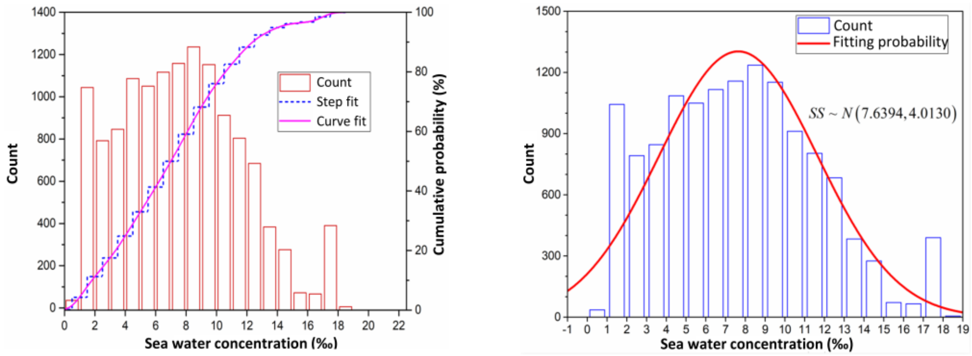


Figure 5. Statistical analysis on ion concentration near selected bridge: (a) histogram and ECDF; (b) normal distribution fitting.

Prior research has shown that the cement-water ratio can substantially influence the diffusion rate (D_0) [19]. On this basis, this parameter was calculated for the high-strength concrete (≥50 MPa), see **Eq. (10)**.

$$D_0 = 2.519\frac{m_W}{m_{(C+B)}} - 0.681\frac{m_{FA}}{m_{(C+B)}} - 0.04816 \tag{10}$$

in which m_W is the water mass, $m_{(C+B)}$ is the overall mass of cement and grains, while m_{FA} is the mass of fly ash powder as additives. The concrete component consists of cement (202 kg), water (167 kg), fly ash powder (314 kg), grains (1709 kg) for unit stere. And this leads to the initial diffusion rate at 15.67 mm/ yr. In addition, the factors (k_e, k_t, k_c) in **Eq. (1)** were also designated with uncertainty using normal distribution. The mean value was set to 0.79 and 2.70 for k_e and k_t, while the curing factor takes 1.0 for a standard curing treatment. The coefficient of variance (Cov) was specified at 1.48 for k_e and k_t, while 1.05 was assigned to the curing factor.

Additionally, the threshold ion concentration for the corrosion process to begin is determined in accordance to the Duracrete report, and the value at distinct position along the pier height was presented in **Table 1**. The threshold value depends on the cement-water ratio, leading to the distribution of $N(0.89, 0.15)$ using interpolation. Note that only the tidal-splash zone was considered here because the prototype bridge uses a high-rise pile cap. Based on this, the corrosion analysis can be carried out in accordance to Section 2.

Table 1. Threshold chloride concentration at corrosion onset [20]

Corrosion environment	Cement-water ratio (w/c)	Distribution of critical chloride concentration
Underwater	0.3	*N*(2.3,0.2)
	0.4	*N*(2.1,0.2)
	0.5	*N*(1.6,0.2)
Tidal-splash zone	0.3	*N*(0.90,0.15)
	0.4	*N*(0.90,0.13)
	0.5	*N*(0.50,0.10)

4. DISCUSSION ON RESULTS

Fig. 6 indicates the initiation corrosion time when the concentration at the cover depth equals the threshold value. It can be seen that the highest probability density occurs at around 12 yrs, while the median value of initiation time was obtained at 23 yrs. In addition, the probability of corrosion occurrence within the bridge lifespan was approximately 72%, compared to only 3% during the first 10 yrs. Building upon this basis, the regression analysis was performed by fitting the data. To this regard, an logarithmic Gumbel distribution (**Eq. (11)**) was introduced herein to align with the modeling results, and the comparison of modeling and analytical ECDF curves were also compared in **Fig. 6**. It is clear that the regressed distribution matches well with the sampling outcome, showing good applicability of the proposed method.

$$F_T(t) = \exp\left[-\exp\left(-\frac{\ln t - 3.333}{1.232}\right)\right], t > 0 \tag{11}$$

$$f_T(t) = \exp\left[-\exp\left(-\frac{\ln t - 3.333}{1.232}\right)\right] \cdot \left[-\exp\left(-\frac{\ln t - 3.333}{1.232}\right)\right] \cdot \left(-\frac{1}{1.232}\right) \cdot \frac{1}{t} \tag{12}$$

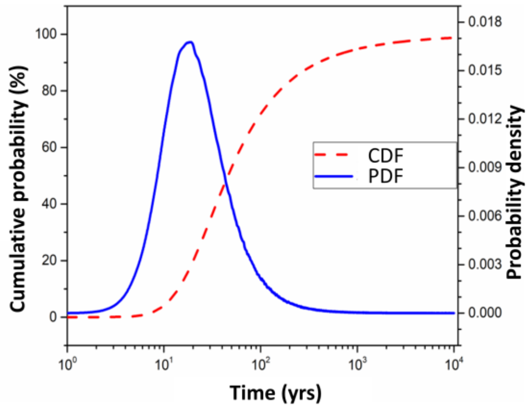


Figure 6. Modeling results of initiation corrosion time.

Additionally, the corrosion development during the residual life time was analyzed using **Eqs. (2)-(5)**, leading to the distribution of mass reduction ratio in **Fig. 7(a)**. It can be found that the erosion-induced mass loss rises significantly as the residual time increases. The median value increases from 8% (10 yrs) to 40.5% (100 yrs). The mass reduction corresponding to the median initiation corrosion time (23 yrs) is 32.8%, showing that nearly 1/3 steel material was eroded during the following 77 yrs. The maximum value of the reduction ratio remains lower than 60% across overall residual corrosion time. This implies the minimal likelihood for the rebar to be completely eroded. On this basis, the fitting analysis was also applied in accordance to **Eq. (8)**. And the Gumbel distribution (**Eq. (13)**) was employed here to fit the data in **Fig. 7(a)**, with the results shown in **Fig. 7(b)**.

$$F_{CR}\left(cr;\mu(t),\beta(t)\right)=\exp\left[-\exp\left(-\frac{x-\mu(t)}{\beta(t)}\right)\right] \tag{13}$$

in which $\mu(t)$ and $\beta(t)$ are both the parameters in Gumbel distribution, and they are correlated to the time variable (t) to reflect the corrosion development with time. The power function was utilized here for the fitting analysis. As can be seen in **Fig. 7(b)**, the fitting curve shows good agreement with the parameter from the regression analysis. Hence, the corrosion state at arbitrary time of the bridge lifespan can be computed via **Eq. (8)**.

Fig. 8 displays the distribution of mass reduction ratio at various service periods, including 20, 50, 70 and 100 yrs. Accordingly, the diameter reduction ratio and the strength reduction ratio were also included. It can be seen here that, the probability density remains comparable within certain ranges for different period examined. For example, the result at T = 50 yrs coincides with T = 25 when the mass ratio (Q_{corr}) is lower than 0.1. Also, T = 75 yrs yields similar results as T = 50 yrs before Q_{corr} rises to 0.23. The probability density of diameter reduction exhibits comparable results, see **Fig. 8(b)**. By contrast, the maximum value of strength reduction takes merely 0.2 owing to the multiplication factor in **Eq. (5)**.

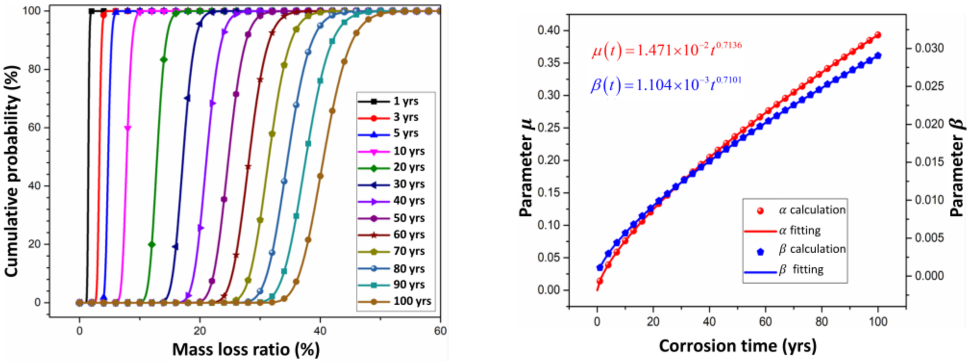
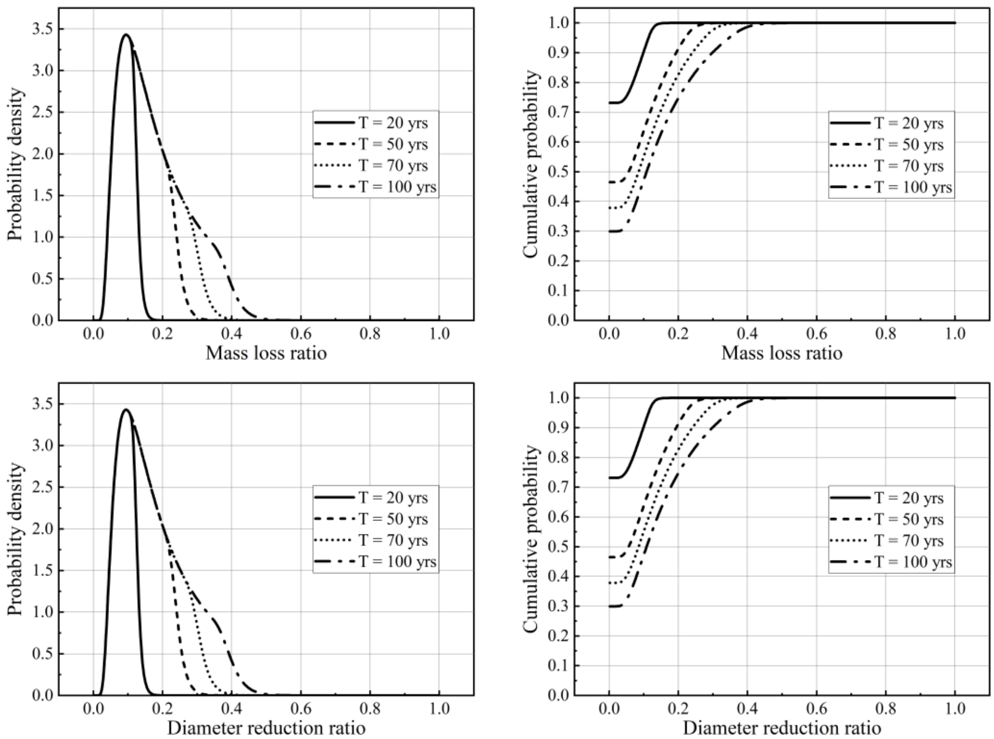


Figure 7. Modeling results of corrosion in residual life time: (a) mass reduction ratio; (b) parameter regression.

The cumulative probability was shown in the (b) subplot. It can be found that the corrosion probability increases as the considered time period becomes longer. The initial values at Q_{corr} = 0 increases from 0.3 to over 0.7 for the period equal to 20 and 100 yrs, respectively, as shown in **Fig. 8(a)**. This shows the essential influences of corrosion on the bridge with long lifespans. The initial value here is larger than zero because of the last term in **Eq. (7)**, which implies the initial corrosion time exceeds the designed lifespan of bridges. Therefore, the above proposed method can well predict the corrosion evolution without repeated sampling demand.



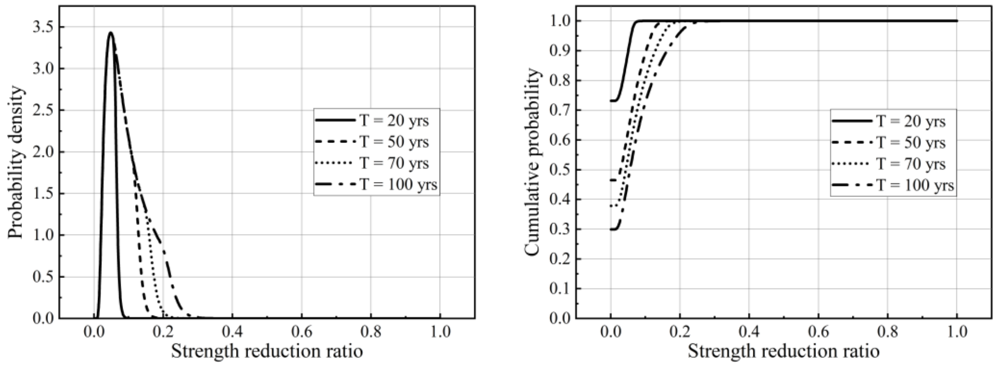


Figure 8. Estimated corrosion effects at various service time: (a) mass loss ratio; (b) diameter reduction ratio; (c) strength reduction ratio.

5. CONCLUSION

Coastal bridges are essential for the transportation in offshore areas. They are highly threatened by multiple hazards accompanied with the degraded performance due to corrosion effects, leading to the necessity to safeguard them in their life-cycle periods. In this study, the chloride-induced corrosion around the coastal bridge pier was investigated with emphasis on their time-varying property within the design lifespan. The primary efforts and contribution of this study can be concluded as follows,

(1) A lifetime corrosion model was proposed to estimate the corrosion state at arbitrary service time within the lifespan.
(2) A case study was conducted to inspect the time-dependent corrosion for a prototype bridge, with the historical ocean salinity data obtained for the corrosion analysis.
(3) The corrosion probability takes 72% throughout the bridge lifespan, whereas it was reduced to 3% within the first 10 years. The median time of corrosion initiation takes 23 years, showing good resistance of the inspected bridge to corrosion effects.
(4) The fitting analysis shows good applicability to both the initial corrosion time and the consequent mass loss ratio, and the life-time corrosion model also has good effectiveness by regressing the time-dependent parameters.
(5) The probability density of corrosion at different service periods matches in certain ranges, while the cumulative probability increases significantly as the examined time prolongs.

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CHALLENGES AND OPPORTUNITIES IN THE REDEVELOPMENT OF PUBLIC OPEN SPACE WITHIN MULTI-FAMILY HOUSING ESTATES IN POST-SOCIALIST CZECH REPUBLIC

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Abstract

This research explores the evolution of public open spaces (POS) in large housing estates (LHE) within the post-socialist context, using the Czech Republic as example. The study investigates the challenges and opportunities associated with the redevelopment of POS, considering the impacts of privatization, socio-economic transformations, and urban renewal policies. It also explores the continuity of urban morphology from the socialist era in the post-socialist period, pointing out the complex connections between inherited urban forms and contemporary needs for urban renewal. The methodological approach is based on an exemplar of best practice analysis, with a specific focus on the Na Dolika LHE, which serves as an illustrative example of POS revitalization efforts. The findings highlight key factors that influence successful redevelopment, including community engagement, sustainable design, and policy frameworks. Additionally, it discusses the first state-level urban renewal policies in Czechia, such as the Program PANEL and Green Light for Savings Program, which aimed to improve technical standards and energy efficiency in buildings, along with public area enhancements. The research contributes to the understanding of post-socialist urban transformation and offers insights for the improvement of POS in similar contexts.

Key words: *Public open space (POS), Multi-family housing estates, Housing policy,*

Czech Republic, Post-socialist period, POS redevelopment, Case of Na Dolika LHE

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1. INTRODUCTION

The socialist urban planning in Czechoslovakia was greatly influenced by Marxist theories, where space was considered as a product and an instrument of social relations [1]. The transformation of public open spaces (POS) within large housing estates (LHE) is a critical issue in the context of post-socialist urban development. As Eastern European countries, including the Czech Republic, transitioned from centrally planned economies to market-oriented societies, the role and management of POS within these estates underwent significant changes. The importance of POS in fostering community cohesion, enhancing urban quality of life, and contributing to sustainable urban development cannot be overstated.

In the post-socialist period, the privatization of housing and shifts in ownership structures posed numerous challenges for the maintenance and redevelopment of POS. These spaces, once under state control and often neglected during the transition period, now face issues such as deterioration, inadequate investment, and unclear management responsibilities. However, the revitalization of POS presents not only challenges but also opportunities for improving the urban environment and social fabric of LHEs.

Previous researches have explored various aspects of urban transformation in post-socialist cities, yet there remains a gap in understanding the specific processes and outcomes related to the redevelopment of POS in LHEs. This study aims to fill this gap by focusing on the Czech Republic, a country that provides a representative example of post-socialist urban dynamics.

The research will first present the basic morphology as a typical construction in socialism, and later that morphology was reflected on the period of post-socialism with examples that experienced regeneration in public open spaces. That is why it is important to consider the morphology that arose in socialism, because such that morphology continued in post-socialism as a legacy. The research will examine the evolution of POS in LHEs, with particular attention to the challenges and opportunities that have emerged in the context of privatization and urban renewal policies. The post-socialist transition in this country, marked by significant political, economic, and social changes, provides valuable insights into the broader trends affecting POS in LHEs across the region.

Private spaces were confined to the household, while public spaces were areas of communal living and state influence. This dichotomy was critical in shaping everyday life and social interactions within the estates. The Housing Act in Czechoslovakia was adopted in 1964. This act played a significant role in the allocation of housing during the socialist period, with specific characteristics that reflected the social and political priorities of the time. The Housing Act emphasized the allocation of housing based on social criteria. This approach was reflective of the socialist ideology of prioritizing collective needs and social welfare over individual preferences. The act gave a high priority to the creation of family housing units

This characteristic of the Housing Act showcases the state's less favorable attitude towards single adults in comparison to families, which can be interpreted as a reflection of the social norms and values promoted by the socialist government. While it was technically possible to build a home privately, the act made it difficult to do so. This aspect of the Housing Act aligns with the broader socialist agenda, which tended to favor state control and planning over individual initiatives in sectors like housing. This regulation reflects the central role of the state in managing and directing housing construction and allocation. The goal set by the Central Committee of the Czechoslovak Communist Party (KSČ) to construct 1,200,000 dwellings by 1970 and the shift towards industrialized construction methods is analyzed with reference to Musil, a prominent urbanist and sociologist who assisted in urban planning at the time [2].

The construction of housing estates in Czechoslovakia, as well as other East-Central European countries like Poland and Hungary, was at its peak during the 1970s, continuing until the late 1980s. The construction of these housing estates was made as industrial in character as possible, justifying the standardization in housing form and engineering practice from the mid-1960s till the end of socialism [3]. The housing estates were built on "Greenfield sites" separated from the already existing urban areas, with full public services and sufficient working opportunities for the residents. The physical appearance of these housing estates showed a direct connection to modernist architecture, but the ideas behind their creation were also related to the aspiration of socialist ideologues to make a positive change in the name of socialist modernization.

The dawn of the 90s ushered in a new era for post-socialist societies, a time when the fabric of institutional planning and housing policies underwent significant transformations. This period saw the emergence of new organizational frameworks for multi-family housing complexes, introducing a novel approach to handling Public Open Spaces (POS). Alongside the construction of new buildings, there was a pressing need to breathe new life into the existing Large Housing Estates (LHEs) and their adjacent POS.

This paper is structured as follows:

The first section provides an overview of the housing policy and urban planning context in the post-socialist Czech Republic, followed by an analysis of the morphological types of LHEs and their transformation over time. The third section focuses on the treatment of POS within inherited LHEs, exploring both the challenges and opportunities for the redevelopment. The role of POS in the urban renewal and revitalization of legacy LHEs. A detailed case study of the Na Dolika LHE is presented to illustrate practical examples of POS revitalization. The paper concludes with a discussion of the findings and their implications for urban planning and policy.

This research adopts a case study approach to investigate the reconstruction of public open spaces (POS) within large housing estates (LHE) in the post-socialist Czech Republic. The case of Na Dolika LHE was chosen as a representative example to illustrate the transformation of POS in the post-privatization era.

The research is based on the analysis of available data, information and findings from previous research and reference literature related to urban development, urban and housing policy in the Czech Republic in the post-socialist period. The analysis is framed in the broader context of post-socialist urban transformation, drawing on relevant theoretical frameworks and previous research on the role of POS in community cohesion and sustainability.

2. HOUSING AND URBAN DEVELOPMENT IN POST-SOCIALIST PERIOD: SETTING THE CONTEXT

Fifteen years following the abrupt end of the socialist regime, Eastern European countries, having courageously dismantled their communist governments, declared the successful transition to market-oriented democratic societies. This pivotal achievement was formally recognized with their accession to the European Union in 2003, marking these nations' full membership, with additional former Eastern Block countries joining in 2007 and more listed as candidates. This period highlights two critical observations: firstly, the majority of these erstwhile socialist states have significantly progressed in enacting comprehensive political and economic reforms. Secondly, the pace and outcomes of these reforms have varied across the Eastern block, yielding diverse results. This variance makes the past fifteen years a prime period for examining the intricate interplay among market dynamics, political developments, and historical contexts [4]. As Sýkora observed regarding the reforms after socialism "The political change took only a few weeks and the core institutional transformations of economic system were accomplished within a few years, however, the change of settlement structures will take many years or decades" [5].

2.1. Morphology of large housing estates (LHE)

The morphological analysis of large housing estates (LHE) in the Czech Republic reveals significant variations in their design and layout, which have evolved over time. During the socialist era, LHEs were characterized by standardized, industrialized construction methods, resulting in uniform and often monotonous urban landscapes. However, the post-socialist period has witnessed diverse approaches to the transformation of these spaces, influenced by the privatization and changing urban policies. From the perspective of urban morphology, Czech residential areas can be classified into six basic types:

Rows: The development is characterized by simple, predominantly right-angled geometry and a sequence of repeating rows of houses arranged along guiding lines (Fig.1). The row structure represents the earliest form of breaking up the traditional closed urban block.

Figure 1. Mining estate Poruba, Ostrava; [6]

Classic examples of row settlements include Solidarity or the first phase of construction in Poruba – the so-called Emergency Miners' Settlement, which followed older pre-war examples (Břevnov, Zelená Liška) or international settlements like New Frankfurt or the Siemensstadt settlement in Berlin. This type of settlement later found application in a number of settlements of the so-called final phase of settlement construction, such as Pankrác, Krč, or Novodvorská in Prague, reflecting the evolution of urban planning approaches and adaptation to changing social demands over time.

Field: A characteristic feature of this system is the organization of tower buildings (Bohnice, Barrandov in Prague, Nový Pustkovec in Ostrava, or settlements in the central part) or lower point block buildings (Prosek, Ďáblice in Prague, or the Southern Slopes in Zlín) arranged in rows or grids (often in a chessboard layout), but in many cases organically without a clear leading geometry (Fig. 2). This type of construction is often applied as a complement to other structures, and only exceptionally can examples be found where it clearly dominates - for instance, Žabovřesky in Brno, or the settlement at J. Fajmonová Street, or Muglinov in Ostrava. As a complement to other structures, it has been implemented throughout the development of settlement construction since the early 1960s.

Figure 2. Žabovřesky estate, Brno; [6]

Pseudoblocks: Characteristic of pseudo-block development is the organization of building volumes that primarily exhibit formal similarity to the traditional urban block structure, i.e., development along the perimeter surrounded by urban blocks (Fig. 3).

Figure 3. Žabovřesky estate, Brno; [6]

Pseudo-block development appears in the Czech area mainly at the beginning of more systematic construction of settlements, specifically in their socialist-realist phase (Poruba, Ostrov nad Ohří, etc.) and simultaneously at the very end (postmodern phase: parts of Prague's Southwest City: Stodůlky, Velká Ohrada, Nový Barrandov, or the Ostrava Bělský Les 1 and 2, or the younger phase of Zlín's Southern Slopes), when this type emerged as a reaction to the appearance of settlements from the technocratic phase. The return to traditional urban typology, however, was not – given the construction method and prevailing building regulations – consistent, and this development often exhibits problems in the readability of spatial organization, where formal blocks do not correspond to the communication layout and type of defined spaces. The area inside the blocks often has the character of a public space, not a shared or at least semi-public space. This loses, or at least significantly weakens, the orienting polarity of space ("front-back").

Superblocks: The arrangement of this type of development is based on the composition of clearly visible and spatially separated units. A superblock may take the form of a block, but it is also created in other forms: for example, as a block close to a "spiral" (Lužiny) specifically arranged pair of slab houses (part of the Ďáblice housing estate) (Fig. 4). The basic defining factor is not necessarily the size of the "superblocks," but primarily the treatment of the block as a cohesive unit independent of the classic street network system. Characteristic of this type of housing estate is a clear spatial concept, which is a feature that housing environments often otherwise lack. However, this concept tends to be non-standard and, therefore, more difficult to grasp in terms of the conventional use. Despite its external resemblance to the usual block structure, this development is also significantly larger in scale than traditional blocks. Superblock arrangements are exhibited by some architecturally significant housing estates (Prague's Ďáblice, Lužiny, or parts of the Ostrava estates Nový Pustkovec, Fifejdy II, or Dubina). They are more often found in the peak phase of housing estate development designed in the 1960s.

Figure 4. Lužiny Estate, Prague; [6]

Free compositions: Typically, these are abstract mass compositions, mostly groups of slab (occasionally point) buildings of various proportions and arrangements (Fig. 5). From the perspective of the average pedestrian, they are just as difficult to decipher as the abstractly conceived, continuous public space of variable proportions without a more systematic hierarchy, which surrounds them. The communication framework often features a tree-like arrangement with dead ends, with significant routes usually moving entirely outside the structure. The majority of "free compositions" were created in two phases of housing estate construction. From an architectural-urbanistic perspective, these are innovative and valuable sets built as part of the peak phase of housing estate development, radically expanding the idea of development freely composed in a park like landscaped terrain (Brno's Lesná, Prague's Skalka, or the first phase of the Ostrava housing estate Fifejdy I.).

Figure 5. Housing estate Starý Lískovec, Brno; [6]

Large compositions: This concerns a grouping of house masses whose spatial organization is rigorously subordinated to the mass composition on the scale of a locality or even a district. The scale and clear geometry distinguish them from free compositions (Fig. 6). Such a district or locality is perceived as a kind of a spatial object. To this arrangement, more or less closely (it is difficult to find a precise boundary between "large" and "free composition"), a number of Czech housing estates primarily in larger cities, belonging to the late peak phase or the technocratic phase, approximate. The specific structure occurs in a variety of variations from the multiplication of simple corner shapes assembled exclusively from residential sections (Řepy) or repeating broken slab houses (Letiště III., Ostrava-Hrabůvka), through cross compositions involving civic amenities (Jižní Město), up to long folded continuous slabs (Nové Butovice).

Figure 6. Jižní mesto housing estate, Prague; [6]

2.2. General characteristics of housing, housing policy and urban planning

After 1989, Czechoslovakia shifted its focus to the privatization of LHEs and the creation of “condominium associations.” This process created ownership challenges, as there were individual, public, and commercial claims to the land. To revitalize the socialist landscape, ownership needed to be transparently transferred either to individuals or through partnerships, leading to fragmented cities [7].

In Czechoslovakia, the initial years of the transition period were focused on economic restructuring. Beginning in 1989, the country shifted from a centrally planned economy to a market-oriented economy based on private ownership, while also working to establish democracy and address previous irregularities. Although housing policy was centrally developed, both federations had authority over rent regulations within their territories. While some estates have benefited from regeneration and have become stable residential areas, others face the risk of social and physical degradation. The variation in the development of these estates is influenced by several factors, including the economic success of regions, the attractiveness of cities, and the quality of local governance [8].

By 2000, approximately 50% of new construction was carried out by private investors, as the state lacked the necessary funds for new projects and maintenance of the existing housing stock. This approach continued in both the Czech Republic and the Slovakia after their separation in 1993, with the privatization of housing taking a secondary role to broader economic reforms. The transition to a global market-oriented economy led to challenges in administrative capacity and management. During this period, housing privatization progressed slowly, with public assets being selectively sold while prioritizing the restitution of properties.

Following the separation in 1993, the Czech Republic introduced new reforms in housing policy, dividing it into three levels: central, regional, and local. Unlike the communist era, where the state was the primary builder of housing, the post-socialist period saw the state mainly setting regulations for new construction, with the responsibility for implementation shifting to lower levels of territorial and administrative governance [9].

After the socialist period, the high cost of housing and limited job opportunities led to increased migration to small towns and suburban areas, particularly around Prague and Brno. This trend continued until 2005 when a renewed wave of migration towards major cities began, driven by a resurgence in housing construction (Prague, for example, saw an increase of about 40%). The area around Prague experienced the most significant economic development, outpacing other regions in the country [10].

2.3. Transformations, changes and development strategies of inherited residential areas (LHEs)

In the post-socialist period in the Czech Republic, the process of privatization was also prominent, particularly with housing buildings that were divided into flats and subsequently became the private property of the families residing in them. The resident structure within these buildings was diverse, but much like in Slovakia, many did not view their living environments (LHEs) as their own space. As a result, the major changes that occurred were primarily on the buildings themselves rather than the broader communal areas. [11].

Following the fall of the socialist regime and the peaceful separation from Slovakia, numerous LHEs were present in all major cities across the Czech Republic. Unlike Slovakia, where new construction within existing LHEs ceased during the 1990s, the Czech Republic saw a different trend. The country embarked on the transformation of these LHEs, incorporating new infill construction within the existing estates. This transformation process was more pronounced in the Czech

Republic, where regeneration programs were introduced to address the functional, social, and spatial challenges of these estates.

During the 1990s, the Czech Republic witnessed significant changes in its urban landscape, particularly in areas surrounding LHEs [12]. New buildings emerged on the outskirts of these estates, often commercial in nature, and were typically located along main roads constructed post-1990s. Additionally, the Czech Republic experienced a wave of religious buildings construction within LHEs on previously unused land, a response to the restrictions on such constructions during the socialist era.

In the post-socialist period, the Czech Republic recognized the disadvantages associated with LHEs, and by the early 1990s, initiatives to improve the quality of these buildings were underway. Facades were renovated with new colors, flat roofs were replaced by attic areas, and safety in common areas was enhanced. Significant efforts were made to reduce energy consumption, with existing buildings being tested and improved through insulating facade panels and better window glazing. When it comes to spatial types of residential settlements, it is noticed that in historical settlements as well as in contemporary examples of compact urban development, the urban space is defined by sets (streets, squares, parks, etc.) [13], that not only guide this space but also organize the connected construction of buildings. Settlements differ from other urban construction systems precisely by the dominance of open space over defined spatial units with clear boundaries. The resulting organization of space and building volumes, as well as the degree of their mutual separation, nevertheless varies, and certain settlements or their parts often significantly differ in this regard.

Despite the higher prices of new housing developments, there was no significant outmigration from the inherited LHEs in the Czech Republic. This resulted in the maintenance of a heterogeneous social structure within these estates, which had a positive impact on the sense of community. Studies conducted in the 2000s revealed mixed perceptions among residents of LHEs in Czech cities. While there were improvements in the availability and diversity of shopping and commercial services, and some progress in basic services, concerns were raised about worsening security, deteriorating interrelations between residents, and declining environmental quality within these estates.

One of the key findings is the impact of privatization on public open spaces (POS) within LHEs. The shift from state to private ownership has led to a range of outcomes, from neglect and deterioration to innovative revitalization projects. For instance, many POS within older LHEs have suffered from the reduced maintenance and investment, leading to issues such as overgrown vegetation, damaged infrastructure, and reduced functionality. In contrast, some communities have successfully mobilized resources to improve and redevelop these spaces, as evidenced in the case of Na Dolika LHE.

3. TREATMENT OF POS IN MULTI STORY HOUSING AREAS IN POST-SOCIALIST PERIOD

This research delves into Public Open Spaces (POS) across two distinct arenas: post-privatized Local Housing Enterprises (LHEs) and the fresh wave of residential developments. By acknowledging the initial privatization effects on

LHEs and contrasting these with the planning approaches in new residential developments, this study aims to provide a comprehensive understanding of POS's role. Through this lens, the spatial cohesion and completeness of new housing developments, especially at the neighborhood or complex level, are scrutinized to offer insights into how public open spaces are integrated and valued in contemporary urban planning.

3.1. POS in inherited LHE

Following World War II, the Czech Republic, like many other Central and Eastern European countries, experienced significant changes under the socialist regime. These changes were particularly evident in the urban landscape, where large-scale housing estate (LHE) projects were constructed to address the acute housing shortage. This analysis explores the nature of these developments, with a particular focus on the construction, design, and functionality of these estates in the Czech Republic.

The design and construction of these estates were heavily influenced by the principles of functionalism, which emphasized efficiency, mass production, and the fulfillment of basic human needs. Buildings were constructed using prefabricated elements, which allowed for rapid assembly and uniformity across the estates [14].

This uniformity extended to the color scheme and architectural design, resulting in large blocks of identical, monotonous buildings. Between the residential blocks, vast areas of public open space (POS) were incorporated. These spaces were state-owned and intended for the use of all residents. The design of these POS areas reflected the socialist ideology, where the collective ownership and communal living were emphasized over individual property rights [15].

In the Czech Republic, these public spaces were designed to meet the needs of the residents, with a strong emphasis on providing functional, rather than aesthetic, amenities. Playgrounds, green areas, and sports facilities were common features, aimed at promoting social interaction and physical activity. However, the maintenance and development of these spaces often lagged behind, leading to their deterioration over time.

One of the key aspects of the LHEs in the Czech Republic was their connectivity to the rest of the city. The socialist government prioritized the integration of these estates into the broader urban infrastructure [16].

Roads and public transportation networks were designed to ensure that residents could easily commute to work, which was particularly important given the industrial nature of many cities in the Czech Republic. Public transportation, especially trams and buses, played a crucial role in connecting these estates with city centers and industrial zones. The design of the LHEs also included adequate parking facilities, although these were based on the standards of the time, which did not anticipate the rapid increase in car ownership that occurred in the post-socialist era.

In addition to vehicular connectivity, pedestrian areas were a significant consideration in the design of Czech LHEs. Wide sidewalks, pedestrian paths, and underpasses were common features, reflecting the socialist regime's concern for the everyday needs of its citizens. These pedestrian areas were designed to ensure that residents could easily access essential services, schools, and recreational areas without relying on motor vehicles. The emphasis on pedestrian-friendly infrastructure was aligned with the broader socialist objective of creating self-sufficient communities where residents could live, work, and socialize within the same estate. This approach aimed to minimize the need for travel and reduce the reliance on private vehicles, which were less common during the socialist period.

Green areas were a fundamental element of public open spaces in Czech housing estates, much like in other parts of Central and Eastern Europe. These spaces were designed to offer residents opportunities for recreation, relaxation, and social interaction. The emphasis on greenery was part of the broader socialist urban planning approach, which sought to balance the dense residential environment with open, accessible green spaces [17]. In LHE open green spaces became a significant component of residential areas, covering approximately 40-45% of the total area. These spaces were crucial for creating a favorable microclimate, maintaining good sanitary conditions, and providing a well-developed recreational environment tailored to the needs of various community groups. Additionally, they contributed to the creation of an expressive and diverse urban landscape. Green areas contribute significantly to social integration by offering shared experiences for community members. They also enhance physiological health by providing spaces for recreational activities and delivering environmental benefits [18].

Throughout the decades of construction, various types of green areas emerged within these estates. The diversity of these green spaces often depended on their location within the estate and the intended category of users. For example, Central Park in Jižní Město and other larger green spaces were accessible to all residents, while smaller, more intimate green areas were designed for specific blocks of buildings, serving primarily the residents of those adjacent units. This differentiation in green space usage led to the creation of inner block areas with a lower degree of publicity, fostering a more communal and semi-private atmosphere among the residents.

In the Czech Republic, as in other socialist countries, these green areas were predominantly publicly owned. The management of these spaces was typically the responsibility of state or municipal authorities, rather than the residents themselves. This public ownership model was in line with the socialist ideology of collective ownership and public welfare. However, the lack of resident involvement in the management of these spaces sometimes led to challenges in maintenance and the long-term sustainability of the green areas.

The diversity in character and quality in Czechia also reveals a different approach to the creation of public space, particularly in the context of various starting points for creation associated with the period in which the estates were developed. Post-war estates and the first "experimental" collections from the 1960s were created at a favorable distance from the center, in so-called urban gaps (Urban Composition of Southwest City in Prague, Ivo Oberstein). Today, we perceive them as a natural, distinctively different part of the city. There were no significant deformations of the competed designs during their realization. The quality design of the spatial structure, for example, Invalidovna (Fig.7), Malešice, Krč, Ďáblice, or Spořilov, ensured a relatively sensible organization of areas and thus suitable conditions for their maintenance and therefore long-term sustainability [19]. The modest scale of individual units helps with comprehensibility and orientation in public space.

Figure 7. Experimental housing estate Invalidovna [20]

Subsequent decades are linked with the construction of extensive complexes, which, due to their complexity, encountered many problems. A typical example is Jižní Město I, where due to a combination of various factors (lack of funds, limitations of standard and unavailability of atypical materials, insufficient coordination, political pressure from above - increasing capacities, etc.), there was a breakdown of original ideas and fundamental changes in the solution of the urban structure (including the non-completion of centers, etc.), which reflected both in the chaotic organization of public space and in the quality of detail, including the failure to implement most of the proposed landscaping and ground-level adjustments (Fig. 8). In the latter half of the 1980s, a bit more energy was devoted to the outdoor environment of housing estates.

Figure 8. Landscaping of the Central Park in Jižní Město [21]

On the other hand, some of the characteristics of public open spaces in Large Housing Estates for the Czech Republic can be reflected in the following:

- One of the most significant shifts in the post-socialist period has been the privatization of housing and changes in the ownership structures of the large housing estates. This process has had direct and indirect impacts on public open spaces, affecting their maintenance, management, and development. The shift from state-owned to privately owned spaces has sometimes led to neglect or underinvestment in these areas [22].

- Many public open spaces within large housing estates faced issues of deterioration and neglect in the early years of the post-socialist period. The withdrawal of state support and the unclear responsibilities between new owners, local governments, and residents often left these spaces in a state of disrepair [23].
- Recognizing the value of public open spaces for community well-being and social cohesion, there have been numerous efforts to revitalize and regenerate these areas. Projects have focused on upgrading playgrounds, landscaping, improving accessibility, and encouraging community engagement in the maintenance and design of these spaces [24]. Such an examples it can seen in Prague-Jižní Město and Brno.

In some cases, due to a lack of investment, maintenance, and clear ownership structures, POS suffered from neglect, leading to overgrown vegetation, damaged infrastructure, and limited functionality. The ongoing trend of privatization, continuing up to 2010, initiated a significant transformation in the ownership of public open spaces (POS) within large housing estates (LHEs). This shift in ownership led to numerous issues, particularly the neglect of these communal spaces. Originally under state ownership, the public spaces between multi-story buildings were transferred to various city governments and administrative bodies. This transition resulted in a complex ownership structure, and even today, some POS within LHEs lack a clear ownership status. The change in ownership also brought about a shift in how these areas were managed, with a growing emphasis on individualism. As a result, POS began to be used more as transit zones rather than shared community spaces. This change in usage, coupled with challenges in management and maintenance, led to the deterioration and "loss" of these public areas. Despite proposals for the regeneration of certain parts of these estates, issues related to ownership and the absence of proper planning documents have slowed down or even halted the regeneration process entirely [25].

In other instances, parts of the POS in Czech Republic were privatized and converted into parking spaces, commercial buildings, or individual gardens, reducing the overall area and hindering public access. In post-socialist period the transformation of the street network within LHEs has also impacted POS. In some cases, car traffic has been prioritized, leading to wider roads and more parking spaces, often at the expense of green areas and pedestrian pathways. When discussing the reasons for the transformation of POS within Large Housing Estates (LHE) in the post-socialist context, it is essential to consider the intricate layers of socio-economic, political, and environmental shifts that have occurred during the transition from centralized planning to market-oriented economies. This transition has fundamentally altered the urban landscape, particularly in terms of how public spaces are perceived, valued, and developed. The move towards a market economy has been a cornerstone of the post-socialist transformation, profoundly affecting urban development strategies, including the management and redesign of POS.

3.2 Opportunities and Challenges for LHE POS (re) development

When considering the current planning treatment of POS, it can be viewed through multifunctionality. POS are increasingly seen as multi-functional spaces that can cater to diverse needs, including recreation, social interaction, environmental sustainability, and promotion of physical and mental health. Collaborative planning approaches engage residents in decision-making and design processes, ensuring that POS meet their needs and preferences. Utilizing principles of sustainable design and incorporating green infrastructure can create POS that are both aesthetically pleasing and environmentally friendly,

The current planning approach in Czech offers several chances:

- Enhanced quality of life for residents through improved access to functional and aesthetically pleasing public spaces.
- Fostering a sense of community and promoting social cohesion.
- Contributing to a more sustainable urban environment through green infrastructure and improved pedestrian and cycling connectivity.

The 2000s saw the introduction of the first state-level policies for urban renewal in Czechia, primarily aimed at enhancing buildings' technical standards and energy efficiency, along with the improvement of public areas. In Czechia, initiatives such as the Program PANEL, which offered bank guarantees for loans and expert technical support starting in 2001, the Green Light for Savings Program, providing subsidies for thermal insulation and heating systems powered by renewable energy from 2009, and a program dedicated to the revitalization of panel housing estates, with subsidies for the refurbishment of public spaces and technical facilities beginning in 2001, were launched early in the decade [26].

However, limitations also exist:

- Securing sufficient funding for comprehensive regeneration projects can be challenging.
- Navigating complex ownership structures and bureaucratic obstacles can hinder the pace of improvements.
- Ensuring long-term maintenance and sustainability of revitalized POS requires ongoing commitment from residents, authorities, and stakeholders.

3.3 POS redevelopment in practice - Case of Na Dolka LHE

While the demographic composition of residents in post-socialist housing estates remains diverse, past humanization efforts largely concentrated on rectifying technical defects and enhancing urban-architectural aspects, as discussed by (Lux, 2005). These initiatives can be categorized into three primary focus areas: 1. The redesign of individual flats; 2. The refurbishment of apartment buildings; 3. The rejuvenation of communal spaces. These targeted areas represent a concerted attempt to address the multifaceted challenges facing housing estates, striving for a balanced improvement in both the living conditions and the aesthetic appeal of these communities.

Points one and two can be discerned through an examination of the diverse beneficial practices that have been implemented in the Czech Republic. The Czech government has taken steps to address the regeneration needs of panel housing by implementing a series of initiatives, including the provision of direct subsidies. These financial aids are primarily aimed at improving the structural and technical aspects of the buildings. However, a portion of these subsidies is also allocated for the enhancement of communal spaces within the estates. This approach indicates a comprehensive effort to not only upgrade the physical condition of the housing units but also to enrich the quality of life for residents by revitalizing shared public areas.

Subsidy programs for improving housing conditions in the Czech Republic vary in focus, including direct and indirect subsidies. Direct subsidies involve government funding for specific projects, while indirect subsidies create favorable conditions, for example, by reducing interest rates for loans. Other sources of funding include the European Union's Structural Funds. The most common program is the Regeneration of Panel Housing Estates, aimed at transforming monofunctional estates into multifunctional complexes, targeting municipalities with estates of at least 150 flats. Other notable programs focus on urgent repairs, modernization, energy demand reduction, and revitalization of public areas and apartment houses in problematic estates, some of them are: the Programme of Financial Support for the Repairs of Defects in Panel Buildings (1998-2005), The Czech initiatives from 2002 to 2020, encompassing the Panel Programme, Green Savings Programme, and European Structural Funds Programs, were strategically designed for the refurbishment and energy optimization of housing, along with the revitalization of community spaces in dated estates. This approach reflects a concerted effort to boost the sustainability and quality of life within these residential areas. A key transformation within housing estates has been the enrichment of civic amenities, notably shops and services. This development has transitioned the previously singularly residential blocks into multifunctional complexes, significantly uplifting the residents' quality of life, as identified by Herfert [27].

Point three will be illustrated by the case study. Over recent years, Na Dolíká estate has seen numerous enhancements. The makeover of the children's playground (Fig.9), the ball game area for teenagers, and the bin enclosures, along with adjustments to the traffic flow and an increase in parking space capacity, have sequentially revitalized the area.

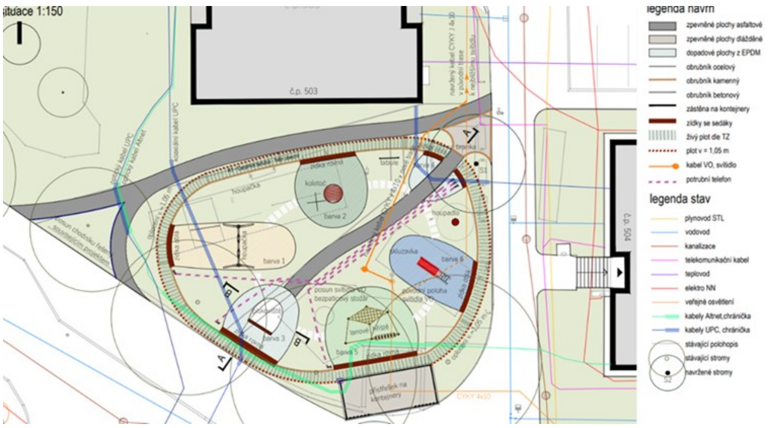

Figure 9. Revitalization of children's court [28]

The introduction of the "Piazzetta" marks a pivotal end to these upgrades, serving as a vibrant hub for the community. Initially aimed at reinstating the area's central role in social and residential life, these efforts have emphasized creating an inviting space for residents from various backgrounds. This project aimed to uplift the social, urban, economic, architectural, and technical aspects of this public space and has been successful in doing so. The inclusion of a relaxation zone with water features, a stone trough with sluice gates leading to a fountain, and enhancements to the garden including new plantings and a lawn, have all contributed to the revitalization of this estate, breathing new life into the community space (Fig.10).

Figure 10. Revitalization of the new public open space [29]

The Na Dolika LHE serves as a notable example of successful POS revitalization. The project involved the redesign of public areas to better meet the needs of residents, including the creation of multifunctional spaces that support social interaction, recreation, and environmental sustainability. Key factors contributing to the success of this project included strong community involvement, effective collaboration between local authorities and residents.

The challenges identified in the maintenance and redevelopment of POS reflect broader issues faced by post-socialist cities. These include the legacy of centralized planning, the fragmentation of ownership, and the socio-economic disparities that have emerged during the transition to a market economy. However, the opportunities for innovation and improvement are equally significant, particularly in the context of evolving urban planning paradigms that emphasize sustainability and inclusivity.

4. CONCLUSION

The morphological analysis of large housing estates (LHE) in the Czech Republic has provided important insights into the transformation of these spaces during the post-socialist period. The research has shown that different morphological types, including rows, pseudo-blocks, super-blocks, free-standing, and large compositions, present specific challenges and opportunities for the revitalization of public open spaces (POS). Therefore, it is crucial to consider the morphology that originated during the socialist era, as this form has persisted into the post-socialist period as a significant legacy. Understanding this continuity is essential for effectively addressing the challenges and opportunities involved in the transformation and revitalization of these spaces today.

The findings of this study contribute to a deeper understanding of the post-socialist transformation of public open spaces (POS) within large housing estates (LHE). The morphological changes observed in the Czech Republic's LHEs highlight the complex interplay between privatization, urban policy, and community engagement in shaping the urban environment. The success of POS revitalization projects, such as the one in Na Dolika, underscores the importance of a holistic approach that integrates newly designed, community participation, and supportive policy frameworks. This study has explored dynamics of public open space (POS) redevelopment within large housing estates (LHE) in the post-socialist Czech Republic. Through a detailed case study of the Na Dolika LHE, the research has highlighted both the challenges and opportunities inherent in the transformation of POS during the post-socialist transition. Key findings include the significant impact of privatization on the maintenance and quality of POS, as well as the critical role of community engagement and new design in successful revitalization efforts.

The regeneration efforts within post-socialist housing estates in the Czech Republic have been marked by a multifaceted approach aimed at addressing both the physical and social challenges inherent in these environments. While the demographic composition of residents remains diverse, past humanization initiatives have primarily focused on three key areas: the redesign of individual flats, the refurbishment of apartment buildings, and the rejuvenation of communal spaces. These targeted interventions reflect a broader strategy to not only rectify technical defects but also to enhance the urban and architectural quality of these estates, thereby improving the overall living conditions.

The Czech government's proactive measures, including the provision of direct and indirect subsidies, have played a pivotal role in this transformation. Programs such as the Regeneration of Panel Housing Estates and the Green Savings Programme have been instrumental in converting monofunctional housing blocks into multifunctional complexes, equipped with improved civic amenities and services, that was discussed at the beginning of Section 3. These initiatives, supported by European Union Structural Funds, underscore a comprehensive effort to upgrade the structural integrity of housing units while simultaneously enriching communal areas, which are vital for fostering community well-being.

A fundamental general deficiency of housing estates is primarily the sectoral approach to planning, which, as was desirable, separated all aspects of the design from each other and addressed them piecemeal. As a result, instead of an integrated whole with a characteristic image, there is a conglomerate of necessary operational infrastructures: access and approach to the apartment units had to be ensured, they had to be connected to networks of technical infrastructure, and the provision of services and shops within walking distance had to be supplemented. The atypical nature of the urban complexes of housing estates led to atypical solutions for ensuring their operational capability. Public spaces, often significantly undervalued, were usually the victim of these problematic circumstances. Andráško [30] underscore the necessity of viewing the dynamics of housing estates and their residents' quality of life from a holistic perspective, acknowledging the intricate web of social and physical dimensions that define these spaces. The administration of these estates thus becomes paramount, with local government bearing significant responsibility. Equally important is ensuring that residents have a voice in the decisions that shape their living spaces, as their engagement is crucial for the success of any revitalization effort. The depth of resident involvement often mirrors their satisfaction with the transformations, tying closely to their sense of community identity. This correlation between participation and positive outcomes in housing estate humanization has been confirmed through various studies in post-socialist settings, illustrating the positive impact of active resident involvement on their connection to and satisfaction with their living environment.

The implications of this research extend beyond the Czech Republic, offering valuable insights for urban planners and policymakers in other post-socialist countries. The lessons learned from successful POS revitalization projects can inform strategies for improving the quality of life in large housing estates, enhancing social cohesion, and promoting environmental sustainability. Future research should continue to explore the dynamics of POS in post-socialist contexts, with a focus on identifying best practices and scalable solutions.

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ANALYSIS OF SURFACE DEFORMATIONS DURING EXCAVATION OF A SMALL OVERBURDEN TUNNEL IN WEAK ROCK MASSES

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Abstract

Excavation of tunnels with a small overburden inevitably implies surface settlements, especially when they are carried out in soft soil or weak rock masses. Subsidence becomes a critical aspect when the construction of tunnels is realized in narrower urban areas, directly below occupied residential buildings. Taking as an example the Kobilja Glava tunnel, which will represent part of the main project connecting Vogošća with Sarajevo and at the same time the connection of the narrowest city center of Sarajevo with the A1 motorway on the Vc corridor, surface deformations were monitored during the excavation and installation of the primary support of the left tunnel tube. Special attention was dedicated to excavation from the entrance side on a certain section of the tunnel where the height of the overburden was less than 2D. During the excavation of the left tunnel tube of the Kobilja Glava tunnel, which was carried out from the entrance portal at chainage km 3+543,202 in the direction of Vogošće, multiple surface settlements were measured from the very entrance to the place where the excavation was stopped (chainage km 3+615,56) compared to the predicted values obtained by assessment. The main reason for stopping the further progress of the excavation of the left tunnel tube from the chainage km 3+615.56 lies in the fact that the direction of the geological layers coincided with the direction of the progress of the excavation, which had a significant negative impact on the movement of the soil itself, and therefore on the increase surface deformations. After a comprehensive analysis of the above, as well as consideration of optional possibilities, it was decided to approach the excavation of the left tunnel tube from another attack point, i.e. to start the excavation from cross passage No. 1 in the direction towards the entrance. In this way, it was possible that the direction of the geological layers under these cirrcustamces positively contributes to the reduction of surface subsidence caused by the progress of the tunnel excavation by over 50%.

Key words: *Tunnel, Excavation, Deformation, Overburden, Settlement, Weak rock*

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1. INTRODUCTION

The rapid development of urban areas in recent decades contributes to the increasing need to use underground space [1]. Tunnels are considered an efficient choice for overcoming congestion problems and reducing traffic pressure. Tunnels are often built in urban areas, where a small overburden is not uncommon, which further increases the complexity of the construction itself [2].

During the construction of tunnels in urban areas, soil deformations on the surface cannot be ignored under any circumstances, because they inevitably lead to damage to a large number of infrastructure and residential buildings, which implies significant material and financial damage, and ultimately can lead to the loss of human life. In other words, the construction of tunnels in urban areas is many times more complex than in areas where there are no infrastructure buildings [3]. Choosing a suitable procedure for the excavation of a long-span tunnel in soft soil is a key factor for its successful construction [4].

The height of the overburden represents the height from the upper edge of the primary support to the elevation of the terrain and is most often marked with H. The classification of the tunnel in terms of the thickness of this layer is closely related to the diameter (D) of the tunnel. If we are talking about a tunnel with a small (low) overburden, the New Austrian Tunnel Method (NATM) defines those tunnels where the limit value is given by the expression H=2D, so this represents a generally accepted approach in construction practice. Excavation of tunnels where the height of the overburden is less than 2D represents a special challenge and requires special attention, including the selection and application of different technologies, based on previous experiences [2].

Surface deformations caused by tunneling primarily depend on: the properties of the soil or rock mass through which the tunnel is constructed, the geometry of the tunnel, as well as the method of excavation and application of the primary support [5, 6]. Taking the Kobilja Glava tunnel, which will be part of the main project connecting Vogošće with Sarajevo and at the same time the connection of the narrowest city center of the city of Sarajevo with the A1 motorway on the Vc corridor, surface deformations were monitored during the excavation and installation of the primary support the left tunnel tube from the entrance side on a certain section of the tunnel where the height of the overburden was less than 2D.

The Kobilja Glava tunnel is a two-tube tunnel that passes through the hill of the same name, on which there are approximately 500 residential buildings. The total length of the right tunnel tube is 635.10 m, of which 587.10 m is the length of the underground excavation. The temporary entrance portal of the right tunnel tube is located at chainage 3+550.15, while the temporary exit portal is located at chainage 4+137.15 (chainage along the axis of the right tunnel tube).

The total length of the left tunnel tube is 638,885 m, while the excavation length is 590,885 m. The temporary entrance portal of the left tunnel tube is located at chainage 3+546,952, while the temporary exit portal is located at chainage 4+128,09 (chainage along the axis of the left tunnel tube). The position of the tunnel is presented in Figure 1.

Due to the large longitudinal slope in the tunnel, the Main Project defined two cross passages between the left and right tunnel tubes. The designed method for construction is the New Austrian Tunneling Method [7].

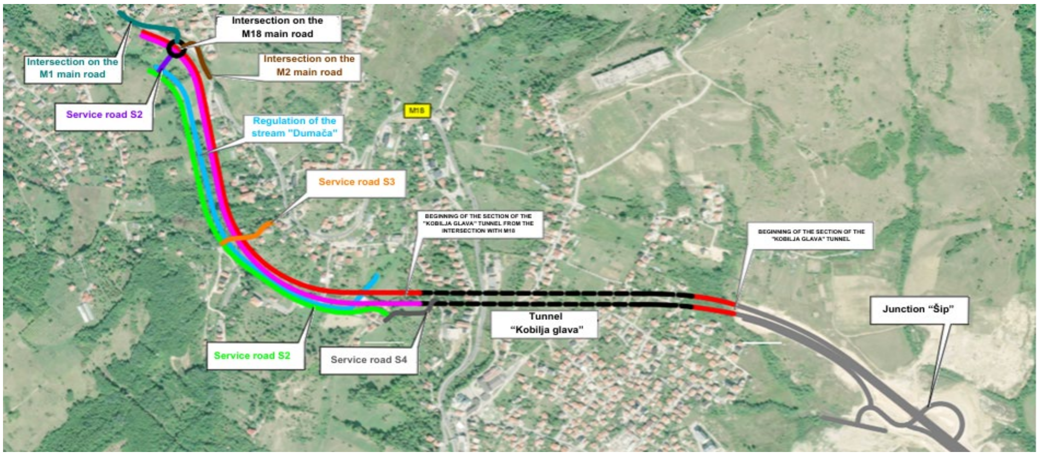

Figure 1. Geographical location of the Kobilja Glava tunnel on the route of the Sarajevo-Vogošća road

Most theoretical studies on the excavation of small overburden tunnels have focused on excavation in urban areas using tunnel boring machines (TBM). However, when excavating shorter tunnels, the application of TBM is still significantly more expensive than excavation with standard NATM, which is why this method is used in practice.

The greatest risk of excavation in weak rock masses with small overburden is associated with large surface deformations, because the consequences can sometimes be very dangerous (Figure 2), even catastrophic, causing human casualties [8].

London (2002.) München (1994.)

Figure 2. Consequences of large ground settlements during tunnel excavation in urban areas [8]

2. WORKING METHODOLOGY

For a successful analysis of surface deformations when excavating a small overburden tunnel in weak rock masses, it is necessary to study carefully all the parameters of the environment in which the construction of the tunnel is planned, which can affect the total height of the surface settlements, and take them into account when assessing the settlement and defining the excavation methodology.

2.1. Engineering-geological characteristics of the rock mass in the "Kobilja Glava" tunnel excavation zone

The geological basis of the wider area of the "Kobilja Glava" tunnel is built by clasts of the Neogene, i.e. Upper Miocene and Quaternary formations (Q) represented by eluvial-deluvial sediments. As part of the Miocene complex, that is, the so-called the Koševo series of geological substrate consists mainly of marls, marly clays, siltstones, weakly bound clayey sandstones, gravels, weakly bound conglomerates and very rarely carbonaceous clays with thin carbonaceous interlayers. Miocene clasts have pelitic-psamitic structures and thin-layered to laminated texture.

As a whole, the rock complex of the geological base of the terrain is "covered" with a Quaternary eluvial-deluvial cover. The eluvial-deluvial cover is isolated on the slope part of the terrain. The structure of this cover includes yellow-brown clays, difficult to putty with the presence of small particles of different diameters.

In the surface zone, there are humus-dusty-sandy clays with the presence of dark brown organic matter. Excavation of the left tunnel tube from the entrance portal of the "Kobilja Glava" tunnel was completely carried out within upper Miocene clastites, i.e. within marl and fine-grained sandstones. During the engineering geological mapping of the initial step of the left tunnel tube, two zones were distinguished that differ in lithological composition, physical-mechanical characteristics and color.

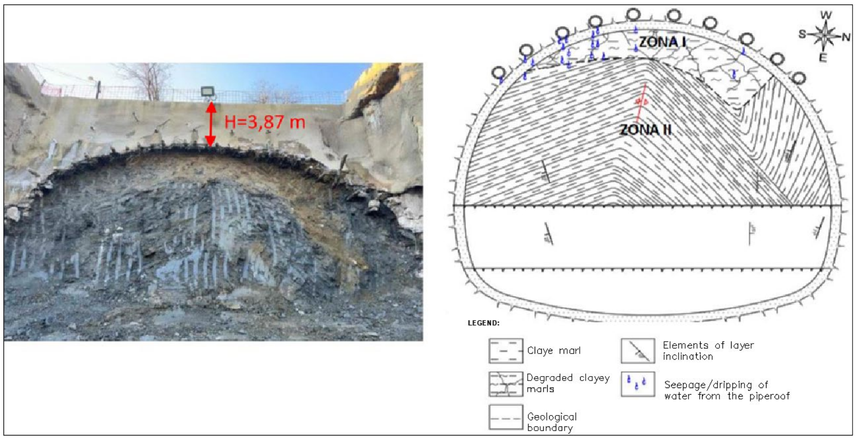

Figure 3. Geological mapping of the initial step of excavation of the left tunnel tube – km. 3+546.20

In the lithological zone I, which was positioned in the upper part of the top heading, there were marly clays with a transition to clayey marl and degraded yellow-brown clayey marls. The feature of the mentioned lithological complex within zone I is the vertical and lateral alternation of the mentioned lithological members without any regularity. The lithological structure of zone II was represented by clayey marls - gray marls. The mentioned materials are characterized by highly variable and uneven physical-mechanical properties that are very prone to change under the influence of tunneling works. Figure 3 shows the appearance of the open face with geological characteristics at the very beginning of the left tunnel tube excavation from the entrance side.

Dip amount of layers measured at the temporary entrance portal of the left tunnel tube were 160/220 (left wing of the anticline); 357/510 (right wing of the anticline) and 195/710 (fall elements in the right side of the top heading).

Regarding the above, a wide range of measured values of the spatial orientation of the layering is visible, which is a consequence of the tectonic activity of a plicative character. Therefore, by measuring the spatial orientation of the deposit, it was established that there was a slanted asymmetrical anticline at the head of the temporary entrance portal of the left tube.

On the analyzed section during the excavation of the tunnel, more or less uniform engineering-geological conditions were established, which can be seen on the longitudinal geological profile, Figure 4.

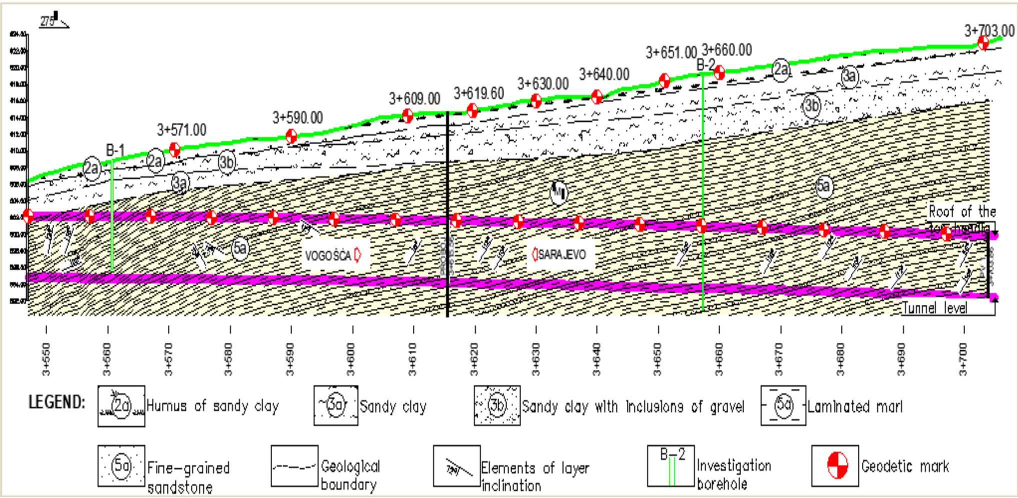

Figure 4. Longitudinal geological profile from the entrance into the left tunnel tube to the first cross passage

2.2. Methods of predicting surface deformations

In the past period, many studies have been dedicated to better predicting the response of the soil to stress changes resulting from the construction of tunnels and defining demanding solutions for these problems [9]. Due to the nature of the tunnel excavation process, the excavated shape of the tunnel will always be larger than the designed shape resulting in a real series of displacements towards the cavity.

This phenomenon is described by the term "soil loss" or, more commonly used, "volume loss" (Peck, 1969). Peck (1969) defines surface settlement as radial in the direction of the cross-section and longitudinal deformation on the axis of the tunnel (Figure 5).

These two settlements proved difficult to separate, and therefore, estimates of volume loss were determined by considering plane strain. In other words, tunneling is a three-dimensional problem. For purposes of analysis, some studies have split this into two, two-dimensional problems (Figure 5). These are transverse settlements (plane x-z, which is called the stress plane) and longitudinal settlements (plane y-z).

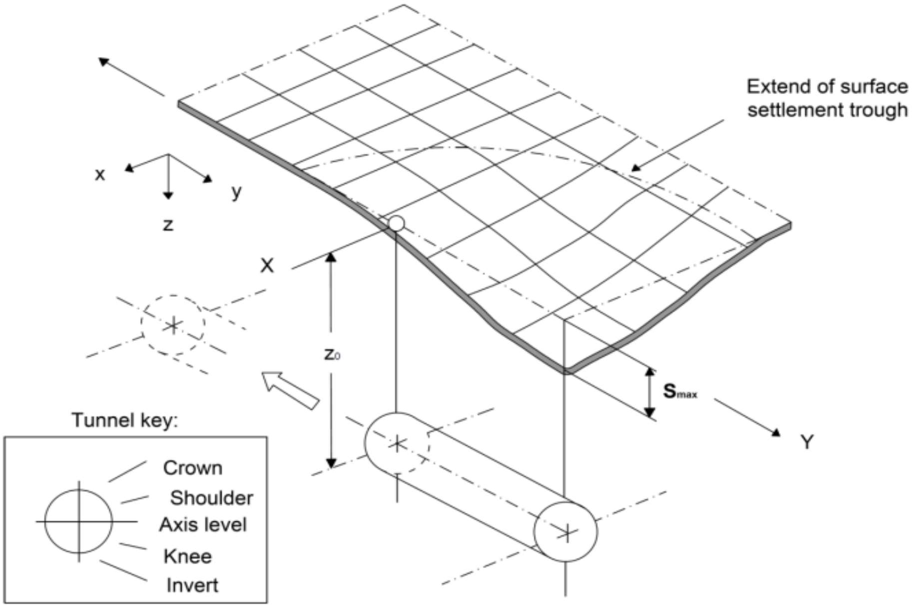

Figure 5. Settlement above the advancing tunnel direction [10]

There are various methodologies for accurate prediction and management of maximum surface settlement, including empirical, analytical, numerical and artificial intelligence methods [11].

Traditional approaches often rely on empirical or analytical equations, which are developed through engineering experience and theoretical assumptions. Empirical methods for estimating surface settlement caused by tunneling are generally consistent with engineering practice and measured field data. They provide a rough estimate of soil settlement with permissible precision. In other words, empirical methods are proposed simple mathematical equations based on measurements collected in the field. These formulas can be used to approximately determine the surface subsidence and calculate the ground displacement at any point in a certain area. The first form of surface settlement above the underground tunnel construction was analyzed by Martos (1958) [3]. Morts suggested that a normal distribution curve can well represent the shape of the surface settlement as shown in Figure 5. Peck (1969) extended the research and showed that the Gaussian curve is suitable for fitting tunneling-induced ground settlement. He analyzed settlement data from many tunnels as well as mining projects and found that the settlement curve was roughly symmetrical above the tunnel's vertical axis. A semi-empirical approach is adopted to calculate soil deformation based on Eq:

$$S_V = S_{max} \exp\left(-\frac{x^2}{2i^2}\right) \tag{1}$$

Where:

- S_v - settlement value,
- S_{max} - theoretical maximum settlement on the center line of the tunnel,
- x - lateral distance from the center line of the tunnel,

- i - lateral distance from the center line of the tunnel to the point of inflection in the Gaussian distribution curve.

Empirical formulas in predicting tunneling-induced surface settlement can still be used for preliminary estimation [12]. However, in a more complex situation, it is suggested to perform a finite element analysis and soil structure interaction study [13]. Numerical simulations such as the finite element method (FEM) and the finite difference method (FDM) provide a more sophisticated approach. These simulation techniques can be adapted to a wide range of soil parameters and capture the complex interaction between soil layers and tunnel walls.

Tunnel construction is three-dimensional in nature and time-dependent. Compared with 3D analysis, the application of 2D simulation can simplify the constitutive model and save calculation time. However, 2D analysis requires that the effect of 3D tunneling as a result of volume loss be taken into account [14].

Numerical methods are widely used in geotechnical engineering. It is a theoretically more realistic and rigorous method for estimating surface subsidence [15].

With the possibility of considering various relevant parameters, such as nonlinear soil behavior, soil heterogeneity, groundwater level, and soil-tunnel interaction, the numerical method has proven to be an effective approach to tunnel analysis. However, the numerical method has been criticized for its effectiveness because the simulation models are time-consuming and sensitive to boundary conditions [16].

The accuracy of numerical methods depends on the grid size and the choice of failure criteria model. In addition, the excavation process is difficult to simulate, and the results obtained sometimes differ from those obtained by field measurement [17].

2.3. Excavation of the left tunnel tube from the entrance in the low overburden zone

Before the start of the excavation of the left tunnel tube, the right tunnel tube was excavated with an embedded primary support over 300 meters, and based on the measurement of total deformations in the right tunnel tube, its stability was confirmed, which established that the right tunnel tube could not affect the excavation of the left tunnel tube.

On the basis of all available data collected by geodetic monitoring of movement during the excavation of the right tunnel tube and the results of geological mapping of the frontal slope, the following supporting measures were proposed for the start of the excavation of the left tunnel tube on the entrance side of the Kobilja Glava tunnel [18], namely:

1) Step of excavation 0,5 m;
2) Anchors IBO R51-630 (Ø51mm), 530 kN in following distrubition:
    a) top heading l=6,0m 6/4;
    b) bench l=6,0m 4/6;
3) Thickness of shotcrete layer (C25/30) is 5 cm for excavation face;
4) One layer of the wire mesh of type Q257 for excavation face (if necessary);
5) Protection of the excavation face with 8 pieces of IBO anchors (Ø32mm) l=12.0 m and lap length of 4m, 250 kN.

6) The thickness of the shotcrete in the top heading, bench and primary invert (C25/30) is 30 cm;
7) Two layer of the wire mesh of type Q257;
8) Lattice girder PS 95/20/30;
9) The thickness of the shotcrete (C25/30) for the primary invert in the top heading is 25 cm;
10) Two layer of the wire mesh of type Q257 for the primary invert;
11) For the protection of the excavation face installation of one row of steel pipes (Ø114mm, L=12,0m, e=40cm, with 4,0 m overlap, 29 pieces).
12) Installation of the elephant's foot at the connection of the top heading and the bench for the first 8 meters of the excavation, and further installation will be defined as necessary.

In order to reduce deformations of the surrounding material and the primary support, the following technological sequences must be respected (Figure 6):

- The maximum distance between the top heading and primary invert is 2 m ;
- The maximum distance between the top heading and bench is 10 m;
- The maximum distance between the bench and primary invert is 4 m.

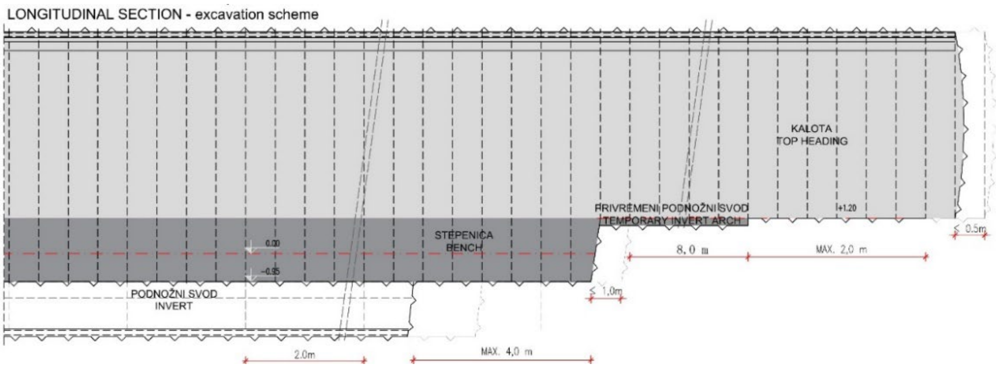

Figure 6. Longitudinal section - excavation scheme

Before the start of the excavation, a profile was installed to monitor the settlement on the surface above the left tunnel tube at distances of approx. 10 m (Figure 7). Three marks were installed on each profile (one along the axis of the tunnel, and the other two at a distance of 10 m from the axis, left and right).

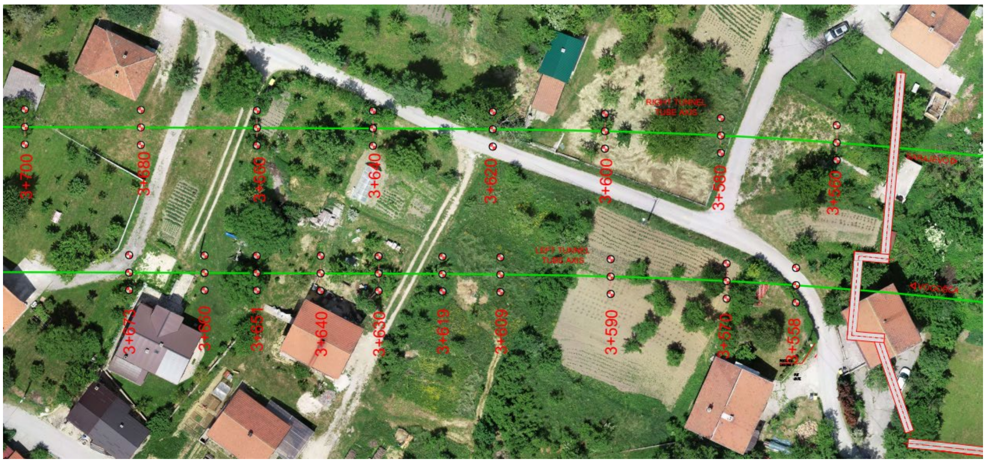

Figure 7. Arrangement of geodetic marks on the surface above the left tunnel tube

Excavation of the left tunnel tube on the entrance side starts from km: 3+543,202 where the height of the overburden was 3.87 m (Figure 3). During the excavation and installation of the primary support, there were no deviations in observing the technological sequences prescribed by the geotechnical mission (Figure 6).

During the excavation, geodetic measurements (observation) of deformations on the surface and in the tunnel were carried out daily. On the entrance side, the excavation was stopped at km: 3+615.56 due to the appearance of large deformations on the surface of the ground above the excavated part of the tunnel, which exceeded the forecasted values several times.

The main reason for stopping the excavation is reflected in the appearance of inevitable deformations on the surface of the ground in front of the excavation face, which can cause damage to residential buildings located at km: 3+630.00 and km 3+660.00. In order to reduce the impact of the tunnel on the surface of the field, it was proposed to excavate out the left tunnel tube from the cross passage number one towards the entrance to the km. 3+615.56 (Figure 8).

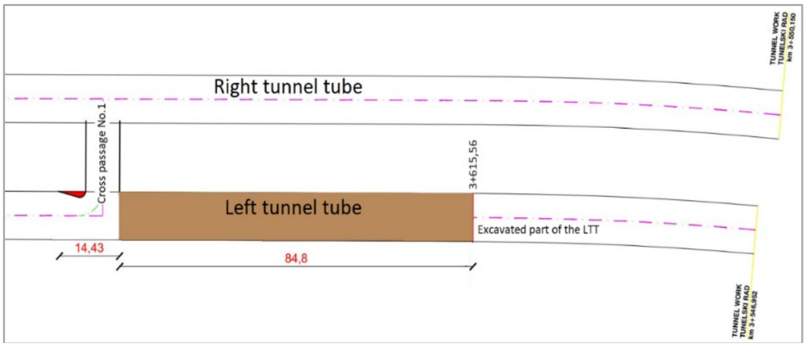

Figure 8. Situation view of the excavation of the left tunnel tube from the cross passage no. 1 to km. 3+615,56

Excavation of the left tunnel tube was carried out technologically after the excavation of cross passage no. 1 and the creation of a curve towards the exit while maintaining the same (smaller) profile as in cross passage no. 1. After reaching the full excavation profile of the left tunnel tube, the excavation was stopped towards the exit.

Given that a technological curve was made when entering the left tube from cross passage no. 1, the curve was reprofiled and the excavation of the left tunnel tube from cross passage no. 1 to km. 3+516.56 (Figure 8) in the length of 84.80 m. During the excavation, geodetic measurements and observation of deformations on the surface above the excavation were carried out daily.

3. THE RESULTS

Before the start of the excavation, an assessment of the surface settlement above the axis of the left tunnel tube was made for the given geological conditions and assumed support elements using the finite element method in the PLAXIS program (2D analysis that takes into account the 3D effects of tunnel excavation) [18]. The obtained results showed that maximum displacements on the surface above the axis of the left tunnel pipe are expected up to 3.2 cm (Figure 9).

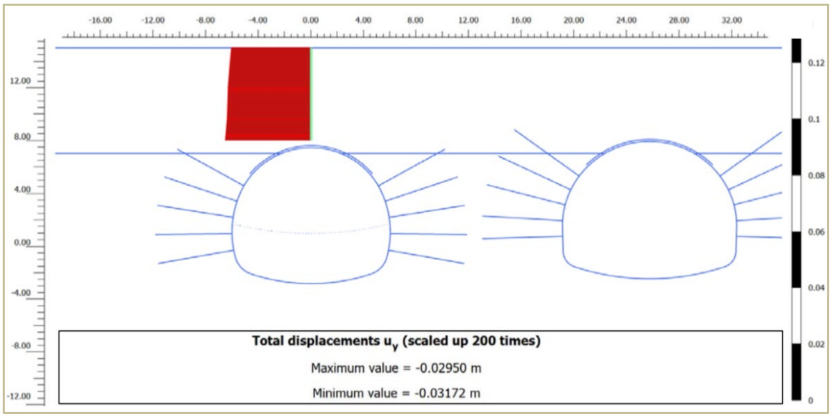

Figure 9. Presentation of the results of the settlement assessment expected above the left tunnel tube from the entrance, using the program PLAXIS [18]

Optical methods were used to observe daily surface settlements during the excavation of the left tunnel tube from the entrance to the stop of the excavation (chainage km: 3+615.56), as well as during the excavation from cross passage no. 1 to the chainage km: 3+615.56. Table 1 shows the total surface settlement recorded by geodetic measurement above the excavated part of the left tunnel tube from the beginning of excavation on the entrance side to the moment when excavation was stopped (chainage 3+615,56).

Table 1. Results of measurement of total surface settlements above the excavated part of the left tunnel tube from the entrance to the km: 3+619,00

Chainage	Tunnel axis (mm)	Overburden height (m)
3+558,00	210,00	6,33
3+570,00	212,00	7,88
3+590,00	207,00	9,80
3+609,00	174,00	12,55
3+619,00	30,00	13,07

Table 2 shows the total surface setllements recorded by geodetic measurement above the excavated part of the left tunnel tube from the cross passage to the previously excavated part (chainage 3+615,56).

Table 2. Results of measurement of total surface settlements during the excavation of the left tunnel tube from the cross passage to km.3+615.56 in the low overburden zone

Chainage	Tunnel axis (mm)	Overburden height (m)
3+673,00	50,00	20,07
3+660,00	55,00	18,46
3+651,00	58,00	17,28
3+640,00	60,00	15,23
3+630,00	62,00	14,62
3+619,00	70,00	13,07

The total settlement of the surface above the left tunnel tube at chainage 3+619.00 is 100.00 mm, of which the recorded settlement of 30.0 mm occurred during the excavation from the entrance to the chainage 3+615.56 and the difference of 70.00 mm is the settlement during excavation from the cross passage to the connection point.

4. DISCUSSION

During the construction of the tunnel, the natural state of stress in rock mass in which the tunnel is being constructed is disturbed, which leads to potential settlements of the surface. Therefore, an appropriate assessment of the surface settlement above shallow tunnels is of great importance in the design of the tunnel, regarding all the essential parameters of the rock mass through which the tunnel is planned to be constructed.

The estimation of settlement that was performed using the finite element method (Figure 9) is many times smaller compared to the values measured on the surface above the left tunnel tube. Multiple measured displacements of surface settlement from the entrance to the stop of excavation at the chainage km: 3+615.56 compared to forecast values is the result of relaxation caused by tunnel excavation. The direction of the longitudinal movements occurring in front of the tunnel excavation face coincides with the direction of the terrain, Figure 10.

At the same time, the layer of water-permeable cover on which the structures are located rests on a layer of impermeable substrate - marl, which creates a suitable environment for the occurrence of sliding, as a result of which the settlements in front of the front were measured and over 50% of the total settlements at individual chainages, Figure 11.

Due to the coincidence of the direction of movement and the terrain, there was an increase in the influence of the excavation of the left tunnel tube on the surface deformations from the entrance to the stop of the excavation at the chainage km: 3+615.56. Changing the direction of the excavation of the left tunnel tube from the entrance side, and continuing the excavation from the cross passage no. 1 towards the entrance, canceled the influence of the deformation that occurs on the surface of the ground because the direction of longitudinal movements (longitudinal) is opposite to the extension of the ground. In this way, multiple surface settlements were reduced (Table 2), which are inevitable on the surface of the terrain due to tunnel excavation in the low overburden zones.

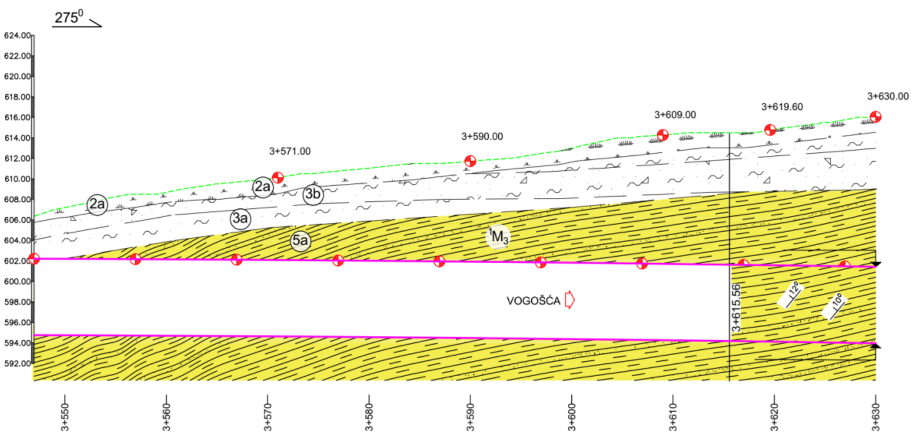

Figure 10. Longitudinal geological profile from the entrance to the stop of excavation on the entrance side

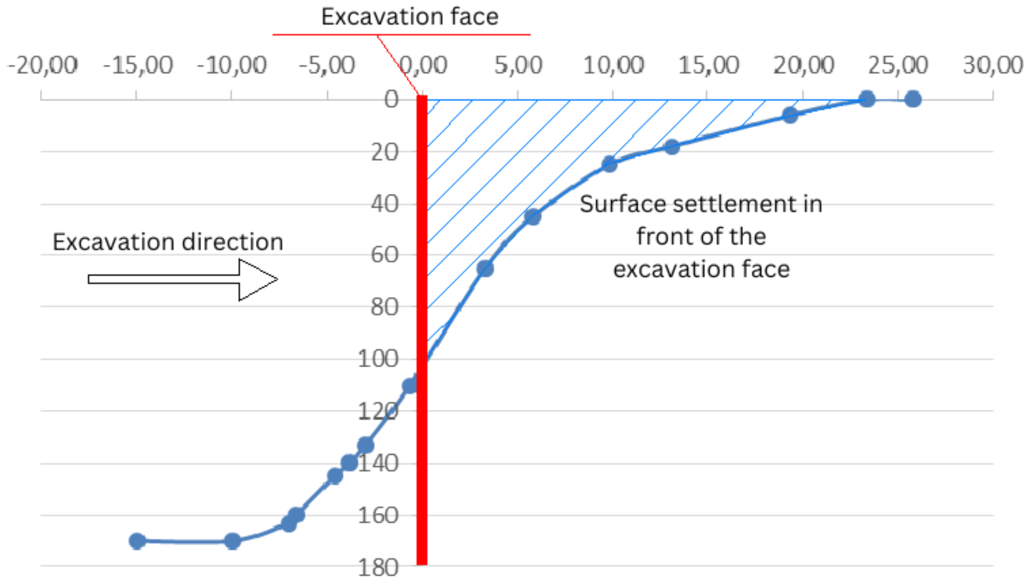

Figure 11. Results of measurement of total settlements on the surface, chainage km: 3+609,00

5. CONCLUSION

In narrower urban areas where significant construction works have been carried out during the construction of infrastructure and residential buildings, the soil is usually characterized by extremely variable and uneven physical and mechanical properties that are a direct consequence of the execution of these works, as well as natural factors with unfavorable physical and mechanical characteristics.

Anyone who carries out underground constructions is faced with solving a particularly complex problem, because compared to above-ground constructions, it is extremely difficult to determine in advance the basic design data for underground works, which is why the appropriate assessment of surface settlements above shallow tunnels is of great importance when designing each underground excavation.

The need for accurate assessment of surface settlements caused by tunnel excavation and potential damage to structures on the surface has led to increased interest in research into this problem.

However, when assessing soil settlement, it is not always easy to take into account all the necessary parameters that can significantly affect the total settlement on the surface above the tunnel excavation. The behavior of the soil when tunneling in incoherent or multi-layered soil is still a big unknown.

Therefore, when choosing an excavation method, care must be taken to ensure that the selected methods ensure a safe working environment and minimal surface settlements that will be in function of the geological and geotechnical properties of the rock mass, cross-section of the tunnel and applied excavation technologies.

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SOME DEEP FREEZE STORAGE HEAT TRANSFER PROBLEMS

Aleksandar Rajčić[1]

Abstract

The paper discusses the specific problems that occur with deep freeze storages, from the aspect of building physics. A special review is given of the phenomenon of soil stability, i.e. soil bearing capacity, in the context of soil freezing, deformations of the floor structure, and functional disorders in the interior of deep freeze stores.

A case from practice was presented, in which serious problems occurred in the process of exploitation, which led to the fact that the existing floor structure with all layers had to be completely demolished, a new one constructed with newly designed layers, as well as to improve the connection with existing facade construction.

An analysis of the causes and a proposal for a solution for that building are presented. The focus of the work is on the design concept of the relevant wall and floor structures, the calculation of the temperature in the ground under the building, considering conditions of operation that are specific and include a very low interior temperature of -27°C, a low winter design temperature of the external air -15°C, with an emphasis on the necessity of application of an adequate heat system of under-slab structure. The paper provides recommendations that engineers can use in similar cases.

Key words: *Deep freeze storage, Heat transfer, Soil freezing, Under slab heating*

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1. INTRODUCTION

Building physics of high-rise buildings is an area that we apply in our daily work and which is regulated by domestic and foreign regulations. It can be said that there are no major unknowns, because the projects are such that they mostly resemble each other:

- In winter, there is a need to heat the interior, because the internal design air temperature is higher than the external design air temperature;
- In summer, the situation is reversed, and it is necessary to cool the interior, because the external design air temperature is higher than the internal design air temperature.

However, with buildings that have different needs in terms of maintaining the interior temperature, things become more complicated.

In deep freeze storages it is necessary to maintain a constant temperature both in the winter and in the summer, which must not depend on fluctuations in the outside temperature.

The internal design temperatures in the deep freeze storages depend on the technological process, that is, the level of freezing that should be achieved on the product (material) stored in the interior. The lower the temperature that needs to be achieved and maintained, the greater the temperature difference that HVAC systems need to compensate for, and the building's thermal envelope needs to overcome.

Deep freeze storages/warehouses are buildings that are not studied in architecture studies (in Belgrade), and this text aims to publish some experiences from practice, in order to help designers in overcoming perceived problems.

2. METHODOLOGY

This paper discusses an existing deep freeze storage, relatively recently constructed, which operates in deep freezing mode at Ti= -27°C. Building is constantly lying on the ground. The location is flat, with pronounced gusts of wind and the external design temperature in winter is Te= -15°C.

In the interior, racks were designed and built for storing goods. The racks can be moved electrically via a rail system built into the floor structure.

2.1. Problem

During operation, it was observed that the racks could not be moved, because the floor structure had been deformed in certain areas of the building (the floor is no longer completely horizontal), therefore the rail system for movement was deformed.

The investigation revealed that there are multiple reasons for this:

- There was a significant penetration of atmospheric water from the roof, whose flooding of the underfloor and foundation structure was not planned;
- The heaters in the floor structure had an unexpectedly long interruption in operation;
- The architectural-construction details of the connection between the floor and wall structures in the foundation area are not designed and executed well enough.

These problems resulted in the freezing of the ground in critical zones, which consequently led to the expansion (lifting) of the floor structure due to the force created by the action of the ice.

What is quite specific for buildings of this type is the need to keep the soil temperature above the freezing point, despite the influence of the external air temperature (which is -15°C), and especially the influence of the design temperature in the interior (which is -27°C).

Therefore, the boundary conditions for the design of the structure, i.e. architectural construction details, are very unusual.

The conditions of structural stability cannot be met without the additional heating energy of the layers that are oriented towards the ground, in order to reduce the effect of cooling that takes place in the interior, as well as in the exterior.

In this sense, the system for heating the subfloor structure must be designed and implemented in order to achieve the desired energy balance between cooling and heating. In the existing state, the pipe distribution of floor heating was carried out, with projected temperatures of the heating fluid ranging from +12°C to +30°C. A problem of discontinuity in the operation of that system was observed, due to a failure, and since there was no backup system, the period of time in which the system did not function contributed to the freezing of the ground under parts of the floor structure, which led to the deformation of the structure.

2.2. The task

The task of reconstruction in relation to the observed problems consisted of the following:

- To solve the problem of draining atmospheric water, so that it does not flood the subfloor and foundation structure;
- Design the heating system of the subfloor structure so that there is a backup system. Change the system, so that instead of pipe distribution and heating fluid, electric heaters are provided. The potential price difference was not a consideration in the decision-making process, as the existing fluid distribution pipeline proved unreliable;
- Design the architectural construction details of the joint of the floor and wall structures in such a way that calculations from the aspect of building physics prove that considering the defined conditions of use, the ground does not freeze in the area under the building.

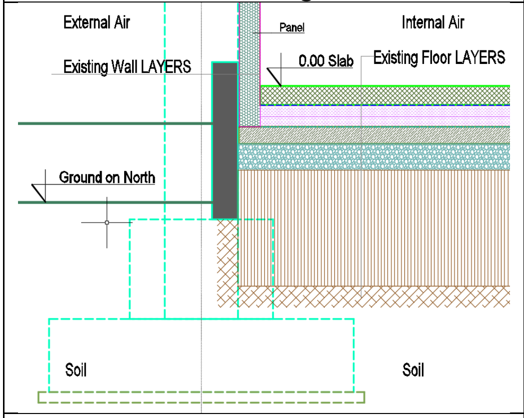
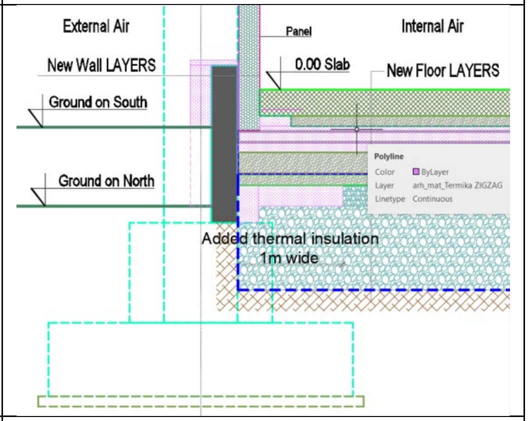
2.3 Architectural detail – concept

Existing structure and designed structure for intervention are shown in the following table.

Considering problems on the site, it was decided to demolish the complete floor and subfloor structures, including RFC slab, all layers, up to soil, and to form a completely new floor structure.

Regading the adequte wall structure (insulated industrial panels), the focus was on the RFC foundation component (plinth wall), which was not insulated at all, and to add some thermal insulation on the external face of this position, which has a contact with the external air.

Table 1 – Architectural details of floor-wall connection (existing and intervention)

Existing	**Intervention**
	
Floor layers:	Floor layers:
Top / RFC slab Hydroinsulation Thermal insulation, XPS 20cm Foil Concrete / heat system Aggregate, 1 layer Soil	Top / RFC slab, acocording calculation Concrete, anchors Foil Thermal insulation, XPS 25cm Concrete / heat system Hydroinsulation Concrete Aggregate, 2 layers Soil
Wall layers:	Wall layers:
Inside Panel (industrial, 20cm) RFC (foundation wall/beam) Outside	Inside Panel (industrial, 20cm) RFC (foundation wall/beam) Added facade thermal insulation, 20cm External covering

The assumption was that it is necessary to add a layer of perimeter thermal insulation in a width of 1m under the first concrete slab, in a contact with the RFC construction of the plinth wall (an element of the foundation construction).

3. RESULTS AND DISCUSSION

The following general parameters applies in the calculations:

- Design temperatures in the deep freeze Ti= -27°C
- External design temperature Te= -15°C
- The thermal conductivity of the material is in accordance with the data from the Rulebook on Energy Efficiency of Buildings [6].
- Heating of the floor slab is planned with electric heaters, which are placed with distance of 40 cm. The external temperature of the heater is adopted at +20°C.

The goal of this analysis is to establish what the temperatures are at the control nodes, which are at intervals of 1 m in the base and 1 m vertically. They cover the depth from the ground level to 4m below the ground level. Basically, they are arranged from the foundation wall, up to 2m into the building field.

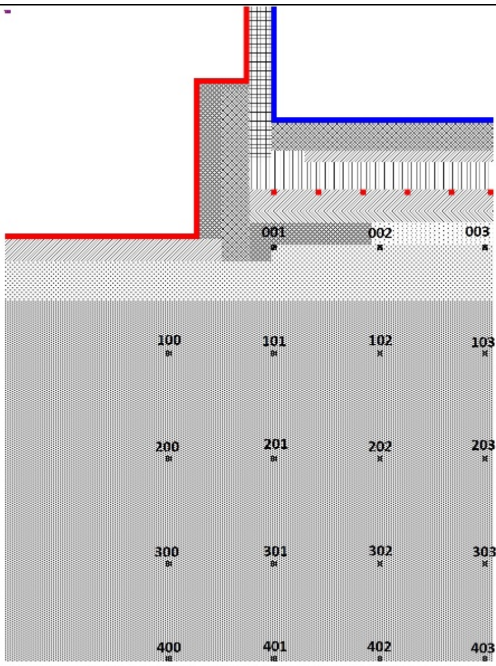
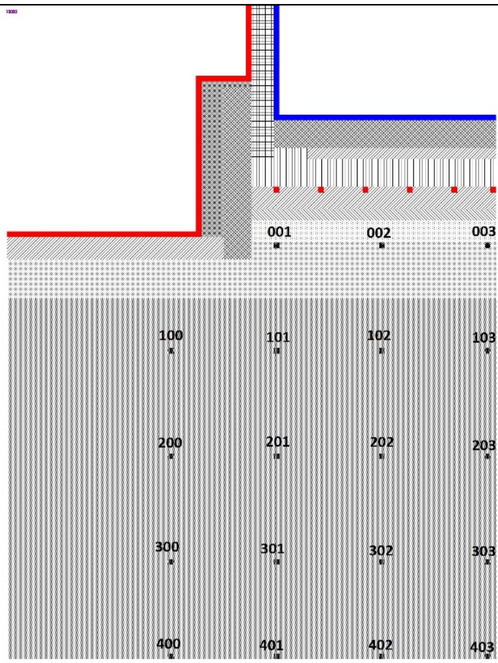
With added under slab perimeter insulation – detail D1	Without added under slab perimeter insulation – detail D2
	

Figure 1 – Illustration [2] of 2D model of intervention, source: Author

Ideally, the analyzed temperatures below the contour of the object should be positive, in order to reduce the risk of freezing and consequent destruction.

The following details were analyzed:

- D1, detail with higher plinth and perimeter insulation under the slab;
- D2, detail with a higher plinth without perimeter insulation under the slab.

The calculation was carried out in accordance with EN ISO 10211-1 [5], using T-Studio software [7].

Graphic illustration of temperature fields, and numeric results of temperatures in soil nodes are shown in Figure 2 and Table 2 (for Detail D1), and in Figure 3 and Table 3 (for Detail D2).

[2] External air is given with the red line, and internal air is given with the blue line, and those colors does not correspond with the following temperature scale graduation.

Table 2 – Calculated temperatures in the nodes in the soil for detail D1

D1, Te = -15°C (very low temperature of external air in winter)							
Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]
		001	1.2	002	9.0	003	11.1
100	-5.8	101	-0.7	102	3.8	103	5.7
200	-3.7	201	-1.0	202	1.4	203	2.4
300	-2.7	301	-1.1	302	0.3	303	1.0
400	-2.5	401	-1.1	402	0	403	0.6

D1 Temperature field

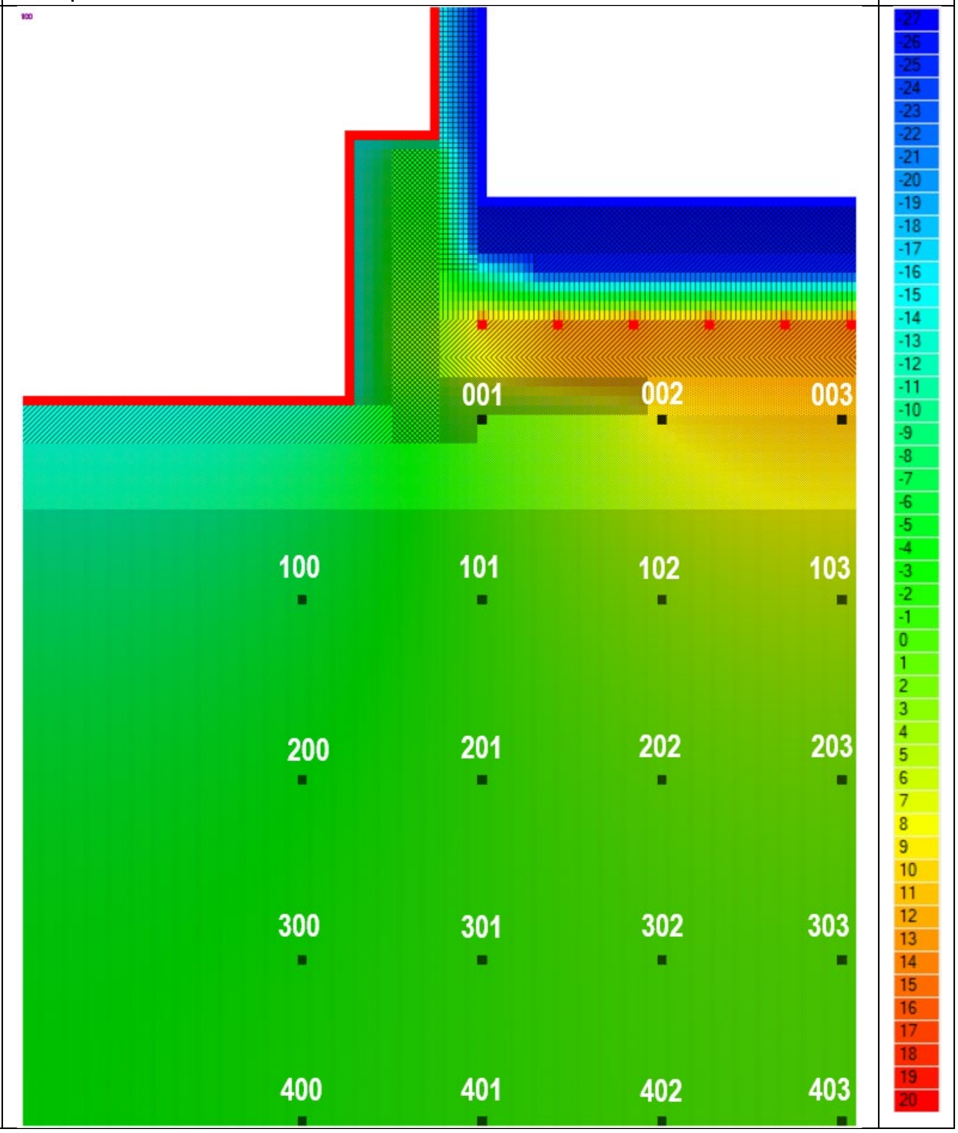


Figure 2 – Illustration of the temperature field for detail D1, source: Author

Table 3 - Calculated temperatures in the nodes in the soil for detail D2

D2, Te = -15°C (very low temperature of external air in winter)							
Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]
		001	3.7	002	9.7	003	11.4
100	-5.1	101	0.6	102	4.9	103	6.3
200	-3.1	201	-0.3	202	2.0	203	3.0
300	-2.3	301	-0.7	302	0.8	303	1.4
400	-2.1	401	-0.7	402	0.5	403	1.0

D2	Temperature field

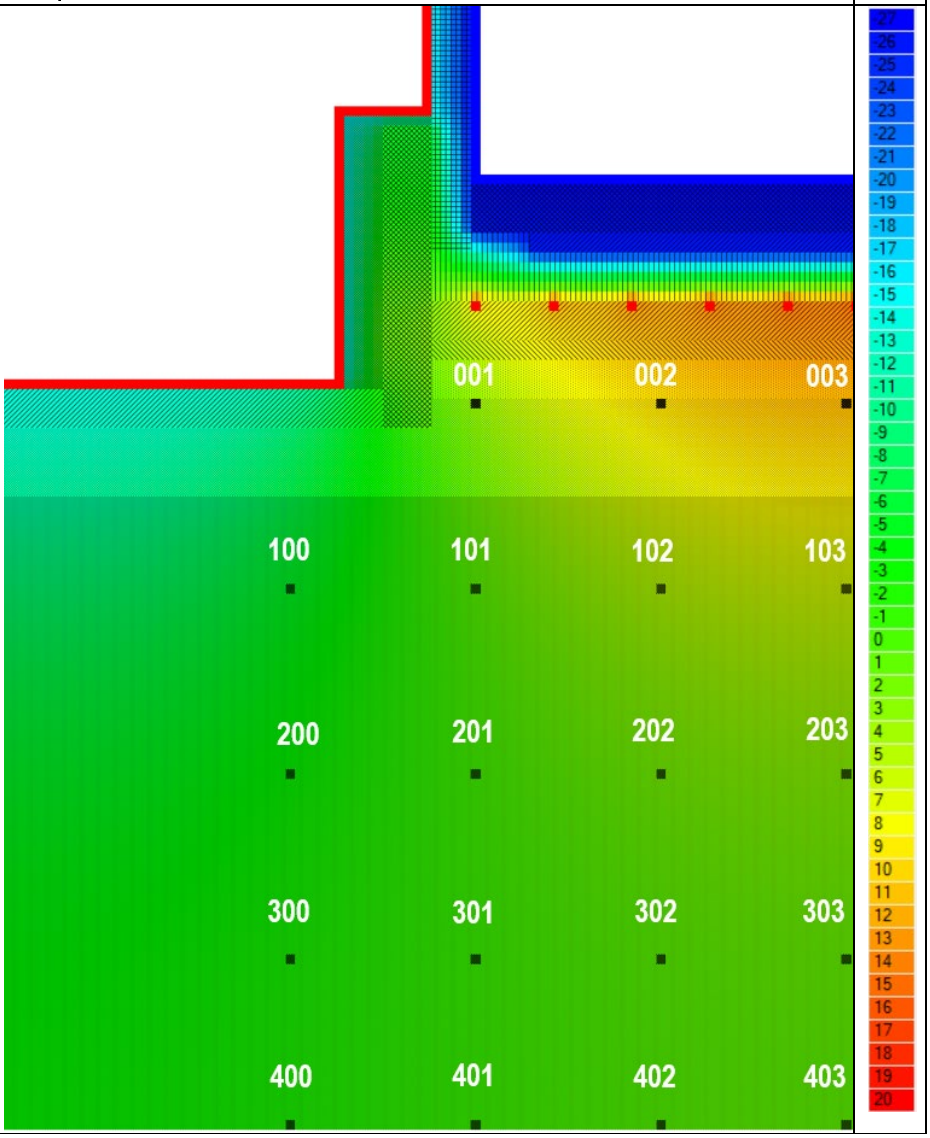


Figure 3 - Illustration of the temperature field for detail D2, source: Author

Variations

Several variations for external air temperatures were conducted, in order to calculate temperatures in relevant nodes in the soil. In the Figure 4, an illustrations of temperature fields are shown, for the temperatures of -10°C, -5°C, and 0°C, and in Table 4, results of temperatures in the soil nodes are presented, all for details D1 and D2.

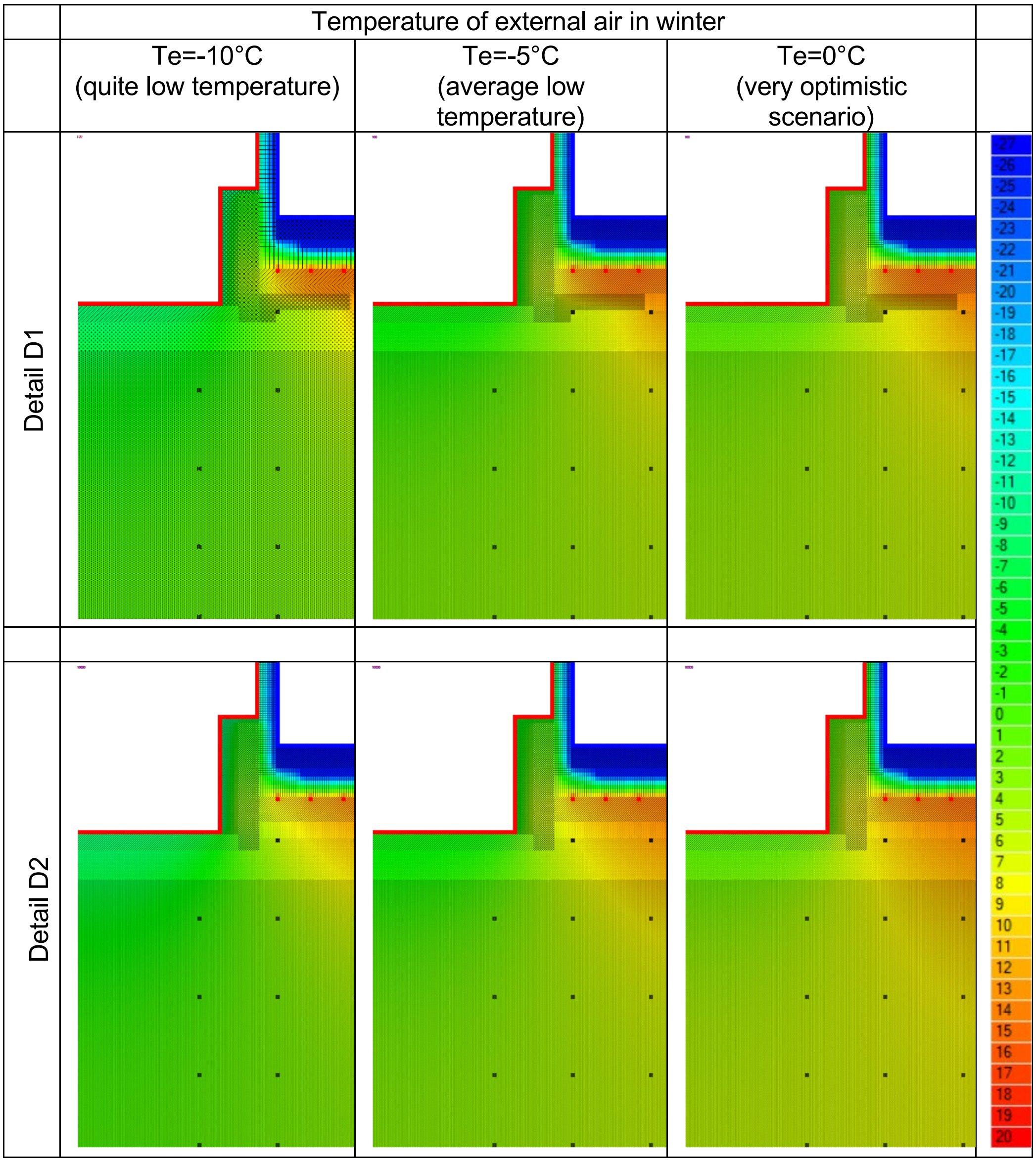


Figure 4 - Ilustration of temperature fields for variated external air tempertures, source: Author

Table 4 - Calculated temperatures in the nodes in the soil for varied exter. temperatures

Detail	Air temper. Te [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]	Node	Temp [°C]
Detail D1	**-10°C** (quite low air temperature in winter)			001	4.0	002	10.6	003	12.4
		100	-2.0	101	2.5	102	6.3	103	7.9
		200	0.1	201	2.4	202	4.4	203	5.3
		300	1.1	301	2.5	302	3.7	303	4.2
		400	1.3	401	2.5	402	3.5	403	3.9
	-5°C (average air temperature in winter)			001	6.1	002	11.5	003	13.1
		100	1.2	101	4.7	102	7.8	103	9.2
		200	2.6	201	4.4	202	6.1	203	6.8
		300	3.2	301	4.3	302	5.3	303	5.7
		400	3.4	401	4.3	402	5.1	403	5.5
	0°C (very optimistic scenario)			001	7.9	002	12.3	003	13.6
		100	3.9	101	6.5	102	8.9	103	10.0
		200	4.5	201	5.8	202	7.1	203	7.6
		300	4.6	301	5.4	302	6.2	303	6.5
		400	4.6	401	5.3	402	5.9	403	6.2
Detail D2	**-10°C** (quite low air temperature in winter)			001	5.8	002	10.9	003	12.4
		100	-1.6	101	3.3	102	6.9	103	8.1
		200	0.1	201	2.5	202	4.5	203	5.3
		300	0.8	301	2.2	302	3.5	303	4.0
		400	1.0	401	2.2	402	3.2	403	3.6
	-5°C (average air temperature in winter)			001	7.8	002	12.1	003	13.4
		100	1.8	101	5.8	102	8.7	103	9.8
		200	3.2	201	5.1	202	6.8	203	7.4
		300	3.7	301	4.9	302	5.9	303	6.3
		400	3.8	401	4.8	402	5.6	403	6.0
	0°C (very optimistic scenario)			001	9.8	002	13.2	003	14.2
		100	4.9	101	8.0	102	10.3	103	11.1
		200	5.7	201	7.2	202	8.5	203	9.0
		300	6.0	301	6.9	302	7.7	303	8.0
		400	6.0	401	6.8	402	7.4	403	7.7

From the previous shown data, it can be concluded, that in all analyzed cases, the temperature in the soil nodes is above 0°C, so there is no risk of soil freezing. Note that the temperatures which are below 0°C is in nodes which are outside building boundary. In practice, it can be expected that the real results relate to external air temperature between -10°C and -5°C.

4. CONCLUSION:

General conclusions:

- It is necessary to design continuous layers of thermal insulation in the floor construction, above the layer where the heaters are located. The required thickness of this thermal insulation is significantly greater than the thicknesses used in buildings with other, common functions, so a thickness of over 20cm is recommended (in this project it is 25cm). In this case, XPS

(eXtruded PolyStyrene) was used, because of its low thermal conductivity (λ=0.035 W/mK), resistance to moisture as well to mechanical pressure (compressive strength for 10% compressibility ≥700 kPa and permissible compressive load for 2% compressibility ≥250 kPa;
- The plinth on the facade, which is not covered with a thermal panel, must be thermally insulated in order to reduce the thermal bridge (in this project 20 cm XPS is used).

Particular conclusions:
- Comparison of the results between the analyzed details D1 and D2 (with or without added perimeter thermal insulation under the slab) indicates a very small difference. It is observed that the temperature values of the soil in the zone (nodes) directly under the slab (nodes 101, 102 and 103) are more favorable with detail D2 (without added perimeter insulation under the slab). This can be explained by the fact that the heat flow from the downward direction of the heater does not encounter the thermal resistance that the edge insulation does. In this sense, it can be concluded that the added perimeter insulation can be omitted. In the analyzed details D1 and D2, there are few negative temperatures in the soil nodes, only in the area that coincide with the inner line of the facade (101, 201, 301, 401), as well as at all nodes on the outside of the facade line (100, 200, 300, 400);
- The temperature of the nodes immediately below the floor structure (points 001, 002 and 003) is positive in all cases;
- In reality, the external design temperature Te= -15°C occurs in an interval of only a few days (usually in mid of January), so for a wider time frame of observation, and taking into account the thermal inertia of the soil, all relevant results should be positive;
- All the mentioned results may vary in relation to the calculated values of soil characteristics (natural soil, replaced soil, embankment, etc.).

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THE COST-BENEFIT ANALYSIS OF WASTEWATER TREATMENT PLANT DISPOSITION - THE MUNICIPALITY OF PIROT CASE STUDY

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Abstract

Because of the significance of the river Nišava for the city, the Municipality of Pirot has adopted a water protection concept for the city of Pirot and several smaller settlements located upstream along the Nišava River (Krupac, Veliko Selo, Veliki Jovanovac, Mali Jovanovac, Trnjana, Izvor). The wastewater treatment would be done either at the central wastewater treatment plant (WWTP) Pirot or at several decentralized treatment facilities, despite the settlements being smaller than 2000 population equivalent (PE). Three variants were considered for the analysis of water protection in the Municipality of Pirot: the first variant involves the treatment of wastewater from the city of Pirot and all the considered settlements at the central WWTP Pirot; the second variant involves the treatment of wastewater from the city of Pirot and suburban settlements at the central WWTP Pirot, and upstream settlements at the WWTP Krupac; the third variant involves the treatment of wastewater from the city of Pirot and suburban settlements at the central WWTP of Pirot, and the other settlements at their respective decentralized WWTPs. The aim of this paper is to determine the most economically viable solution by applying a cost-benefit analysis, using criteria related to wastewater treatment and water pollution prevention. The paper applied the basic steps of economic cost-benefit analysis, concluding that the third alternative solution with a centralized WWTP Pirot and three decentralized WWTPs is the most cost-effective and ensures the project sustainability, which is crucial for achieving long-term development goals.

Key words: Cost-benefit analysis, Water protection, Wastewater treatment plants

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1. INTRODUCTION

Europe has witnessed growing levels of water stress, both in terms of scarcity and the deterioration of quality. This situation has prompted many municipalities to identify more efficient uses of water resources [1]. The Water Framework Directive (WFD) assigns significance to economic analysis to achieve suitable water resource management [1].

The Urban Waste Water Treatment Directive 91/271/EEC states that all generated wastewater agglomerations of between 2000 and 10000 population equivalent (PE) must set up collection and treatment systems. Therefore, one of the main challenges for European authorities for the achievement of good ecological status of water bodies is to implement the appropriate treatment of wastewater in small agglomerations [2].

In addition, the EU Commission has concluded that additional sensitive areas and their related catchments should be designated. This fact entails the need of upgrading the treatment applied for a significant number of discharges and the development of new facilities in the near future. In this context, it is crucial to find out the most feasible technologies from an integrative point of view to tackle with new wastewater management projects, depending on each specific scenario [2].

The construction of wastewater treatment plants (WWTP) is an economic activity which demands considerable resources (costs) in order to achieve an increase in services in a certain time period, with the end goal of meeting population needs and environmental protection requirements (benefits) [3].

Considering that financial resources are limited, and that use of resources for one project depletes resources for other projects, a concept of wastewater treatment should be chosen so that it brings the biggest benefits compared to the costs [3]. This is why all social benefits as well as all involved costs expected out of a certain project should be systematically researched [3].

The most often used method for assessing the profitability of an investment in a project of public significance, as well as the method required by the EU legislation, is the cost-benefit analysis [4].

Cost-benefit analysis is a method of economic analysis which compares and assesses all advantages and disadvantages of an economic endeavor or project through the evaluation of the involved costs and benefits [2, 5, 6]. This analysis is used not only for investment projects which bring a direct commercial effect which can be measured and quantitively represented, but, most importantly, for projects with significant indirect and immeasurable effects [7].

Based on the results of the analysis it is possible to rank projects or investment alternatives. The project or the investment alternative which when realized is expected to bring the greatest financial profitability and social justification is the most favorable for the investor and should be chosen [8].

Cost-benefit analysis is an analytical approach to decision making, which demands definition of goals and identification of alternatives which bring the biggest benefit for given costs or the required benefit with the least costs [8].

This paper shows a cost-benefit analysis of three variant solutions for wastewater collection and treatment in several settlements upstream of the city of Pirot, by the banks of the river Nišava (Krupac, Veliko Selo, Veliki Jovanovac, Mali Jovanovac, Trnjana, Izvor) and the choice of the alternative which is expected to bring the greatest financial and social feasibility when implemented, as well as be the most cost-effective for the investor.

2. STUDY AREA

The Municipality of Pirot is located in southeastern Serbia, in the Pirot Basin. It is the administrative center of the Pirot district, and with an area of 1232 km2 is the third largest municipality in Serbia. The city of Pirot is the center of the Pirot Municipality as well as the industrial, economic, cultural and administrative center of the Upper Ponišavlje region.

In accordance with the Urban Waste Water Treatment Directive 91/271/EEC, it is necessary to establish the collection and secondary treatment of urban wastewater for all settlements bigger than 2000 PE, which include only the city of Pirot and the suburban area Gnjilan.

The city of Pirot, along with the suburban areas of Novi Zavoj, Gradašnica, Berilovac, Gnjilan, Barje Ćiflik and Poljska Ržana already have a built sewer system for collection of urban wastewaters of the city and suburban areas. However, sewage is discharged without treatment into the river Nišava downstream of the city. In order to comply with the requirements of the Directive 91/271/EEC it is necessary to build a centralized WWTP for the city of Pirot, for the treatment of urban wastewater collected from the city and suburban areas connected to the existing sewer system. According to the Directive 91/271/EEC collection and treatment of wastewater of other settlements in the Municipality of Pirot is not necessary [8].

Because of the significance the river Nišava has for the city, the Municipality of Pirot has adopted a water protection concept according to which the wastewater collection and treatment would be done for several smaller settlements upstream of the city of Pirot, along the banks of the river Nišava (Krupac, Veliko Selo, Veliki Jovanovac, Mali Jovanovac, Trnjana. Izvor), even though these settlements are smaller than 2000 PE [9]. The treatment would either be done on a centralized WWTP in the city of Pirot or on several decentralized compact WWTPs.

The analyzed settlements are geographically concentrated and a degree of urbanization is present within them. They have a built water supply network and enough drinking water, but no sewer systems for efficient evacuation of wastewater out of the settlement.

The settlement of Krupac, located along the right bank of the river Nišava, around 8 km upstream of the city of Pirot, already has a built sewer system and a compact decentralized WWTP (2500 PE) [8]. The settlement of Izvor, located along the right bank of the river Nišava, around 2 km upstream of the city of Pirot, also has a built sewer system and compact decentralized WWTP (1000 PE) [8]. The remaning settlements of the Municipality of Pirot do not have built sewer systems [8].

According to the devised water protection concept, it is necessary to build sewer systems for collection of wastewater of settlements Veliko Selo, Veliki Jovanovac, Mali Jovanovac and Trnjana, as well as wastewater treatment on the existing (WWTP Krupac) or newly built wastewater treatment plants (WWTP Pirot or decentralized compact WWTP for certain settlements) [9].

The discussed settlements are shown in figure 1.

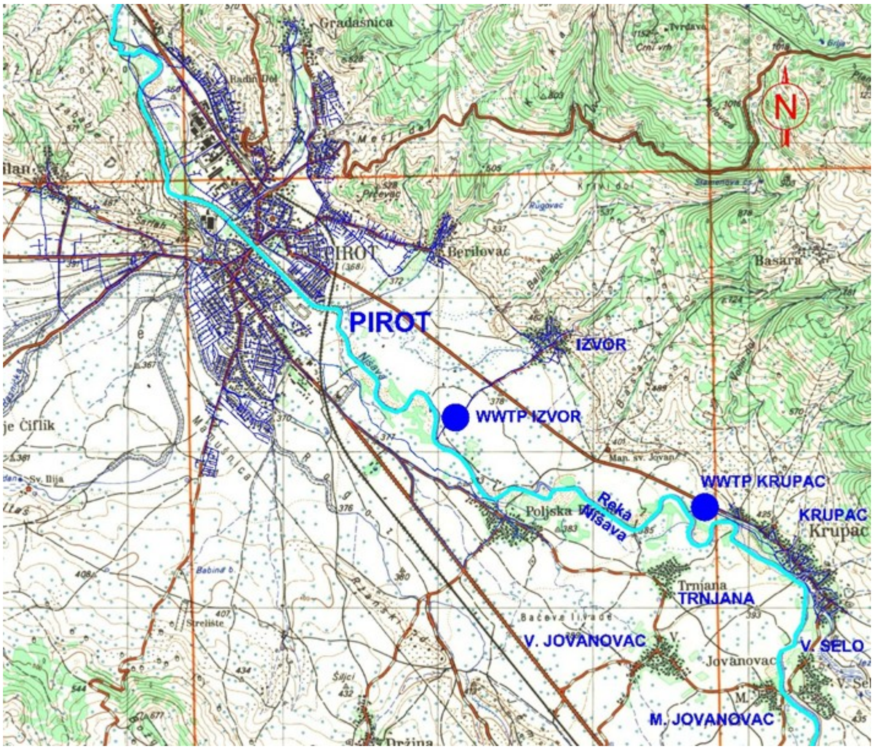

Figure 1. Discussed settlements in the Municipality of Pirot

3. METHODOLOGY

3.1. Variant solutions

With regard to the topographic characteristics and distances of the analyzed settlements from the city of Pirot or the settlement of Krupac, which have already built sewer systems, it is necessary to analyze the method of collection and evacuation of wastewater from the analyzed settlements.

Through the analysis, starting with topographic characteristics, the sizes of the settlements, the distances between each other as well as other relevant factors, the following problems should be solved [9, 10 - 12]:

1) The concept of the sewer systems taking into consideration that the systems of all the analyzed settlements should either be part of the sewer system of the city of Pirot with centralized treatment on the WWTP Pirot, or that each settlement or group of settlements should have its own independent sewer system along with a WWTP;
2) The technical solutions of the sewer system for the analyzed settlements should have the needed operational security and as few problems in operation as possible, meaning that, if possible, the sewer systems should be gravitational;
3) Considering that several variants of the technical solution of wastewater collection and treatment for the analyzed settlements present themselves, an economic analysis should be done and the most cost-effective variant solution should be chosen.

Three variant solutions were considered for the analysis of the problem of water protection in the municipality of Pirot [9]. Figures 1-3. show the planned systems of all three variants, with the color blue representing already built systems including: the city of Pirot sewer system (1), the settlement of Izvor sewer system (2), WWTP Izvor (3), the settlement of Krupac sewer system (4) and WWTP Krupac (5) and the color pink representing planned systems.

The first variant solution includes the treatment of wastewater of the city of Pirot and suburban areas already connected to the city's sewer system (1) as well as wastewater of the considered settlements Veliko Selo, Veliki Jovanovac, Mali Jovanovac and Trnjana on the planned centralized WWTP Pirot (60 000 PE) (7). This variant includes construction of a shared sewer system (1,2,4) for the settlements Veliko Selo, Veliki and Mali Jovanovac and Trnjana which would be connected to the sewer system of the city of Pirot via a main collector (6), as well as a pumping station for the settlement of Veliko Selo (3) and a pumping station for the settlement of Trnjana (5) [8]. The benefits of the first variant solution include the improvement in public health, overall quality of life, economic development and environmental protection as well as improvements in the existing sewer system efficiency and quality of service. The operational security of this variant is lower compared to the other variants, in case of failure of the main collector or WWTP, a large percent of the population on the analyzed area would be left without wastewater collection and treatment services. The variant solution 1 is shown in figure 2.

Figure 2. Variant solution 1

The second variant solution includes treatment of wastewater of the city of Pirot and suburban areas already connected to the city's sewer system (1) on the centralized WWTP Pirot (60 000 ES) (6). The wastewaters of settlements Veliko Selo, Veliki Jovanovac, Mali Jovanovac and Trnjana would be treated on the reconstruted and upgraded WWTP Krupac (upgraded to 3 500 PE, from the existing 1 000 PE) (5). In this variant the newly constructed sewer system of the settlement of Veliko Selo (1) would connect to the existing sewer system of the settlement of Krupac (4), while for Veliki Jovanovac, Mali Jovanovac and Trnjana a shared sewer system (2) would be constructed and connected to the sewer system of the settlement of Krupac via collector (3) and pumping station (4) [8]. The social and environmental benefits of the second variant solution are the same as the first solution, with improved operational security compared to the first solution, the failures on the network or WWTPs would have a reduced, localized impact. The variant solution 2 is shown in figure 3a.

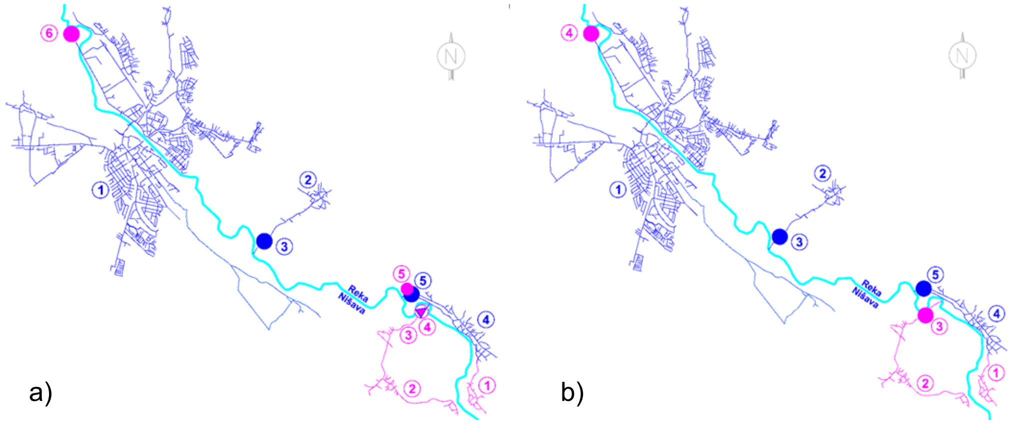

Figure 3. a) Variant solution 2; b) Variant solution 3

The third variant solution includes treatment of wastewater of the city of Pirot and suburban areas already connected to the city’s sewer system (1) on the centralized WWTP Pirot (60 000 ES) (4). The wastewater of the settlement of Veliko Selo would be treated on the reconstruted and upgraded WWTP Krupac (2 500 PE) (5), while the wastewater of the settlements of Veliki Jovanovac, Mali Jovanovac and Trnjana would be treated on a newly constructed shared WWTP Trnjana (900 PE) (3). This variant includes construction of a sewer system for the settlement of Veliko Selo (1), which would be connected to the existing sewer system in the serttlement of Krupac, as well as a shared sewer system for the settlements of Veliki Jovanovac, Mali Jovanovac and Trnjana (2). The social and environmental benefits of the second variant solution are the same as the previous two variant solutions, with the highest operational security out of all analyzed solutions and a further reduced failure impact area compared to the second solution. The variant solution 3 is shown in figure 3b.

3.2. Cost-benefit analysis

Cost-benefit analysis is a comprehensive and complex process which encompasses numerous evaluations, sums and comparisons [1]. This is why the analysis is realized following a defined procedure, as the basis of completing a valid economic analysis in the macro aspect. In accordance with the legislation of the European Union, it is recommended the cost-benefit analysis be completed in the following six phases [4]:

1. contextual analysis and definition of project goals,
2. project identification,
3. feasibility and options analysis,
4. financial analysis,
5. economic analysis,
6. risk assessment.

Financial analysis enables the calculation of desired indicators of financial gain during the planned period based on the estimated cash flows of the project. For calculation of financial indicators, the only relevant parameters are cash inflow and outflow. Only the cash flows which will occur if the analyzed project is realized should be taken into consideration. The main focus point of the analysis is the financial gain the investors or financiers of the project could expect from said project. The prices relevant in financial analysis are market prices.

For calculation of financial indicators, it is necessary to define cash flows, namely the costs and the benefits of the project. Costs and benefits can be categorized in multiple groups based on type. The primary categories to be taken into consideration are direct/indirect, material/immaterial and real costs and real benefits [13]. The total costs and benefits should be calculated and presented with the defined categories. It is important to take into account the short-term and long-term costs, therefore the projections should be completed based on project duration, including analysis of how the costs would evolve and change over time. The basic costs should be included, but thinking outside the box is desirable as it can lead to identification of unforeseen costs which could impact the project both short-term and long-term [13]. When analyzing future costs and benefits it is important that they be transformed into their current values through discounting using the appropriate discounting rate.

The calculation of benefits in water management can be done in various ways, depending on the specific goals and terms of the project. It is important to note that the calculation of benefits in water management can be very challenging because some benefits, like the improvement of public health or ecological benefits, are difficult to quantify in monetary values.

The value assigned to costs and benefits depends on when they are realized. In some cases, public policies, new regulations or their changes, cause immediate costs, but certain costs and benefits can emerge only after a certain time period.

Net present values of costs and benefits for the i-th variant solution and a time period of N years, where the parameter r is the fixed discount rate [14], are given in the following equations:

$$C_{i,N} = \sum_{n=1}^{N} \frac{C_{i,n}}{(1+r)^n} \tag{1}$$

$$B_{i,N} = \sum_{n=1}^{N} \frac{B_{i,n}}{(1+r)^n} \tag{2}$$

where: n – observed time period; N – considered time period; r – discount rate; Ci,N – costs over time period n, Bi,N – benefits over time period n.

Contemporary methods for evaluation of cost-effectiveness of an investment are based on evaluating expected future cash flows and the concept of the time value of money. The most often used methods for evaluating cost-effectiveness of a project are financial net present value (FNPV) and financial rate of return (FRR), given in the following equations [4]:

$$FNPV_{i,N} = \sum_{n=0}^{N} \frac{NT_{i,n}}{(1+r)^n} \tag{3}$$

$$NSV_{i,N} = \sum_{n=0}^{N} \frac{NT_{i,n}}{(1+FRR)^n} = 0 \tag{4}$$

where NSVi,N represents the net summary value while NTi,n represents the cash flows for individual years.

When it is needed to choose one option out of multiple ones with FRR $\geq$ r, the option with the largest FRR value should be chosen [6]. The rule of ranking can be represented in the following way:

if FNPVA > FNPVB and/or FRRA > FRRB option A is chosen

if FNPVB > FNPVA and/or FRRB > FRRA option B is chosen

Economic analysis aims to evaluate the contribution of the project to economic prosperity of the region or country. In economic analysis the focal point are benefits and costs that society as a whole will gain from the project. In contrast to financial analysis, where market prices are relevant, for economic analysis accrual prices, also called shadow prices, are used [4].

In order to compare cash flows occurring during different years of project realization in economic analysis, discounting should be done using an appropriate social discount rate [4].

To evaluate the feasibility of a project the most used economic indicators are the economic net present value (B - C) which is calculated as the difference between the discounted benefits and discounted costs of a project, along with the ratio of discounted benefits and discounted costs (B/C) [14].

The conditions for economic feasibility of a project are the following:

(B – C)i,N > 0

(B/C)i,N > 1

Information on costs, benefits and risks when it comes to future projections of a project, can rarely be known with certainty. This is why risk analysis, also known as what-if analysis or sensitivity analysis, is recommended for validation of collected and projected data, as well as for prediction of outcomes depending on changing values of different, and especially key factors [13]. Key factors are factors whose positive or negative changes have the biggest effect on the financial and economic feasibility of a project. In order for these factors to be discovered it is necessary to vary each factor of the analysis one by one, and observe how the project feasibility changes as a result. Numerous factors can be identified with regard to sensitivity analysis, but some of the more important ones are: population, rate of inflation, real wage growth rate, electricity price, project implementation delay, equipment lifespan, energy use, tariffs, etc. [4].

Necessary attention should be given to changes in project feasibility depending on the change of discount rate. If the increase of the discount rate still brings a positive result, the project is financially feasible [13].

Based on the results of the conducted analysis a clear decision can be made, based on real data of the performed projections [13]. When the net present value and the B/C ratio are calculated for several options (variants), the options can be compared.

Out of multiple options the advantage is given to the option with the greater net present value and B/C ratio. The ranking rule can pre presented in the following way:

if (B – C)A > (B – C)B and/or (B/C)A > (B/C)B option A is chosen

if (B – C)B > (B – C)A and/or (B/C)B > (B/C)A option B is chosen

However, when other options have advantages which cannot be quantified, it is possible that the first-ranked option based on net present value or the B/C ratio is not first-ranked in the complete analysis [13].

A big part of the risk related to cost-benefit analysis can be connected to the human factor. Participants or interested parties can influence the results of the analysis by enlarging or minimizing costs and benefits. In some cases, participants supporting the project can be personally or institutionally biased [13].

3.3. Costs

Costs can be categorized into direct costs, related to the use of resources in construction of the WWTP (e.g. construction of the plant and supporting structure, operational and maintenance costs, land purchase or expropriation costs) and indirect costs, related to secondary negative effects of the project such as environmental degradation, effect on the wastewater recipient, loss of income from WWTP land not being used for other purposes (e.g. agriculture, urbanization), electricity use, exchange rate losses for chemicals and spare parts if imported mechanical devices are used, losses in income from increased water price, nuisances from noise and mosquitoes, negative sentiment from the local population.

In this paper for the total cost of the project investment costs for construction of all elements of the wastewater collection and treatment system for a certain variant were taken into consideration, along with the operational costs (gross pay of employees hired for system maintenance, electrical energy costs, costs of chemicals).

The investment costs of WWTP construction were obtained based on the unit price of 220 EUR/PE, obtained based on the unit price of similar WWTP built in the country (WWTP Kruševac, WWTP Leskovac). The prices for the remaining elements of the technical solution were obtained based on the bill of quantities and the priced bill of quantities in the project documentation [15 - 17].

The gross employee income was determined for 6 workers who would be employed on the WWTP Pirot, who would occasionally oversee and maintain WWTP Trnjana as well, since WWTP Trnjana is a compact automated plant which does not need a constant operation crew, meaning that the number of employees and their gross income is the same in all three variant solutions. The gross employee income was estimated based on the average gross employee income of 1063.11 EUR per month [15].

The use of electricity was estimated based on the installed capacity of the WWTP (WWTP Pirot 30 kW, WWTP Trnjana 5 kW, WWTP Krupac 7.5 kW in variant solution 2, 2.5 kW for variant solution 3) and installed capacity of the pumping stations (PS Veliko Selo 2.2 kW, PS Trnjana 2.2 kW) for individual variants using the assumption that the pumping stations operate 8 hours a day, with a unit electricity price of 0.11 EUR/kWh for the industry [1].

Chemical use (sodium hypochlorite, coagulant) was estimated basted on the relevant average daily flow of wastewater into the WWTPs (WWTP Pirot 140.52 l/s, WWTP Trnjana 2.11 l/s, WWTP Krupac 1.17 l/s) with the unit price of 0.025 EUR/m3 adopted based on experiential data from similar WWTPs.

3.4. Benefits

Benefits can be categorized as direct benefits, encompassing obvious services produced by the project, such as water and soil protection from uncontrolled dispossession of wastewater, improvement in cleanliness and public health protection services, wastewater recycling for irrigation or urban use, employment opportunities, and indirect benefits or secondary positive effects, such as protection of consumer health from polluted water, quality of life improvement on a local level, protection of pastures and grazing animals, indirect employment opportunities [3].

The total benefits of the project taken into consideration in this paper are the wastewater treatment fee [17] and the cost savings from wastewater pollution, obtained as the difference between pollution costs for untreated wastewater and pollution costs for treated wastewater [18].

Wastewater treatment fees were determined based on the WWTP capacities (WWTP Pirot 140.52 l/s, WWTP Trnjana 2.11 l/s, WWTP Krupac 1.17 l/s) with the unit price for wastewater treatment of 0.35 EUR/m3 adopted based on the data for similar WWTPs [17, 19, 20].

The cost savings of wastewater pollution were also determined based on the WWTP capacities with the assumption that the average amount of pollutants in wastewater are SM 150 mg/l, BPK 250 mg/l, HPK 500 mg/l, while in treated wastewater in accordance with the requirements of the Directive and plant treatment level the amounts are SM 35 mg/l, BPK 25 mg/l i HPK 125 mg/l. The cost savings of wastewater pollution were determined with unit prices of pollution for relevant pollutants (using the so-called shadow prices) SM 0.01 EUR/kg, BPK 0.03 EUR/kg i HPK 0.21 EUR/kg [20]. The unit prices per kilogram of pollutants emitted into water, or shadow prices, represent benefits achieved through reduction of environmental degradation, hospital care costs, loss of live costs, etc.

3.5. Financial and economic analysis of variant solutions

Financial and economic analysis was conducted based on the obtained values of costs and benefits. All cost and benefit values are given in table 1.

Discount rates from 1% to 10% were used for calculation of present values of costs and benefits. For further financial analysis discounted future values of costs and benefits were obtained using the recommended financial discount rate of 4 %, based on the recommendation of the Ministry of Finance of the Republic of Serbia [21].

Table 1. Investment and operational costs

	VARIANT 1	VARIANT 2	VARIANT 3
INVESTMENT COSTS (EUR)			
Sewer Systems	1 947 620.73	1 165 629.71	
Pumping Stations	102 514.14	44 301.41	
WWTP	13 200 000.00	13 430 770.86	
TOTAL	15 250 134.87	14 640 701.97	14 558 406.64

OPERATION COSTS (EUR/year)			
Gross employee income (6 employees)	76 543.71	76543.71	76543.71
Energy used	29 905.92	36336.96	356 40.00
Chemicals used	109 264.64	110175.18	111 814.15
TOTAL	215 714.27	223 055.84	223 997.85
BENEFITS (EUR/year)			
Wastewater treatment fee	82497.25	86839.21	86839.21
Pollution cost savings	1507782.7	1587139.67	1587139.67
TOTAL	1590279.94	1673978.89	1673978.89

For further economic analysis discounted future values of costs and benefits were used, obtained by using the recommended social discount rate of 7%, recommended by the Ministry of Finance of the Republic of Serbia [21].

4. RESULTS AND DISCUSSION

Based on the discounted values of costs, benefits and cash flows thfinancial feasibility factor FNPV (financial net present value) was calculated, using the recommended financial discount rate of 4%. Results of the calculation are given in table 2.

Table 2. Determining present value of cash flow

Year	Net present value of cash flow NT (EUR)		
	Variant 1	Variant 2	Variant 3
0	-15 250 134.87	-14 640 701.97	-14 558 406.64
30	423 804.26	447 346.66	447 056.22
FNPV	8 518 900.55	10 448 707.56	10 514 713.64

Taking into account the time value of money and the recommended discount rate of 4 % per year, based on the results shown in table 2, it can be concluded that the analyzed investment, with the observed cash flow, is feasible for all three variants, since it brings in greater net benefits than costs.

For calculation of FRR (financial rate of return) analysis of future values of costs and benefits was conducted, using discount rates from 1% to 10%. It was calculated that NPV = 0 for ERR = 8.1% in variant 1, ERR = 9.2% in variant 2, and ERR = 9.25% variant 3. Considering that:

FNPV3,30 = 10 514 713.64 EUR > 0 and FRR3,30 = 9.25% > r = 4%

FNPV2,30 = 10 448 707.56 EUR > 0 and FRR2,30 = 9.2% > r = 4%

FNPV1,30 = 8 518 900.55 EUR > 0 and FRR1,30 = 8.1% > r = 4%

it can be concluded that all three variant solutions are financially feasible.

Considering that:

FNPV3,30 = 10 514 713.64 EUR >

FNPV2,30 = 10 448 707.56 EUR >

FNPV1,30 = 8 518 900.55 EUR and

FRR3,30 = 9.25% > FRR2,30 = 9.2% > FRR1,30 = 8.1%

it can be concluded that, based on financial analysis, the most feasible variant solution is variant 3, followed by variant 2, and lastly variant 1.

Based on discounted values of costs, benefits and cash flows, indicators of economic feasibility were determined, using the recommended social discount rate of 7%. Results of the calculation are given in table 3.

Table 3. Analysis of economic feasibility indicators

		Variant 1	Variant 2	Variant 3
Total costs [EUR]	C	17 926 942.09	17 408 611.14	17 338 005.24
Total benefits [EUR]	B	19 733 849.29	20 772 472.93	20 772 472.93
Economic indicators	B – C	1 806 907.20	3 363 861.79	3 434 467.69
	B/C	1.10	1.19	1.20

Considering that:

(B – C)1,30 = 1 806 907.20 EUR > 0 and (B/C)1,30 = 1.10 > 1

(B – C)2,30 = 3 363 861.79 EUR > 0 and (B/C)2,30 = 1.19 > 1

(B – C)3,30 = 3 434 467.69 EUR > 0 and (B/C)3,30 = 1.20 > 1

it can be concluded that all three variant solutions are economically feasible.

Sensitivity analysis was conducted with a variable social discount rate ranging from 1% to 10 %. Based on the results of the sensitivity analysis it can be concluded that all suggested variant solutions are economically feasible with the increase of the social discount rate up to 8% for variant 1, or 9% for variants 2 and 3, considering that the B/C > 1. If the social discount rate is increased above 8% or 9% respectively, the B/C ration becomes less than 1 for the suggested variant solutions, meaning that the solutions are no longer economically feasible.

Considering that:

(B – C)3,30 = 3 434 467.69 EUR > (B – C)2,30 = 3 363 861.79 EUR > (B - C)1,30 = 1 806 907.20 EUR and

(B/C)3,30 = 1.20 > (B/C)2,30 = 1.19 > (B/C)1,30 = 1.10

it can be concluded that, based on economic analysis, the most economically feasible variant solution is variant 3, followed by variant 2, and finally variant 1.

Based on the sensitivity analysis it can be concluded that variant 3 is the most favorable with the increase of the financial and social discount rate.

Considering that variant 3 is the most feasible in both the financial and economic analysis, it is finally concluded that the most favorable option in the cost-benefit analysis is variant 3.

5. CONCLUSION

Because of increased complexity, numerous challenges, a wide spectrum of insecurity and high investment costs in the field of water management, it is very important to conduct a feasibility analysis of an investment project, no matter how big the project may be.

When evaluating feasibility of realization of water management investment projects, the effects on the project on the wider community should be taken into account. Investment projects like these can optimally be evaluated if the total effects of the project are considered. Project realization feasibility analysis is most often done using the cost-benefit analysis which is based on a great number of variables and assumptions, which makes it very complex. The cost-benefit analysis gives a clear picture of a favorable ratio between investment and benefit, and highlights the importance of economic efficiency in the choice of investment projects.

In this paper, the basic steps of the cost-benefit analysis were applied, and it was concluded that out of three suggested water protection solutions in the Municipality of Pirot, variant solution 3 was shown to be the most feasible. This shows that applying even a relatively simple analysis for economic valuation of alternative solution enables the choice of the most feasible one, which ensues the economic benefits and sustainability of a project, both of which are key for attaining long-term development goals.

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PRINCIPLES AND SOLUTIONS OF BIOCLIMATIC ARCHITECTURE ON THE PROJECT OF A FAMILY HOUSE IN KRAŠIĆI, MONTENEGRO

Vukašin Stefanović[1]

Abstract

The aim of the presented work is to present the design of a residential house on the Montenegrin coast in the town of Krašići, designed according to the principles of bioclimatic architecture with reference to the systems whose implementation is foreseen during the design process. They refer to the applied measures of reducing total energy consumption, achieving thermal comfort during the winter and passive cooling during the summer. The work shows how solutions such as a green roof, glasshouse, green facade and other solutions are implemented during the design process in order to achieve the mentioned goals. Due to the increased construction of buildings in cities, the need for energy also increases, which is mainly satisfied by the use of non-renewable sources, known for leaving lasting consequences on the environment. Green construction and rational use of energy can contribute to saving resources and preserving the environment. The presented solution of the family house is trying to reduce the need for energy necessary for its efficient use throughout the year through a smart analysis of the location's potential. Coastal architecture, to which Montenegrin architecture belongs, is recognizable by its architecture in stone, stable and authentic. The author's aim is to create a modern house that is in step with the times with its design expressions and applied systems, while at the same time respecting the Mediterranean tradition of building with stone. The family house, in addition to the desire of implementing the principles of bioclimatic architecture, first of all required a well-designed function so that, all together would result in a high-quality space for a family to stay on the attractive Montenegrin coast. Given that almost 90% of the time is spent in buildings, the family house, in addition to the desire to implement the principles of bioclimatic architecture, first of all required a well-solved function so that, all together, it would result in a quality space for the family to stay on the attractive Montenegrin coast.

Key words: *Bioclimatic architecture, Montenegro, Krašići, Sun energy, Sustainable design, Green architecture, Greenhouse, Green roofs, Green facades*

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1. INTRODUCTION

The location intended for the construction of a family residential building is located in the town of Krašići in the Bay of Kotor, opposite the town of Tivat on the Montenegrin coast. The climate in Krašići is characterized by a large number of warm and sunny days, the average temperature in the summer period being around 27ºC (the month of August is the warmest with a temperature of 27.3ºC), with a relative humidity of 61%. During the winter days, the average temperature is around 5.1ºC (the month of January is the coldest with a temperature of 2.7ºC), while the relative humidity is around 74.6%. During the winter, the bay is protected by high hills from strong winds, while during the autumn, southerly winds are present, which bring rain. The corner plot on which the house is planned to be built has an irregular geometry, formed on the north-west and south-west sides by streets, while the other two sides are shared with the neighboring plots. The terrain is on a slope that extends parallel to the longer borders of the plot oriented in the southwest-northeast direction. The plot is positioned in a neighborhood dominated by individual residential buildings, raised to the highest elevation with open views to the sea that stretches to the north and east. The content necessary for the permanent stay of a family of four is defined by the project assignment. A deeper analysis of the climate of this area and the architecture of these spaces defined the functional schemes and the concept of implementation of some of the principles of bioclimatic architecture, so that the house would meet modern high standards of housing, sustainability and energy efficiency. Applying sustainable construction effectively contributes to global sustainability goals, creating prosperous communities, while also stimulating economic growth. Its influence is also directly reflected in the quality of life and harmonizes it with the local climate, tradition and culture throughout the life of the building. When designing, it is necessary to take into account that weather influences, the type of constructive system of the building, then the physical characteristics of the materials used in construction, as well as the AHC systems (air conditioning, heating and cooling) can affect the energy performance of the building itself [6]. Another of the more important reasons for applying sustainable construction solutions and applying bioclimatic architecture solutions is to increase the value of the structure.

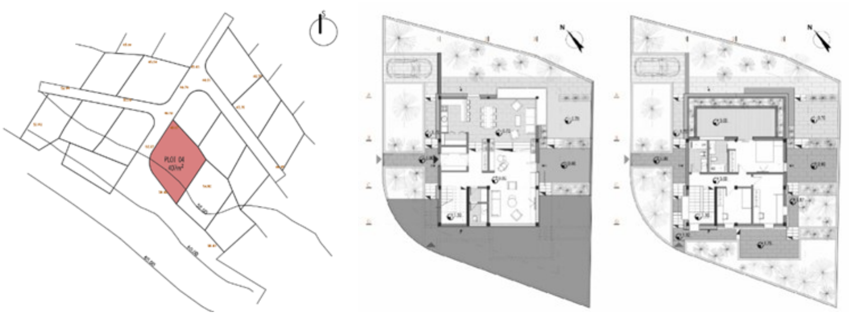
a)

b)

Figure 1. a) Landscape of Krašići; b) Map of Montenegro with the position of Krašići sources: a) https://sh.wikipedia.org/wiki/; b) https://sh.wikipedia.org/

2. THE DESIGN PROCESS

The examination of the site's potential initially refers to the orientation and approaches, while at the same time searching for the best position of the building on the plot, taking into account urban parameters, regulations and terrain configuration. Construction on the slope terrain brings with it the problem of overcoming heights, but also conditions the house‘s shape potential, which must not exceed the prescribed maximum values with its surfaces. In this regard, it is of great importance to correctly set the input data that define the guidelines for the development of the initial idea. The restrictions included a defined building and regulatory line, the maximum development of the plot, the required distance of the building from the neighbors, the maximum height of the same, as well as the minimum percentage of greenery in direct contact with the ground.



a) b) *Figure 2. a) Position of the given plot, source: Author's archive; b) Site plan with the position of the system for collecting atmospheric water*
Source: Author's archive: (Authors: Vukašin Stefanović and Anđela Stevčić)

By adopting the central position of the house on the plot, with dimensions that are in accordance with the permitted values of the parameters, the first outlines of the form in the architectural sense were defined. The basic zoning of contents within the framework of functional schemes implies the long-accepted practice of organizing daily contents within the ground floor, while the first floor is reserved for private rooms. By researching the local architecture of stone houses, research was actually carried out on the topic of designing buildings in areas with a very warm climate. The main task of the architect in such situations is to provide thermal comfort for users who need cooled rooms in the summer and heated rooms in the winter. It is precisely the old architecture of coastal houses that shows how effective the application of massive stone walls is, which prevent heat from entering the interior in the summer, while retaining it in the winter. Old builders also used increased room heights to create pleasant spaces, as well as frequent darkening of windows with blinds and similar elements. Also when the terrain is sloping, it is a common practice to bury certain parts of the house in order to achieve the aforementioned thermal comfort.

The temperature of the earth at a certain depth is a constant 12.2ºC, which is about 8-10ºC difference from the required 20-24ºC, which can easily be replaced by an efficient heating system during winter days.

Houses protected by the earth tend to lose less heat during the winter (the earth is then warmer than the outside air), which means that much less energy is needed to heat the house than for buildings with completely free facade walls, which, together with the carpentry, are responsible for 70% of the heat losses of buildings. Also, the temperature of the earth during the summer is lower than the air temperature, which greatly helps to create a pleasant climate inside the house during hot summer days. Other advantages of burying the building in the ground are soil retention, i.e. the soil can be used for greening the plot and has further benefits in terms of receiving atmospheric water, protecting the house from vibrations and earthquakes, which leads to achieving good sound comfort in the interior. The soil also protects the buried walls from freezing, which can damage the building's structure, and effectively provides protection from wind blows [8].

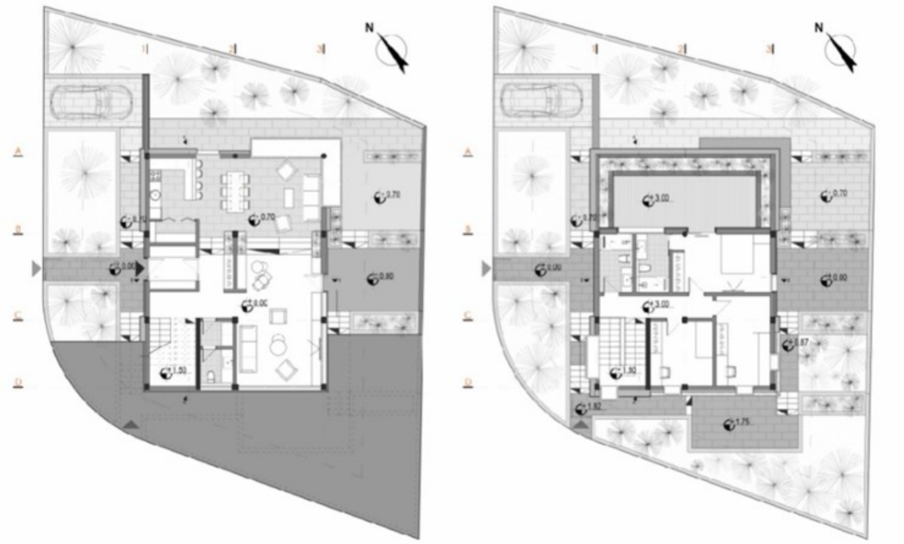


Figure 3. Functional schemes - Ground floor and first floor plans
source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

The ground floor was formed in accordance with the orientation and available views, all in accordance with the sloping terrain. The north-east organization of living rooms on the one hand represents a gain, but at the same time a minus that manifests itself during the winter days. Speaking of which, the functional organization and utilization of views requires the organization of daily contents in the north. In order to avoid such a positioning of the main room, a living room is planned in the southern part of the house, partially buried in order to prevent overheating of the interior space during hot summer days. This achieved the positioning of the living room in the south, tucked away by massive walls and earth, while an "extension" was defined in the north, which can be used both in summer and in winter, enjoying the soothing views of the sea. Due to the penetration of views into the deepest part of the house (southern living room), within the base of the ground floor, the height grading of two rooms is applied, which achieves an increased room height of the north-east part, constructively developed in accordance with the slope of the terrain. The southern living room is lit by tall windows positioned in such a way as to bring natural light into the interior but also to avoid overheating the space with the strong southern sun. The slightly overhanging volume of the first floor also helps to form a sharp angle of intrusion of light. As already mentioned, the night area or in another words, private area has been moved upstairs and includes two children's and parent's bedrooms, equipped with separate bathrooms. The children's rooms are oriented to collect as much southern light as possible, while the parents' room with a spacious roof terrace faces the sea. The reduced area of the first floor in an architectural sense provides a fine gradation of the mass, the upper cube drawn towards the steep terrain, which dynamically develops the volumes of the house following the fall of the terrain.

Figure 4. Three-dimensional view of the house
source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

Figure 5. Three-dimensional view of the house
source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

At the same time, the set-up of the floor together with the base of the ground floor gives the maximum allowed built-up area at the given location. Defined functional schemes and a rough definition of the volume of the building in further elaboration required the refinement of fine architectural details that round off the appearance of the facade planes. The positioning of the openings and their dimensions were adjusted according to the orientation in order to maximize energy gains throughout the year. Also, certain parts of the house receive certain systems of bioclimatic architecture that provide the already mentioned thermal comforts.

The dominant materialization of the house, which emphasizes the load-bearing volumes, is local stone, which, in addition to achieving an appropriate aesthetic impression, achieving continuity of design with the environment, and a pleasant climate in the interior, also reduces the costs of transportation, exploitation, etc. in favor of sustainable construction.

3. ANALYSIS OF THE APPLIED PRINCIPLES OF BIOCLIMATIC ARCHITECTURE

The basic definition of bioclimatic architecture implies a design methodology that, at the beginning of the creation of the solution, thoroughly investigates the natural and created conditions of the site where the construction is planned so that the end result is a building that provides users with all the comforts that improve their quality of stay. Bioclimatic architecture emphasizes sustainability and energy efficiency, so an important aspect is the design of the facade envelope, which ensures a favorable microclimate inside the building, as well as the use of natural materials that have no negative impact on the environment. The goals of bioclimatic design are largely directed towards the popularization of systems that produce energy using clean and renewable energy sources in order to generally reduce the consumption of impure energy sources that leave a carbon footprint.

Some of the bioclimatic design systems were taken from old construction techniques, modernized and placed in today's context of technological innovation, primarily by the application of new materials.

In order for the presented solution of the house to better fit into the climatic conditions of Krašići, the following principles have been implemented that help create a more pleasant microclimate:

1) green roofs
2) green facades
3) natural ventilation – passive cooling
4) glasshouse
5) air collector

The enumerated principles belong to the so-called passive systems of bioclimatic architecture, but the house is also equipped with a system of photovoltaic panels for the independent production of electricity, as well as a tank system for collecting and processing atmospheric water.

3.1. Green roofs

The application of green roofs is not a new concept. Throughout history, it has been used for a long time, starting with certain ancient civilizations, through the Middle Ages, the Renaissance, until today, when the importance of their use in times of global warming is increasingly being recognized. The advantages of using green roofs are multiple, from processing polluted air, improving the quality of atmospheric water, collecting dust particles, protection from noise, positive impact on the human body, etc. The efficiency of green roofs is determined by various factors such as the thickness of the soil layer (a larger layer of soil means better cooling of the interior and greater possibilities in terms of planting different plant species), greenery and its planting density (greenery creates a shadow that has a favorable effect on cooling), climatic elements (precipitation, insolation, relative humidity, etc.). The division of green roofs includes three types: extensive (requires minimal maintenance), simple intensive (requires occasional maintenance) and intensive (requires intensive maintenance). Considering the size of the house and the total surface area of the roof, the application of an extensive green roof is the most rational for the presented project, both from the aspect of maintenance and the cost of construction. For such roofs, a mixture of sedum plants is generally used, which are selected according to local conditions. These are mostly drought-resistant perennial plants that grow in difficult conditions in their natural habitat. Maintenance of the roof involves a year's maintenance and cultivation. This roof design has a direct effect on the coolness of the bedrooms of the presented project, which are located directly under the roof slab, at the same time providing a better integration into the coastal environment.

The use of green roofs can reduce the need for cooling during the summer by 30-100%, while their vegetation can lower the temperature of the roof structure by as much as 50ºC. Due to the aforementioned efficiency, their application can be an excellent way to save energy during summer days in the Mediterranean climate [9]. The importance of green roofs and their wider applications go beyond the needs of individual buildings that can realize certain benefits. Their distribution greatly improves the state of the environment, which has been largely damaged as a result of intensive urbanization.

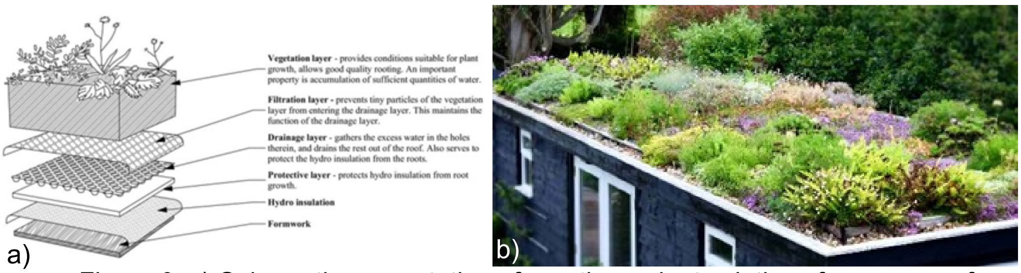


Figure 6. a) Schematic presentation of one the variant solutions for green roof construction; b) An example of a green roof with abundant greenery source: a)https://www.pinuphouses.com/; b) https://herbidacious.calamus.graphics/

First of all, their application is important for mitigating the effect of heat islands, which are even more pronounced in areas where the climate is warm and dry during summer days.

3.2. Green facades

Similar to the roof planes, the walls are starting to be treated with layers of greenery in order to reduce the heating of the space, form picturesque urban views, but also reduce CO_2 emissions and form a pleasant climate in urban areas where green areas have been replaced by concrete ones. According to the installation method, green facades are divided into: green facades and living walls. When it comes to green facades, their installation involves planting plants in the ground (base), which during growth climb up the specially designed elements of the structure of such walls until they reach full capacity. The plants used for this type of wall construction are mainly vines and creepers. In order to achieve full coverage, the facade needs 3-5 years for the plants to fully form. Living walls, on the other hand, involve the installation of ready-made panels or modules with planted plants that are placed on a load-bearing facade wall or some other frame structure. In addition to panels, plants can be arranged in bags or boxes. The panels are made of plastic, EPS (expanded polystyrene), synthetic fibers and other materials, depending on the plant species being planted. An important aspect of the durability of such a facade is regular maintenance and nutrition of the vegetation. Green facades have a positive effect on air purification, temperature reduction, noise reduction, creation of a pleasant environment, restoration of biodiversity, but also increase the durability of walls and make buildings more resistant to fire. In the case of the presented solution, the green facade system was applied to prevent overheating of children's rooms facing south and southwest. The warm coastal climate can affect the formation of an overheated space, so a green facade is an effective solution that will prevent this.

Research conducted in an area with a Mediterranean climate shows that green walls can reduce heat load from the Sun by up to 20%, especially if green walls are provided on the east side of the building [10][11]. The facade designed in this way necessitated the use of cantilevered windows so that greenery would not grow around them and prevent the entry of light. This provides children with a healthier space that positively affects their stay and development.

Designing such a facade system brings a new dimension and picturesqueness to the design of facade planes. The construction of green walls consists of a primary (constructive) wall that serves as a base for the installation of a metal structure (which can also be designed independently when necessary) and a space intended for plants that can be planted in cassettes, bags or can be applied as panels on the base (the solution most often used in the interior - Moschito moss panels).

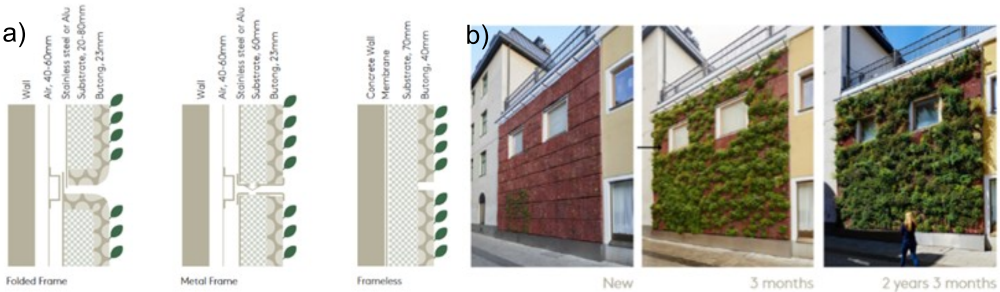


Figure 7. a) Three types of green facade solutions; b) The method of forming a green facade, source: https://butong.eu/

3.3. Natural ventilation – passive cooling

One of the basic conditions for a quality stay indoors is a sufficient amount of fresh air. In order to provide the necessary amount into the interior of the house, and to avoid using mechanical ventilation systems, the use of natural driving forces is usually practiced, as one of the primary principles of bioclimatic design. Natural driving forces are wind, thermal thrust and a combination of their influences. Thermal thrust occurs when there is a difference in density between outside and inside air, caused by a difference in temperature. Due to the formation of the difference, the air from the inside moves to the outside, while the outside air enters the inside. Wind ventilation occurs when there is a difference in wind pressure on the facade of the building, that is, the difference affects the wind entering the building from the side of the facade that is exposed to its impacts, while it exits from the side that is protected from those impacts. The mentioned natural mechanisms can appear independently, but very often they act simultaneously. Thermal pressure mainly occurs in winter, when it is cold outside and the interior of buildings is heated, while the effects of wind are dominant during summer. The direction of the air flow through the house depends on the position of the external and internal openings and other partitions of the internal space. Knowing the principles of movement and exchange of external and internal air, we can recognize the following methods of natural ventilation. The division implies one-sided and two-sided ventilation or chimney effect. One-sided ventilation takes place through openings that are defined on only one side of the building, and in order to be effective, the optimal depth of the room must be 2-2.5 times greater than its room height. On the other hand, double-sided ventilation requires the opening of the facade on two opposite sides so that the air can move.

Practically, double-sided ventilation is the already explained principle of wind movement, the efficiency of which increases if the depth of the room is about 5 times greater than its room height. The chimney effect is mainly used in buildings with higher floors compared to family buildings and works according to the principle of air removal through drains positioned on the highest level of the building, while fresh air enters the interior on the lower floors through ventilation ducts. In order for this principle of ventilation to be effective, a height difference is needed between the air intake and exhaust openings, but it can also be improved by increasing the room height of the rooms, introducing an atrium or increasing the slope of the roof planes if the flat roof solution is not applied. The openings in the presented project of the family residential building are defined in such a way as to enable the movement of air in several directions. By opening all sides of the facade, cross ventilation is enabled, which effectively cools the interior. The warm air of the ground floor moving upwards is discharged through the roof dome above the staircase and other openings when necessary [2].

3.4. Glasshouse

The glasshouse concept appeared in the seventies, as one of the new solutions that can help users to live in harmony with nature in their homes, along with other sustainable systems based on passive energy gains. There are several ways of designing it. It can be solved as: 1) window 2) loggia or balcony 3) independent 4) attached or extended 5) partially built in or integrated 6) fully built in or atrium. The glasshouse belongs to the systems of indirect gains and can be combined with different wall partitions in order to maximize its performance depending on the function and the need of the space. In this specific project, the position of the plot, the orientation and the opening of attractive views determined the position of the glasshouse oriented mostly to the east, so that it captures a small part of the south. The gains from the eastern orientation are not the same as from the southern side, but they are not negligible. The glasshouse space is designed as an air space between transparent glass partitions that do not block views in winter, but still generates a certain amount of warm air that helps heating the spacious space of the ground floor. In the architectural sense, it becomes an important part of the design, which defines the architecture of the ground floor in harmony with the first floor in the part where the green facade is designed. The window-glasshouse solution can be used in children's bedrooms.

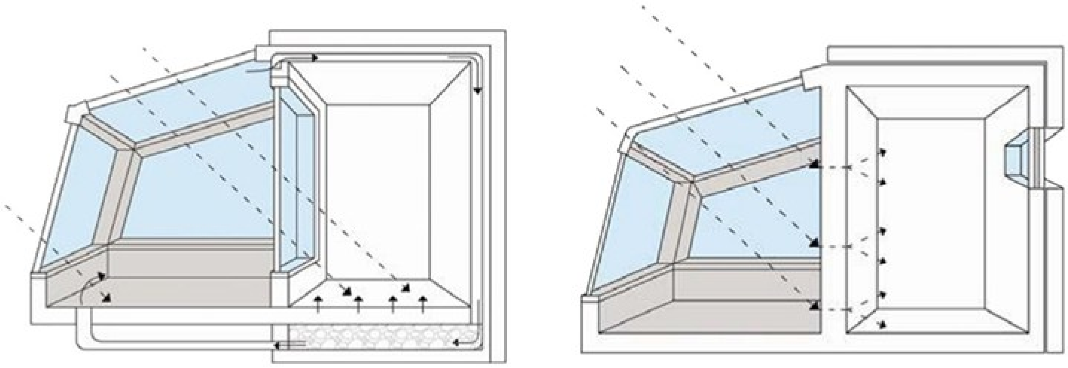


Figure 8. Two variants of glasshouse functioning, source: Lectures on Bioclimatic architecture I (Professors: Miomir Vasov, PHD and Veliborka Bogdanović, PHD – Faculty of Civil Engineering and Architecture, University of Niš)

In a similar way as on the ground floor, the window boxes, which due to the cantilever overhang have a larger volume, can be closed with another glass partition from the inside so that the air space is directly heated in winter under the influence of the Sun and then heats the room. Cantilevered windows have become a characteristic detail of the design of the house [2].

Figure 9. Three-dimensional view of the solution - Glasshouse detail source:Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

3.5. Air collector

Often in sloping terrain, it is possible to build buried rooms under the houses in order to form an air collector. In this case, the installation of a tank for collecting atmospheric water required digging below the dimensions of the ground floor, so the unevenness of the level was used to build a double slab at the level of the foundation in order to provide space for servicing the mentioned system.

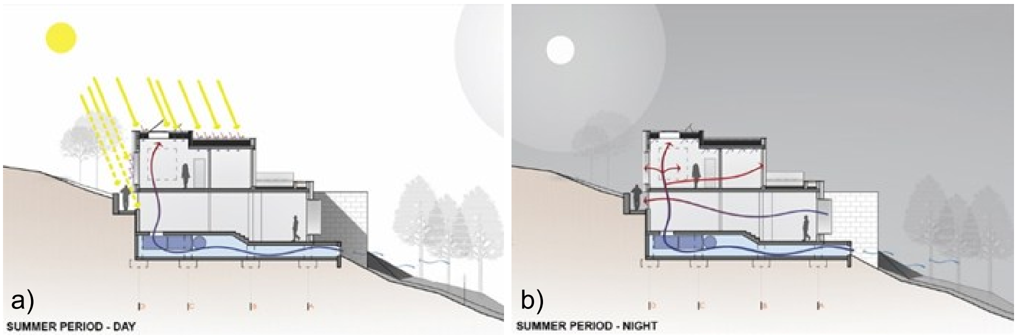


Figure 10. a) Scheme of fresh air movement during summer days - Passive cooling and air collector; b) Scheme of fresh air movement during summer nights - Passive cooling and air collector source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

The same space is used to direct the air coming from the sea, it is cooled in a chamber where the temperature is lower due to its installation in the terrain, and it is further distributed to the rooms on the ground floor through the floor openings. In this way, the circulation of fresh air through the house is completed. If necessary, the external openings, as well as the internal floor openings, can be closed. The system was implemented as a modification of the old ventilation systems used in Africa and Eastern countries, which function through a network of underground tunnels that direct the air through "wind catchers" [2].

4. CONCLUSION

Bioclimatic design implies much more than the mentioned principles, which can be seen in the large projects of advanced architectural practices in the world. The beginning of such design is not the analysis of location and impact, but it starts with creating the sense for awareness of the importance of environmental preservation, from which comes the way of solving needs through sustainable solutions. The presented solution is a response to the modern requirements of functionality, healthy space and preservation of the environment, which created a "machine for living" with a significantly reduced negative impact on the environment. Returning to the old construction methods combined with modern and clean technologies can be a solution in the fight against invasive construction that is not in harmony with nature. The importance of maximum utilization of the location‘s potential where the construction of the facility is planned and the implementation of solutions based on the obtained data certainly brings great savings during a longer period of use of the house, even though the initial investments are higher. It is especially important that principles such as air collector, natural ventilation and greenhouse represent completely clean methods of bioclimatic design.

The key to transformed cities and implemented systems is probably the education of new architects who must develop environmental awareness and literacy so that in the future they will be in a position to insist on the implementation of such solutions in order to realize the idea of sustainable use and development.

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THE METHODOLOGY OF DETERMINING THE LOAD-BEARING CAPACITY OF HIGH PROFILE SHEETS USING THE EXPERIMENTAL METHOD

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Nikola Janković[5]

Abstract

In civil engineering, high-profile sheets (HPS) are widely used. They are used as load-bearing elements in a system of stacked roofs, for covering large-span structures or as permanent formwork when casting concrete slabs. Determining the load-bearing capacity of these elements is a complex task, and designers take this data from the manufacturer's catalog. Data on the load-bearing capacity are usually given depending on the serviceability limit state (SLS), without special consideration of the support conditions. For these reasons, this paper presents an in detail methodology for determining the load-bearing capacity of a standard type of HPS, using an experimental method. The research was carried out on a sheet panel with a span of 6000 mm of a simple beam static system. The length of the support on the purlin was 200 mm and it was secured with eight bolts. The load to failure test was conducted according to the SRPS U.M1.047 standard using the method of applying an equally distributed gravitational load. The experimentally obtained results were compared with the catalog values provided by the manufacturers. The test showed that the applied support conditions (length of contact with the purlin, number and arrangement of connecting means in the connection) have a positive effect on increasing the load-bearing capacity and cost-effectiveness of the HPS.

Key words: *High profile sheet, Experimental test, Load-bearing capacity*

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1. INTRODUCTION

Modern trends in civil engineering necessitate an increasingly frequent use of prefabricated elements, which are an imperative for rapid construction. For this reason, the use of second-generation high-profile steel sheets [1] has facilitated completely new architectural solutions in the design of structures. The main reason for this is that these elements provide, above all, an economically advantageous solution for cladding and covering large industrial, sports and agricultural facilities. Thanks to the specific shape of the cross-section (Figure 1), as well as their light weight, they are most often used for medium and large spans. They are laid over the purlin, connected with appropriate fasteners, so in addition to their basic role, they can often interact with the main structure, contributing simultaneously to its spatial stability (stressed skin concept) [2].

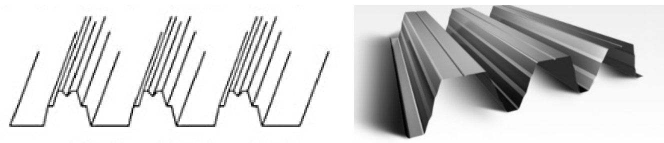


Figure 0. High profile sheets of second generation [1,3]

Data on the load-bearing capacity of HPS are regularly provided in manufacturers' catalogues. The load-bearing capacity is most often given as a function of the allowable deflection (serviceability limit state – SLS), and much less often as the strength at failure (ultimate limit state – ULS). Since in practice HPSs are most often laid on the main supporting steel structure with different support lengths, and the connection is achieved with bolts, data on these support conditions are usually omitted from manufacturers' catalogues.

This paper presents a methodology for determining the ultimate strength of capacity of a standard type of HPS experimentally. A special attention is paid to the support conditions, because in addition to the height of the profile, span and static system, the load-bearing capacity of HPS may also depend on the contact length of the support and the number of fasteners in the connection.

2. EXPERIMENTAL SETUP

2.1. Objectives and the subject of the experimental research

Determining the load-bearing capacity of HPS using analytical methods is a complex task, considering the geometry and complex behavior of the structure in the post-elastic zone. Therefore, in this paper, an experimental analysis was implemented to determine the limit states of the type TR 153 HPS. It will provide recommendations to future designers and manufacturers for designing and conducting their own research when using this type of structure. The analysis will also show to what extent the applied parameters affect the ultimate strength of the HPS.

2.2. Structural static system and support conditions

The determination of the load-bearing capacity of the HPS TR 153 was performed on a sheet metal specimen of a manufactured width of 870 mm, thickness of 0.73 mm and a spacing between supports (clear opening) of 6000 mm. The specimen was made of steel of strength class S320G. The static system was assumed to be a simple beam, which is the most common case when designing and constructing this type of roof covering. The selected type of HPS has a significant load-bearing capacity, and therefore a contact length of with the purlin of 200 mm was adopted. Supports (purlins) consist of two hot-rolled ⊓160 profiles. For the purpose of achieving the desired contact length of 200 mm, additional 10 mm steel plates were welded onto the profiles. Bolts M6x20...8.8 were used as fasteners of the sheet and the purlin, with a wide flat washer between the bolt and the sheet. Purlins are rested over the auxiliary supports anchored into the concrete floor slab. Figure 2 shows the specimen setup with the support structure.

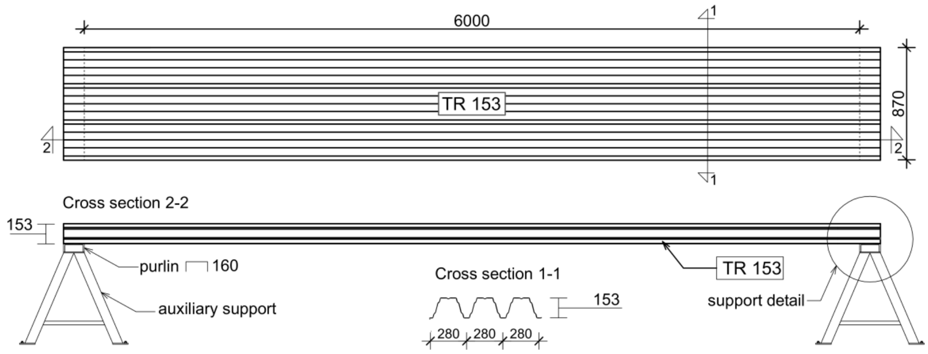


Figure 2. Setup, longitudinal and transversal cross-section of the test specimen, source: Authors

The connection between the sheet and the purlin is achieved with eight bolts, which are placed in two parallel rows at a distance of 40 mm from the longitudinal edges of the purlin. By placing the bolts in two parallel rows, a force coupling is formed in the connection, which brings about a certain degree of restraint (Figure 3).

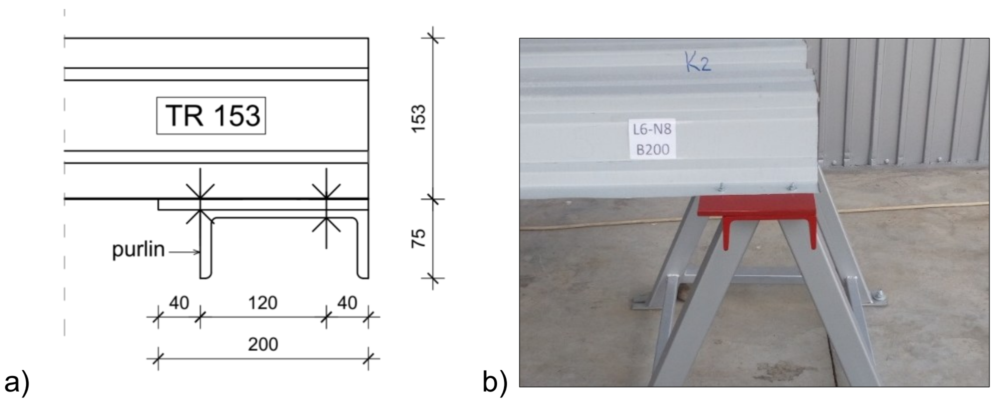


Figure 3. Case N8 B200 support details: a) workshop drawing; b) experiment, source: Authors

2.3 Test load application methodology

The procedure for applying a test load is defined in a large number of world standards [4, 5, 6]. In this study, the bending test of the specimen was performed under an equally distributed - gravitational load until failure, by applying bags weighing 0.25 kN, and according to the adopted loading pattern (Figure). This method of applying the load has been changed by a large number of researchers [7, 8, 9]. Testing under gravitational load is simple and economically advantageous, especially from the point of view of the availability of the test load, as well as the potential of field application. One of the disadvantages of this method is the need to add bags according to a certain scheme, in order to simulate a load equally distributed on the specimen.

Based on the data on the load-bearing capacity of the tested samples provided by the catalogs, and the standard recommendation that a single load step should not exceed 1/6 of the maximum load, it was adopted that the gravity load be applied in steps of 0.2 kN/m^2. Considering that the surface area of the tested specimen was 5 m^2, in each step (stage) 4 bags corresponding to the force of 1 kN were added, which corresponds to the surface load of 0.2 kN/m^2 (Figure). The dead weight of the sample was 0.1 kN/m^2 and it was taken into account when calculating the equivalent surface load in all load stages.

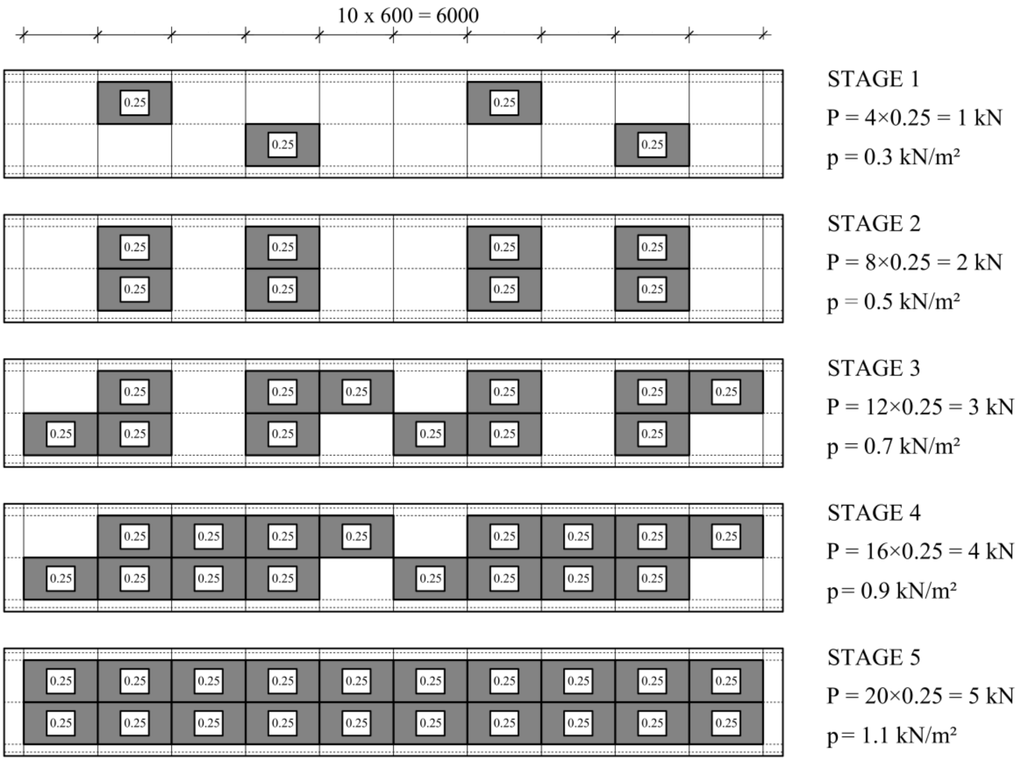


Figure 4. Loading the sample in stages; legend: P – applied force [kN], p – equivalent surface load [kN/m^2], source: Authors

After stage 5, bags were applied in the second layer according to the same load pattern (stages 1-5). The procedure was repeated until the sample failure.

2.4 Measuring points setup and load process

During testing of specimens with equivalent uniformly distributed load, deflection measurements were performed at half and quarter spans. The arrangement of measurement points is shown in Figure 5.

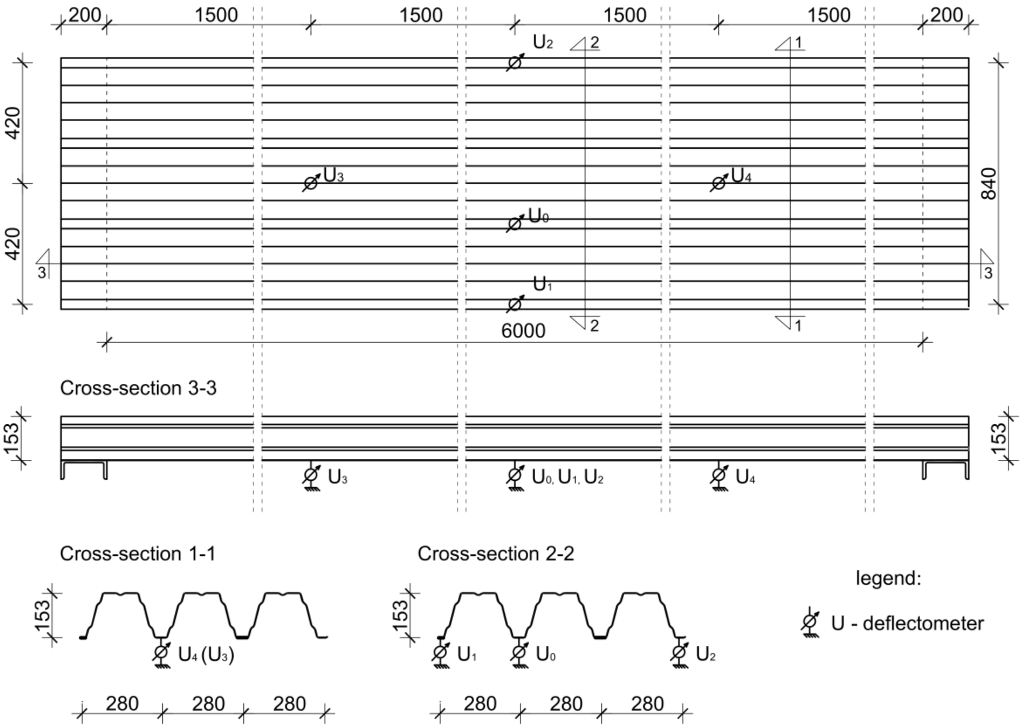


Figure 5. Graphic display of measuring points arrangement, source: Authors

The deflection was measured using linear variable differential transformers (*LVDT*), and mechanical deflectometers and the obtained signals were processed using the measuring-acquisition system *MGCplus* and software package *CATMAN.*

The sample testing process was performed according to the current national standard SRPS U.M1.047 [10] with certain adjustments to the test subject. The sample was first loaded to an operational load of 1.6 kN/m^2, which approximately corresponds to 65% of the assumed load capacity of the sample (p_u). The load was maintained at that value for 5 minutes, after which it was reduced in equal steps to 0.1 kN/m^2. This load was maintained constant for 5 min, and then increased until the specimen failed. The highest load applied during the test was taken as the specimen's load capacity (p_u).

3. RESULTS OF THE EXPERIMENTAL ANALYSIS

Based on the previously described experimental setup, this chapter presents the obtained results of the measured deflection for all measurement POINTS, as well as deflection diagrams in two orthogonal directions (gravity axes). FigureFigure 6 shows sample arrangement and support conditions under load p = 2.5 kN/m^2, where the emergence of a certain degree of restraint in the connection between the sample and the support can be observed. Bolts, set in two rows, reduced lifting of the edges of HPS and rotation of the support cross-section. The lower flange of the specimen, which is in contact with the inner edge of the support is crushed. This is a consequence of the small thickness and rigidity of the base material (Figure 6-б).

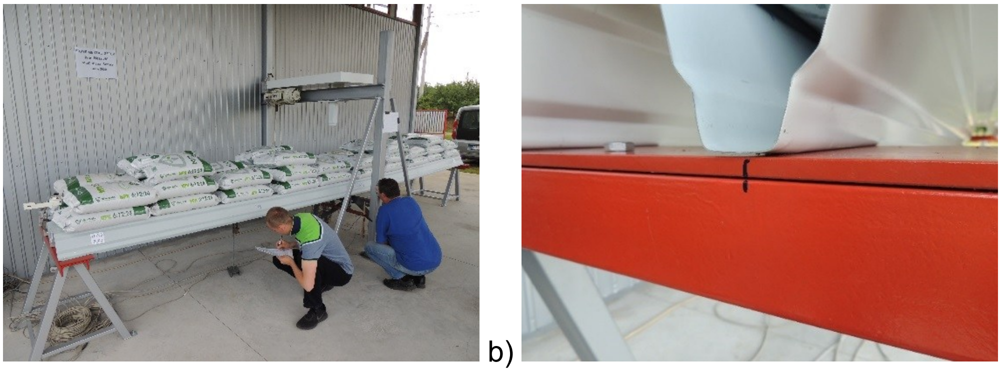
a) b)


Figure 6. Specimen N8 B200: a) Arrangement of HPS under load p=2.5 kN/m^2 b) support detail under p=2.5 kN/m^2, source: Authors

The obtained results are presented in the following diagrams (Figure 7, Figure 8, Figure 9, Figure 10).

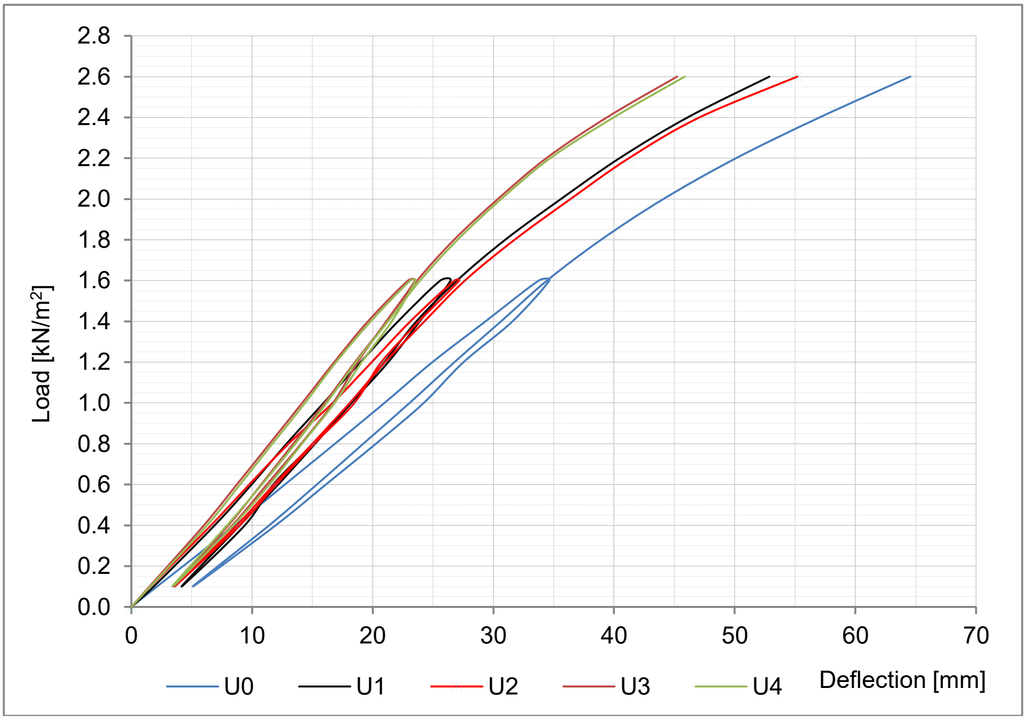


Figure 7. Load-deflection load in the measuring points U_0; U_1; U_2; U_3; U_4

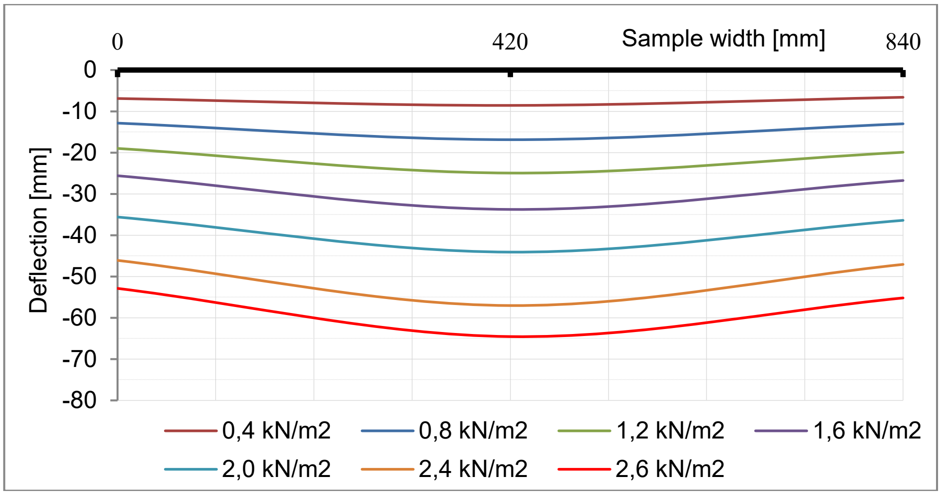


Figure 8. Mid-span cross-section deflection diagram, source: Authors

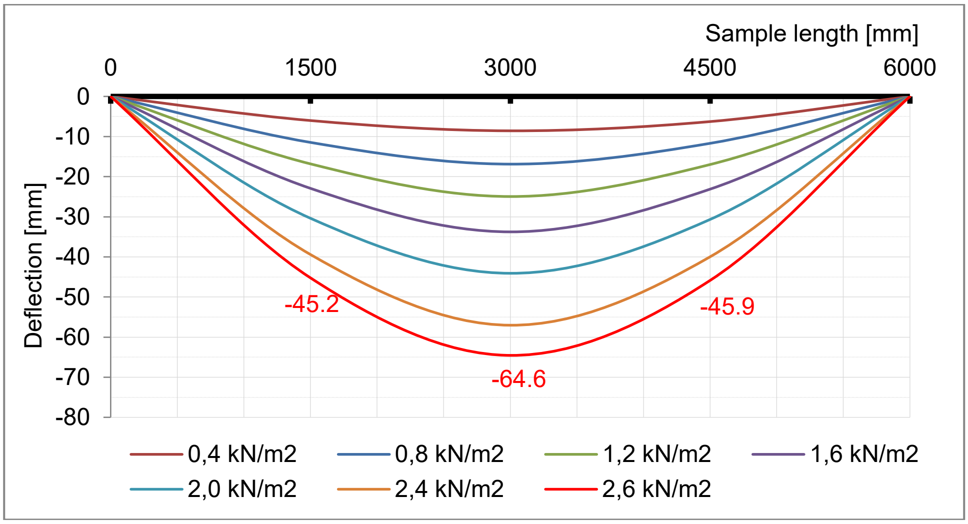


Figure 9. Deflection at the middle of sample width – longitudinal cross-section diagram, source: Authors

a) 

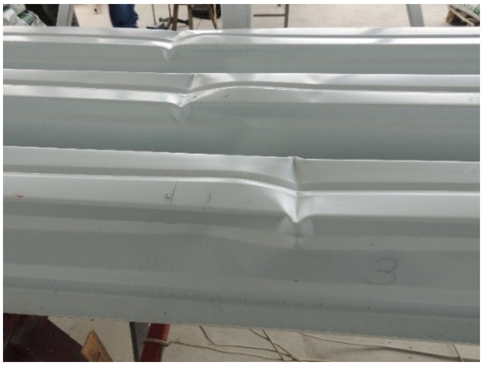
b) 

Figure 10. Specimen N8 B200 under the load 2.6 kN/m^2: a) plasticization of the upper flange of the medium crease, b) appearance of the specimen after failure, source: Authors

In the diagram shown (Figure 7) it can be seen that the load-deflection curves are not ideally smooth, due to the interruption in the load application for reading the results from the deflection gauge. The fracture location of the specimen is approximately at mid-span and occurs as a consequence of the local buckling of the upper flange of the specimen (Figure 10), at maximum load p_u=2.6 kN/m^2.

3.1 Discussion and comparative analysis of the results

Since the serviceability limit state is far more important for practical engineering applications, Table 1 provides comparative results of the load-bearing capacity of the analyzed specimen with the available results from the catalog of well-known manufacturers of TR153, for the most commonly specified deflection limits [11, 12, 13, 14].

Table 1. Load bearing capacity TR153 at the given deflection

source	t [mm]	N [n]	B [mm]	p [kN/m2]			
				l/150	l/200	l/300	l/500
Experiment	**0.73**	**8**	**200**	**1.85 (100%)**	**1.43 (100%)**	**0.90 (100%)**	**0.55 (100%)**
Arcelor Mittal	0.75	-	40	0.84 (45%)	0.84 (59%)	0.76 (84%)	-
Balex	0.75	-	60	1.70 (92%)	1.33 (93%)	0.93 (103%)	-
INM Arilje	0.75	-	-	-	1.27 (89%)	0.85 (94%)	0.51 (93%)
Prodanović	0.75	-	90	1.75 (95%)	1.29 (90%)	0.82 (91%)	0.45 (88%)

legend: „-“ data unknown

From the data presented (Table 1), it can be seen that all manufacturers define the load-bearing capacities of their products without a defined number of fasteners in the connection. Also, some manufacturers recommend a very small conteact length, which is unrealistic for practical application for the considered type of HPS.

5. CONCLUSIONS

Based on the conducted research and previous analysis of the results, the following conclusions were drawn:

- The specimen fracture occurs due to local buckling and wrinkling of the upper (pressed) flange at the half the specimen span, which indicates that stress analysis is not of primary importance in determining the load-bearing capacity of the HPS.
- The cross-sectional deflection diagram at mid-span indicates that the deflections are unevenly distributed across the width of the section, i.e. the deflections at the edges of the section are smaller than the deflection at the center of gravity. This phenomenon manifests itself as end-lifting, i.e. the

tendency for the complex geometry of the cross-section to straighten into a flat plate and behave like a tensioned membrane.

- The constructed connection between the specimen and the support using eight bolts significantly reduced the rotation of the support cross-section and the lifting of the specimen ends from the support plate, which indicates the occurrence of a certain degree of restraint in the connection.
- The analyzed length of the contact area and the number of fasteners in relation to the support contributed to the increase in the load-bearing capacity and stiffness of the HPS. The differences in the results were considered in accordance with the available catalog data and ranged from 3% to 55%.

Considering the results of the experimental analysis, it can be concluded that the applied support conditions have a positive effect on the ultimate bearing capacity of the HPS. By varying the length of the support, the number and arrangement of the fasteners, more favorable solutions could be obtained from the aspect of the bearing capacity and serviceability of the structure.

The methodology described in this paper according to which the experimental analysis was carried out represents a quick and simple way to determine the mechanical behavior of HPS beams. A downside of the application of the gravitational load application test method is the insufficient precision in determining the ultimate load capacity, because the load is not applied continuously, but in stages.

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APPLICATION OF BRISE-SOLEIL IN ARCHITECTURE: A CASE STUDY OF A NEWLY DESIGNED RESIDENTIAL NEIGHBORHOOD IN BAOŠIĆI CONSIDERING BIOCLIMATIC AND URBAN PLANNING PARAMETERS

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Abstract

Global warming and rising energy demand make brise-soleil systems increasingly important in energy-efficient cooling and reducing carbon emissions in warm climates. This study examines a newly designed residential neighborhood in Baošići, Montenegro, characterized by a Mediterranean climate with hot, dry summers and mild winters. The effectiveness of brise-soleil systems in improving energy efficiency and thermal comfort is widely documented; however, there is little research on the performance of such systems in specific residential applications across a range of climates. This research fills that gap by evaluating the performance of brise-soleil in reducing cooling energy consumption from late March to mid-November. Simulation results show that cooling energy demand is reduced by 9% to 31% during summer months and annual savings of 12%. In addition to energy savings, brise-soleil systems help achieve bioclimatic design by minimizing solar heat gain and improving indoor comfort. They also enhance the architectural design. Adaptive shading technologies will be applied in future research to different climates to maximize energy savings and achieve sustainability.

Keywords: *Energy Efficiency, Bioclimatic Design, Sustainable Architecture, Solar Shading*

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1. INTRODUCTION

Bioclimatic architecture merges centuries-old principles of design inspired by adaptations of natural organisms. The approach optimizes energy efficiency (EE) using local climatic factors and natural resources such as solar gain and wind. For example, the orientation of the building can significantly reduce heating and cooling demands, while natural materials enhance insulation and promote sustainability [1,2]. Concerning the urgent need to cut energy consumption (EC) and resource depletion, this design philosophy minimizes the reliance on artificial energy sources and promotes the use of renewable energy [3]. Accordingly, the study by Koç Sena Göknur and Maçka Kalfa Sibel [4] demonstrates that passive solar techniques, central to bioclimatic design, are key to sustainable architecture through brise-soleil systems.

Architects can reduce their ecological footprint, conserve resources, and improve the well-being of their occupants by embracing bioclimatic principles. Stable indoor environments, low energy demands, and good thermal comfort (TC) are achieved through natural ventilation and high-quality insulation. Solar radiation management is, therefore, a significant concern, especially in residential buildings that receive high solar radiation. Brise-soleils are a good solution to balance natural light and cooling needs. They enable simultaneous solar shading, natural ventilation, and EE. Elzeyadi [2] and Meerbeek et al. [5] demonstrate that dynamic brise-soleils dramatically increase TC and energy performance in regions with high solar exposure.

This paper cites the studies that have given the foundation for how shading systems can contribute to EE and TC. This research contributes to existing findings by focusing on brise-soleil systems in a particular residential neighborhood in Baošići, Montenegro, and filling the gaps in understanding their performance in transitional climates. In contrast to other shading studies, the simulations in this paper are detailed and quantify energy savings in a bioclimatic approach that considers urban planning parameters. It provides a unique focus by utilizing EnergyPlus simulations to bridge theoretical research and the practical application of sustainable architecture, specifically through the detailed design and evaluation of brise-soleil systems.

However, their performance depends on precise design, placement, and orientation, especially during cooler months when solar gains are desirable. To optimise their design, Energyplus simulations are used to investigate the effectiveness of brise-soleils as a design element for coastal climates in a residential neighborhood in Baošići, Herceg Novi, Montenegro.

2. SUN PROTECTION THROUGH HISTORY - LITERATURE REVIEW

Sun protection, a cornerstone of bioclimatic architecture, has been integrated for centuries. Socrates' example of the sun-oriented house is an early example of solar control for TC (Figure 1). Over time, architectural progress has incorporated modern materials and technologies and has perfected these principles for more building performance and sustainability [6].

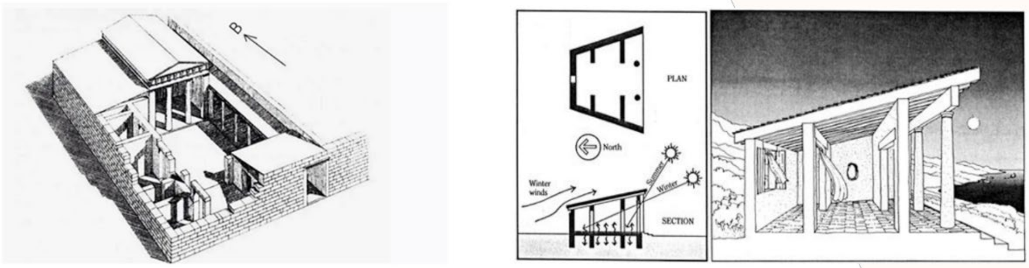

Figure 1. Application of the principle of sun protection in the ancient age - Socrates' house [7,8]

Deep openings and overhangs, as measured by ancient civilizations like the Greeks, Egyptians, and Persians, were used to address solar exposure. In the 20th century, modernist architects such as Le Corbusier and Oscar Niemeyer popularized the brise-soleils as a blend of perfect functionality and aesthetics. However, these systems have become indispensable for EE building designs, which reduce mechanical cooling demands and improve visual appeal [8].

Today's brise-soleils, equipped with advanced materials and intelligent technologies, provide flexible light and temperature control, making them indispensable in sustainable architecture. Different shading devices, from static systems to automated blinds, effectively balance natural light, ventilation, and energy savings.

Recent research highlights the dual impact of brise-soleils on EE and occupant comfort, as Elzeyadi [2] demonstrated in solar radiation control and Meerbeek et al. [5] in occupant satisfaction. Additionally, Lai et al. [1] and Baghoolizadeh et al. [9] demonstrated the flexibility of shading devices for various climates and used such devices with photovoltaic technologies to improve performance.

Self-shading façades have been further explicitly studied for their benefits in reducing cooling loads and improving energy performance [10, 11] and a growing body of literature has further emphasized the effectiveness of shading devices in warm climates. Dynamic shading and glazing technologies have also enhanced energy and visual performance and have placed adaptive shading solutions in a central role for contemporary buildings [12]. In addition, shading devices coupled with radiative cooling strategies are a focus of EE design in hot climates [13]. Our findings support using well-designed shading systems like brise-soleils to enable architecturally responsive climates.

3. CONCEPTUAL ARCHITECTURAL AND URBAN DESIGN SOLUTION

3.1. Climatic Parameters of the Location

Herceg Novi has a Mediterranean climate with mild winters, warm summers, and an annual temperature of 15.8°C, with temperatures regularly over 20°C in summer. The clear skies prevail during summer and get 2,417 hours of sunshine annually. Rainfall averages 1,940 mm annually, mostly in winter, and temperatures seldom fall below 0°C.

The wind conditions vary: In colder months, the jugo brings moist air, while the bora brings cold winter winds. In summer, with a moderate climate, the maestral moderates the climate, but it is ideal for outdoor activities.

3.2. Site Conditions

Baošići has a hot, dry (summer temperature above 32°C, winter temperate above 10°C) Mediterranean climate. It allows bioclimatic architecture by enabling solar energy use without overheating.

Connectivity is guaranteed by the linear laying out of the settlement along the main road. The residential structures blend into modern, tourism-oriented buildings with red tiled roofs and natural stone facades. Mediterranean vegetation and parks add to the scenic and environmental attractiveness of the region.

The site comprises three residential buildings on a gentle slope facing the Bay of Kotor. It is very accessible, close to the E65 highway, and there is a pedestrian path to the bay. A hedge provides sound insulation, and schools and commercial facilities are nearby.

Baošići is an ideal location for permanent residence and tourism-related activities due to its proximity to beaches, cafes, and recreational areas. The site's natural beauty and convenient access to amenities make it highly suitable for future development (Figure 2). Macro- and micro-location analyses highlight the site's strategic positioning in relation to the E65 highway, nearby schools, and recreational areas along the Bay of Kotor.

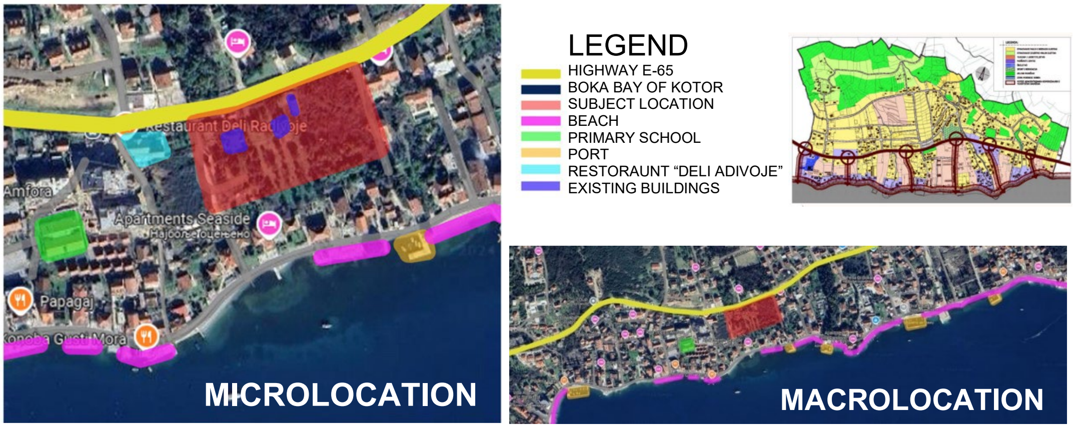

Figure 2. Macro and Micro Location Analysis

3.3. Urban Parameters of the Location

Baošići is urbanized following local regulations, which classify the site for low to medium-density residential use. The layout comprises sixteen detached buildings that conform to the terrain's natural slope and harmoniously fit the landscape.

Type A (6.8 m tall, three levels) and Type B (4.2 m tall, two levels) buildings are categorized as buildings with eight residential units. The design strikes an elegant balance between density and spaciousness in creating a high-quality living environment.

Green buffers between buildings ensure privacy, are natural barriers, and provide acoustic insulation. The E65 highway is mitigated by a green belt, which reduces noise pollution and adds visual appeal to the residential environment.

Density indices meet zoning requirements: Coverage index of 0.4, Construction index of 0.8, and height limit of two stories above ground. Medium-density zones allow up to four-story mixed-use buildings at a construction index 1.2.

Pathways and stairways are included in the ground-level parking, making walking easy. They include courtyards, pools, and outdoor spaces that improve the quality of life while paving materials respect the natural terrain to minimize environmental impact.

3.4. Program Analysis, Architectural and Functional Design Concept

The project is designed as a bioclimatic architectural and urban design for a residential neighborhood in Baošići. Scenic views are encouraged, and the natural slope toward the Bay of Kotor orients buildings.

It favors simplicity, harmony with nature, and better living conditions. Designed to function seamlessly in the environment whilst minimizing visual impact, all sixteen residential buildings are strategically positioned along the slope.

Stability and durability are provided by the robust structural system of reinforced concrete (20x20 cm columns and 20x40 cm beams). Soft white finishes combine with natural stone and wood to create facades that integrate seamlessly with the landscape.

Solar management is achieved through wood-colored aluminum brise-soleils, designed for horizontal adjustments on southern facades to shield against high summer sun angles, and vertical adjustments on eastern and western facades to block lower morning and evening sun, ensuring optimal shading throughout the day and across seasons. These shading devices increase EE, comfort, and privacy while responding to daily and seasonal variations in sunlight. It is arranged with three levels of residential units. (Figure 3).

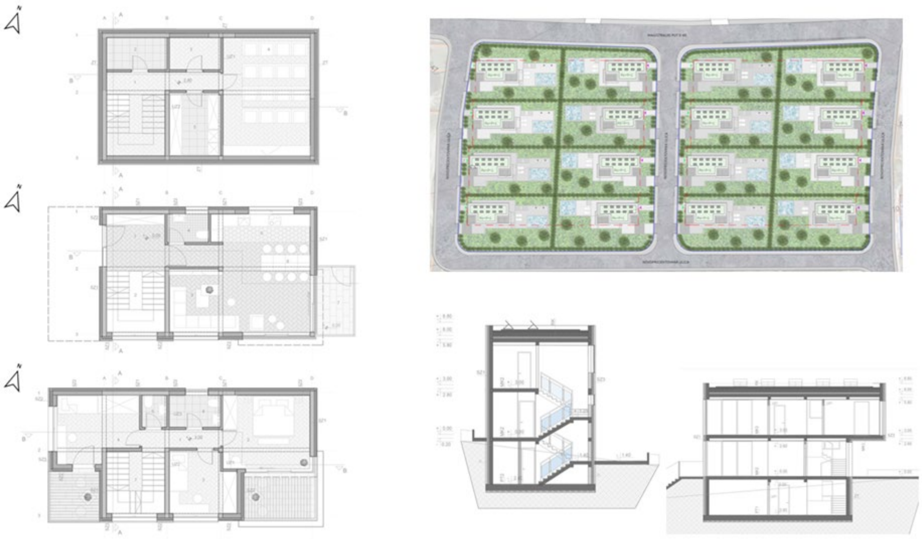

Figure 3. Master plan of the settlement, Floor plans, and Sections of the objects

The design features a highly sustainable approach, with a flat green roof with ten solar panels to generate renewable energy and improve insulation. The swimming pool is integrated with the outdoor area to provide residents with a comfortable and quality life through accessible recreational spaces. Taken together, the architectural and functional aspects of the complex result in a visually attractive, energy efficient, environmentally responsive living environment that meets the visual and environmental requirements of the modern age. (Figure 4.).

Figure 4. 3D render of the designed objects

Diagrams illustrating summer and winter conditions were analyzed to evaluate the buildings' response to solar movement (Figure 5). These diagrams visualize seasonal variations in solar exposure, emphasizing the importance of adaptive shading solutions in balancing energy efficiency and indoor comfort throughout the year.

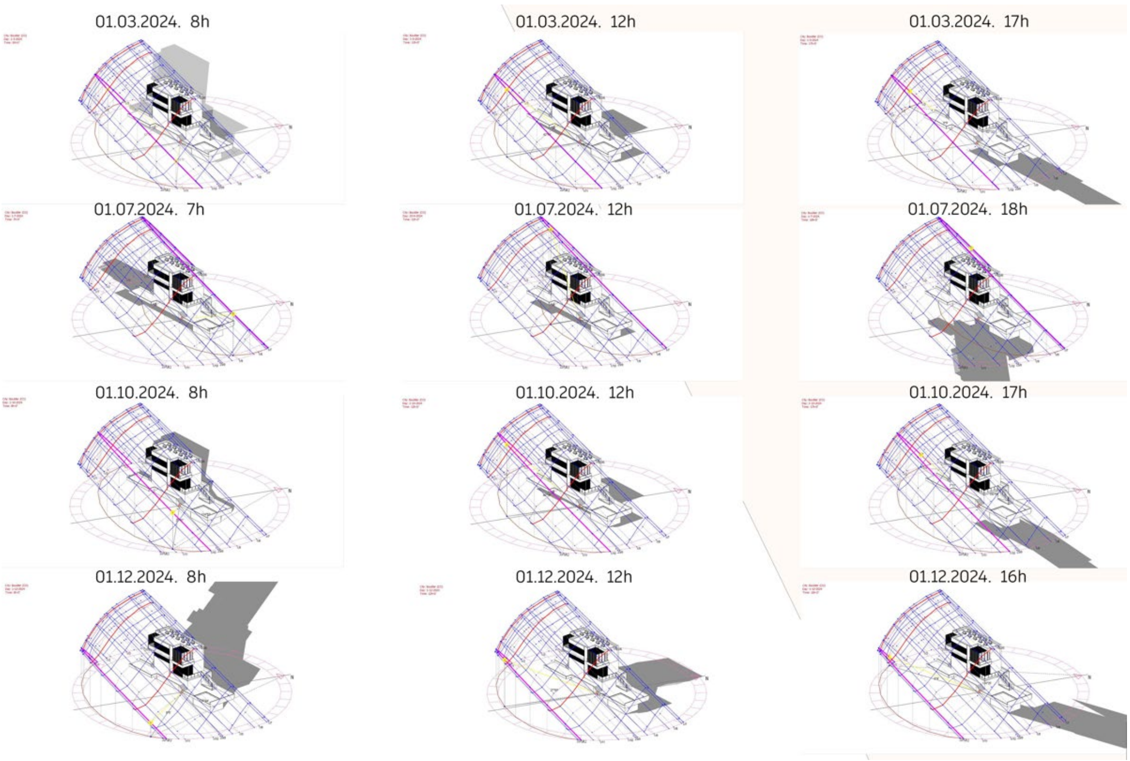

Figure 5. The impact of solar movement

3.6. Seasonal Performance

Brise-soleils reduce heat gain during summer, blocking intense morning and evening sunlight on the eastern and western facades. Solar panels on the roof generate electricity, while the green roof absorbs excess heat, maintaining stable indoor temperatures and reducing cooling loads.

At night, operable windows and vents enable cross ventilation, achieving airflow rates of up to 0.6 air changes per hour, which helps to refresh indoor air and reduce cooling loads by approximately 10% during summer months.

In winter, brise-soleils retract to maximize solar heat gain, while the green roof retains warmth. Solar panels generate electricity even on cold days, and the heat pump adjusts indoor temperatures for comfort.

This dynamic design approach combines passive and active strategies to year-round enhance comfort, EE, and environmental sustainability.

4. METHODOLOGY

Energy simulations can provide valuable insights into a building's energy performance and optimize design and systems under different scenarios. Simulations are imperfect with simplified models and assumptions, but they provide tremendous cost and time savings in the design phase and a base for making informed decisions on EE.

The detailed simulation capabilities of EnergyPlus were selected for their ability to simulate cooling demands and EC under varying conditions, including the presence or absence of brise-soleil systems, to evaluate their impact on cooling EC. Working with the SketchUp package means working with a perfectly matching geometry modeling workflow that enables accurate visualization and input of architectural details. EnergyPlus provides robust support for thermal & energy simulations, and SketchUp's user-friendly interface simplifies the creation of complex structures. Combining the two makes this an ideal setup for research that requires architectural precision and advanced performance analysis. (Figure 6.).

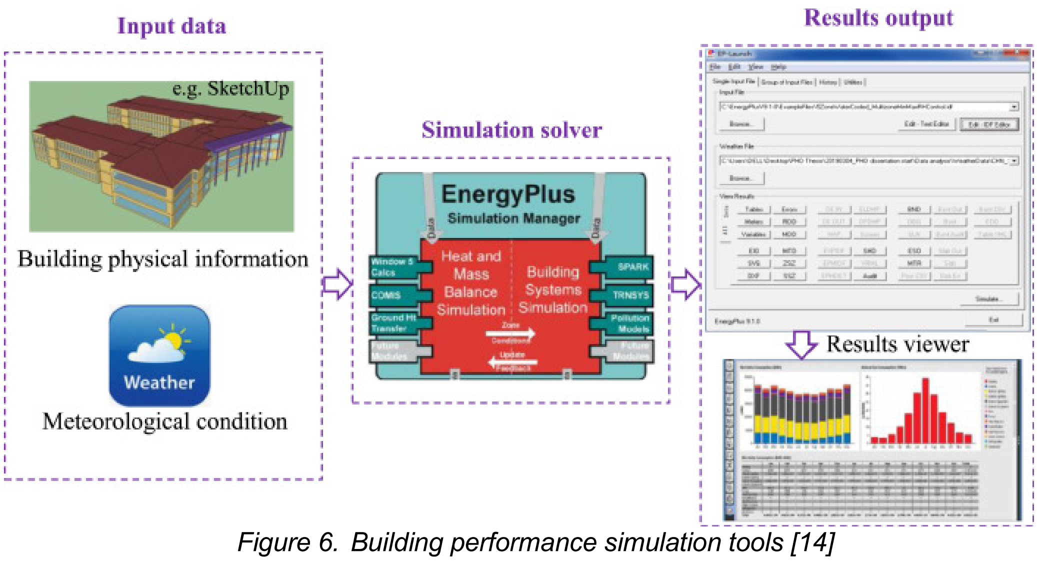

Figure 6. Building performance simulation tools [14]

Cooling demands and electricity consumption were analyzed under seasonal and site-specific climatic conditions (weather data files for Herceg Novi, Montenegro). The role of brise-soleil was assessed to reduce cooling loads and enhance EE.

The modeling process started with a geometric model in SketchUp created down to the detail and was then exported to EnergyPlus. All construction elements were defined carefully based on key material properties, including thickness, density, thermal conductivity, and specific heat. These layers' opaque and transparent surfaces were assigned correctly, so thermal performance representation was accurate.

Each construction's physical and thermal properties are specified in text-based input files (.idf) EnergyPlus uses. All layers, from exterior facades to interior surfaces, were included in the simulation, reflecting real-world conditions. This study uses the 3D model shown in Figure 7, which shows the integration of material properties and shading devices necessary for simulating how the building interacts with its environment.

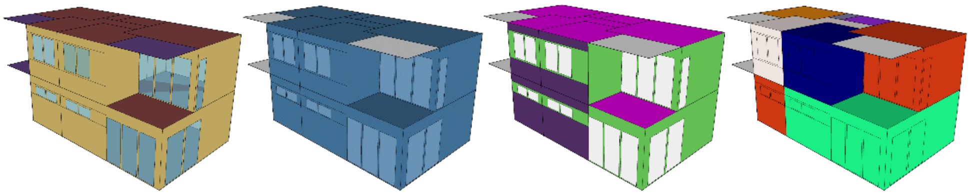

Figure 7. Energy models created in the Open studio plugin in SketchUp

Electricity consumption for cooling was analyzed, and a comparison between scenarios with and without brise-soleil was made using both percentage differences and absolute energy savings. This approach allowed for a clear understanding of the effectiveness of the brise-soleil in reducing cooling energy demand, with a specific focus on seasonal variations and peak months.

5. RESULTS AND DISCUSSION

5.1. Impact on Total Energy Consumption

The results show that brise-soleil is key in reducing cooling EC by controlling solar exposure during the warmer months, with solar gains reduced by up to 25%, leading to a 31% decrease in cooling energy demand during peak summer months.

Nevertheless, to limit beneficial solar heat gains, cooling EC was slightly increased by brise-soleil during cooler months (March to mid-June). This observation is in accord with Alhuwayil et al.'s findings that passive shading strategies may decrease thermal efficiency in climates or seasons with limited sunlight [15]. Their study highlighted how shading devices, while effective in reducing cooling loads in hot climates, can limit beneficial solar heat gains during cooler periods, similar to the slight increase in cooling energy consumption in May due to reduced beneficial solar gains, observed in our study.

However, despite this, brise-soleil was highly effective after July, when peak ambient temperatures occurred. July showed the highest monthly reduction, with energy savings of approximately 24.9%. In July, the configuration without brise-soleil consumed nearly 200 kWh, compared to around 150 kWh with the system installed. These results agree with Koç and Maçka Kalfa [16], who found substantial cooling load reductions from shading devices in Mediterranean regions with high solar exposure. Cooling energy consumption between May and October totaled 639.59 kWh without brise-soleil and 462.21 kWh with it, reflecting a 27.7% reduction. A monthly comparison of cooling EC between configurations with and without brise-soleil is shown in Figure 7, with significant reductions during peak summer months (Figure 8).

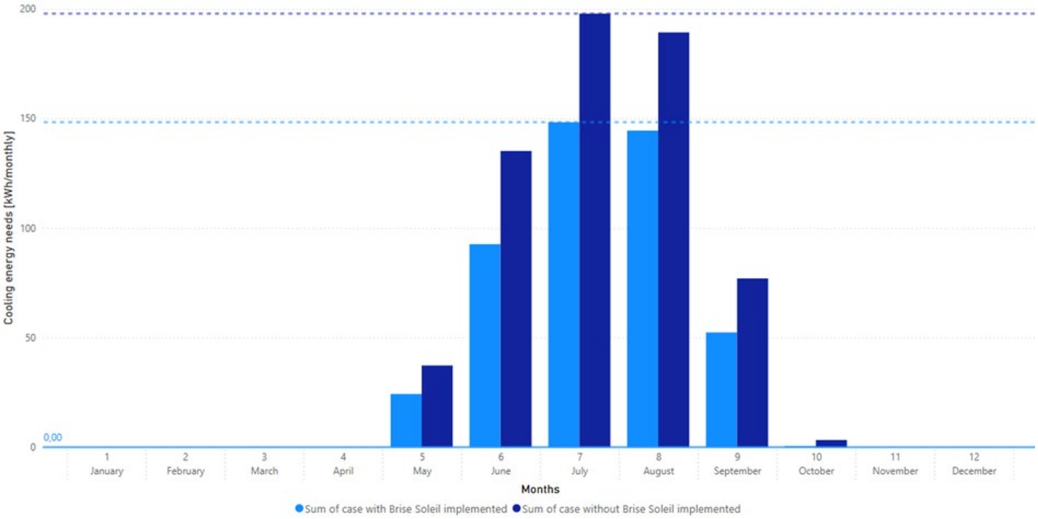

Figure 8. Comparison of monthly cooling energy consumption for brise-soleil and non-brise-soleil configurations

Furthermore, brise-soleil and other shading devices may contribute to sustainable design by decreasing peak cooling demand during heat-intensive periods. This reduces operational costs and conserves the environment by decreasing energy use and emissions, as Mohammed et al. [17] found in high-sun regions, which saw cooling load reductions via shading strategies. In climates with significant seasonal temperature variations, brise-soleil effectively reduces cooling energy needs and greenhouse gas emissions by improving energy performance.

6. CONCLUSION

Brise-soleil systems are increasingly proving to be a practical solution for improving the EE of residential buildings in warm climate zones, where rising global temperatures pose a serious challenge. This study confirms their key role in reducing EC and improving the aesthetics of architectural solutions. The results showed that brise-soleil can reduce monthly cooling EC by up to 31% in the hottest periods while annual savings amount to 12%. This makes them an extremely effective tool for lowering EC and carbon dioxide emissions.

Installing bridge-soleil systems in architectural projects improves EE and functionality and raises the aesthetic quality of buildings. These systems enable adaptable and flexible designs that maximize natural lighting, reduce indoor overheating, and significantly improve building comfort. At the same time, their role in adding dynamic and striking elements to the facades contributes to creating a unique visual identity of the buildings.

The results of this study confirm the key component of sustainable architecture: that brise-soleil systems have significant potential in residential projects to reduce cooling energy consumption by orders of magnitude during the hottest months. Integration of these systems allows urban planners and designers to design projects that fit given climatic conditions, which take energy efficiency, aesthetics, and reduction of carbon dioxide emissions into account. Beyond enhancing the energy performance of buildings, brise-soleil also brings to buildings their visual identity, supporting sustainable development goals. Future research could be directed to developing adaptive brise-soleil systems responding to different climatic challenges and integrating modern technologies, such as solar panels, to enhance energy sustainability in architecture.

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MULTIPURPOSE CHARACTER OF SHOPPING CENTERS - POSSIBILITIES AND DIRECTIONS OF FURTHER DEVELOPMENT

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Abstract

The significance of trade as a public function has strengthened alongside the progress of civilization. In contemporary cities, within the context of an expanding market economy, large-format shopping centers have assumed primacy. Their emergence is regarded as a culmination of human consumer behavior and one of the pivotal shifts in the organization of urban space. Shopping centers are evolving to incorporate a broader range of diverse functions, becoming gathering places and venues where spare time is spent. Consequently, they are no longer perceived solely as spaces for sales, but as places of consumption where trade and leisure intertwine.

The primary objective of the research is to examine current tendencies and strategies in the field of architectural design of shopping centers, as well as to explore successful design methodologies. The research commences with an elaboration of the fundamental characteristics of the modern shopping center. In the next part of the research, various types of shopping centers are analyzed using relevant case studies drawn from both international and domestic architectural practices. Finally, the possibilities and directions for further expansion of the offers are discussed.

Key words: *Shopping Centers, Multipurpose, Architectural Practice, Modern Tendencies, Limitations*

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1. INTRODUCTION

A series of urban, social, economic, and technological opportunities in the first half of the 20^{th} century led to the development of shopping centers. Their proliferation was driven by the following factors:

- limited space for the expansion of the city cores,
- population growth,
- increased car ownership,
- congestion in city centers due to traffic,
- availability of large, accessible land areas, and
- advances in ventilation, air conditioning, and lighting technologies [1].

Seeking a more peaceful environment, residents moved in large numbers to the suburbs, where access to the city's commercial areas was limited. This type of residential suburbanization gained particular momentum in the USA after World War II.

The modern European shopping center originated in Sweden in the mid-1950s. During the 1960s and 1970s, shopping centers first appeared in Great Britain and France, followed by other Western European countries [2]. Their development mirrored the growth of personal incomes and greater consumer mobility, as well as the rise of larger retail chains.

Architect Viktor Gruen, an Austrian who immigrated to the USA in 1938, had a significant influence on the modern form of shopping centers. He envisioned them as a contemporary version of the traditional town square [3], designed as pedestrian-friendly shopping areas. However, he believed that it was necessary to protect customers from external influences and to create enclosed, climate-controlled spaces. As the designer of the first shopping centers, Victor Gruen, also wanted to redefine the modern city proposing that suburban shopping malls become the new urban cores. He saw shopping as part of a larger network of human activities, arguing that sales could be better if commercial activities were integrated with cultural and leisure activities [4]. Gruen saw the design of shopping malls as a way of producing new city centers, or as he called them "shopping cities".

Designing shopping centers as indoor facilities capitalized on the psychological effect that customers would stay longer and spend more if they were comfortable [5,6]. Gruen further explored this effect, finding that people in air-conditioned malls were more willing to walk longer distances. Featuring opaque facades with no connection to the outside - a design resembling a "blind box" - shopping centers used glass roofs to admit natural light. Around central courtyards with fountains, potted trees, gardens, and other furnishings visible from upper levels, Gruen placed restaurants and cafes, which he envisioned as gathering spaces [7] for various social activities [8].

Modern shopping centers have expanded in scale and function, incorporating diverse facilities such as department stores, supermarkets, banks, post offices, kindergartens, and more [9]. The diversity of additional activities from other spheres, unrelated to the primary activities of sales and hospitality, affects the multi-purpose character of shopping centers.

The paper discusses this multipurpose aspect of shopping centers and poses the following research questions: (1) are there opportunities for further expansion of scale and function in these already very complex buildings, and (2) do outdoor activities, as a new preference of visitors, shape the future of shopping centres?

2. METHODOLOGY AND MATERIALS

2.1. Method

The following methods were applied in this research: the descriptive method, the method of classification, and the methods of analysis and comparative analysis.

The research focuses on current trends and tendencies in the reference architectural practice. The base of buildings on which the research was conducted consists of 20 shopping centers from Europe and Asia, built between 2010 to 2024, when it comes to foreign experiences, and 8 buildings built in Serbia, in Belgrade, Niš, Novi Sad and Kragujevac. Three typical examples from these buildings' databases were selected for case studies.

In the next stage, in order to perform more comprehensive summarization and systematization of the characteristics of the selected shopping centers, a system of criteria significant for determining the relationship between the expansion of the indoor and outdoor activities and the future development of these facilities was established.

2.2. Characteristics of modern shopping centers

A whole team of experts from different fields is involved in the process of designing shopping centers. The location of the future building and its characteristics, both strategically and physically, significantly determine the size, type, and character of the shopping center [10].

There are many different types of shopping centers and there are many criteria by which they can be classified. Part of these criteria are the following:

- location (regional, district, and local shopping centers),
- number of people visiting the mall (city and suburban shopping centers),
- constellation of activities
- combining with other functions (shops with additional activities),
- the character of the store (fashion centers, or “lifestyle” centers),
- physical forms (open and closed shopping centers, within shopping parks, shopping resorts, business districts, and mixed-use environments within the city center), and
- generation (measured by the level of changes that have occurred within a certain type [11].

According to the European standards [12], shopping centers are divided into traditional ones (very large, large, medium, and small) and specialized ones (sales parks, factory outlet centers, and themed centers).

Spatial organization should ensure a natural flow of movement through the shopping center. There are two characteristic types of organization of closed shopping centers, namely linear and circular [10]. Linear type (Figure 1. left) is the simplest type of organization of the base of the shopping center. It is defined by two endpoints, in the form of "anchor" stores, which are interconnected. Within them, you can also find "focus points", with the function of housing vertical communications, the hub of horizontal communications, the formation of an angle at the base, or recognizable zones in communication spaces.

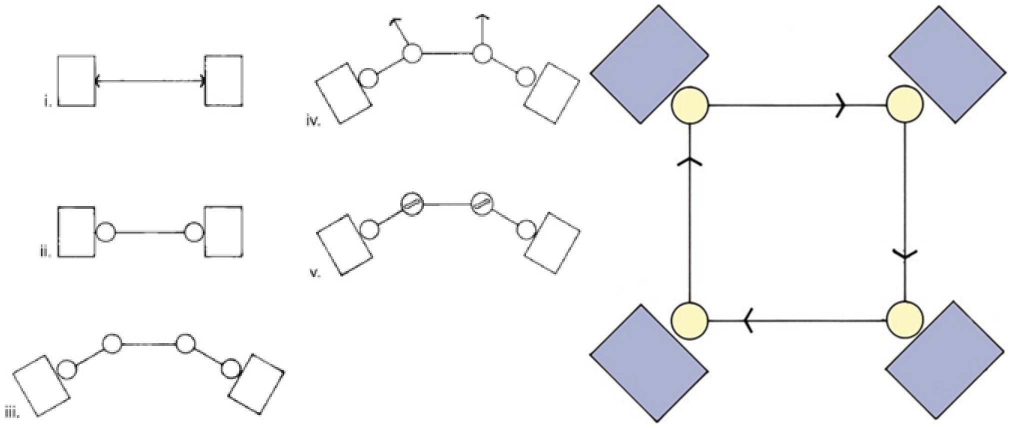


Figure 1. i) a unique sequence between two "anchors"; ii) string with nodes; iii) nodes used to change the direction of movement; iv) nodes receiving other paths; v) nodes that include vertical communications (left); circular organization with nodes anchored by stores (right); source: Beddington, 1982.

In circular organizations (Figure 1, right), visitors can access all parts of the shopping center without retracing their steps, ultimately returning to the point from which they started moving through the center [13]. The form of the number "8" is also considered a form of circular motion. Also, the vertical movement can be part of the circular movement through the center. "Anchor" stores, strategically placed and clearly visible, play a role in motivating movement.

The organization should be simple, easily recognizable, and it must not be monotonous. Points of interest or places of rest must be found every 200-250m because visitors lose interest after crossing those distances.

2.3. Case studies from foreign architectural practice

Among the reference foreign realizations, the following notable shopping center buildings were considered: the „Emporia“ shopping center (Malmö, Sweden), known for its distinctive architectural identity, „Mega Foodwalk“ (Thailand), which blends retail and public space innovatively, and „Parc Central“ (Guangzhou, China), renowned for its fluid design and integration of green spaces, all of which serve as the exemplary models of modern retail architecture.

2.3.1. Emporia Shopping Center / Gert Wingårdh, Malmö, Sweden, 2012.

"Emporia" shopping mall is located in the Hyllie district in the southern part of Malmö, Sweden. It is one of the largest Scandinavian shopping malls (Figure 2.). It has a mixed structure and, apart from about 200 shops, it contains administrative and business premises and certain accommodation capacities.

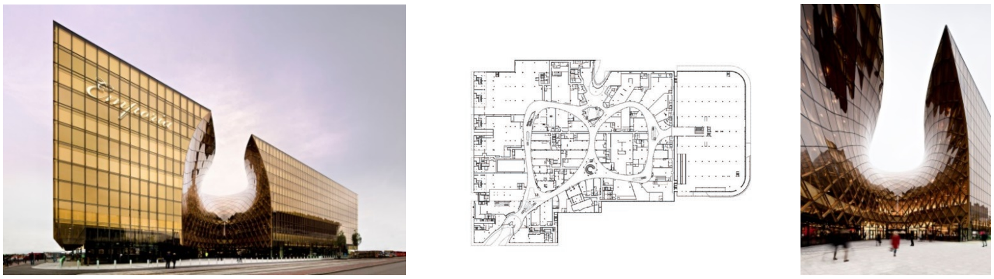


Figure 2. The appearance of the building and the ground floor, source: https://archello.com/project/emporia, 20.11.2024.

The main idea is to create a building with a strong visual identity to attract visitors to enter from the square and then lead them from the entrance deep into the block [14]. Within the block, retail is organized around a three-sided figure eight. There is a park on the roof, designed as the cultivated nature. The vegetation itself and the sun-facing paved gardens are accessible from both inside and outside. On the north side of the complex, a ramp leads to a garage for about 2,500 cars.

2.3.2. Mega Foodwalk / FOS, Tambon Bang Kaeo, Thailand, 2018.

The size of the Megabangna shopping complex is as large as a small town. Its central building is perceived as a downtown, whereas the Foodwalk zone on the east wing is formed as the countryside with more green areas and canals.

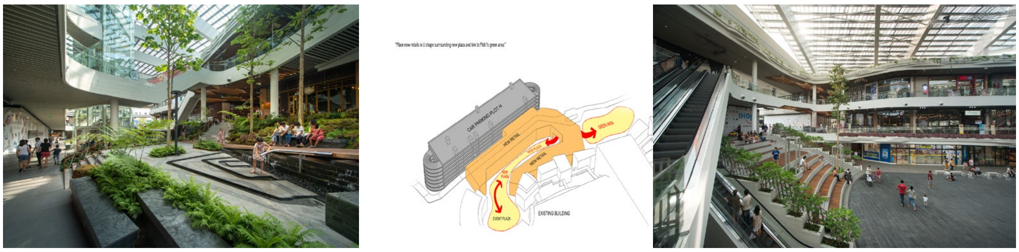


Figure 3. The appearance of the building, the circulation diagram, and the view of the interior of the covered area, source: https://www.archdaily.com/894133/mega-foodwalk, 18.11.2024.

To create a similar atmosphere of a natural valley, an open-air mall is created around a central courtyard space, in which a plaza with an amphitheatre (Figure 3.) in the lower part works as the customers' main social space for gathering and holding all kinds of events. Continuing from the plaza on the bottom level, the sloping green area in the middle of the complex, called 'the Hill', gently ascends to connect with the Mega Plaza on level 1. The Hill is intended to be a relaxing space where people can fully immerse themselves into the lush landscape with water features and outdoor equipment [15]. By embedding greenery into the open-air courtyard and throughout the building, the project becomes a hybrid of a marketplace and a public park where social interactions are more encouraged among people. Simultaneously, a network of walkways along shopfronts on every level is connected to a new car parking building via pedestrian bridges and a covered walkway in order to complete the communication system.

The idea of transforming the natural environment into a unique shopping experience is synthesized through its spatial organization and various architectural elements. A series of walkways are formed, descending gently down from upper to lower levels, to create a similar experience to a 'hill walk'. This results in not only increased saleable areas on the lower levels but also continuous communication, circling endlessly on all four levels.

2.3.3. Parc Central / Benoy, Guangzhou, China, 2016.

Parc Central, Guangzhou is the urban park retail center in the heart of the city's Central Business District. Parc Central has introduced a new typology that uniquely blends the low-rise above and below-ground retail development within a multi-level parkland. Positioned along one of the city's major thoroughfares, this building combines retail, transit-oriented, and public realm design strategies.

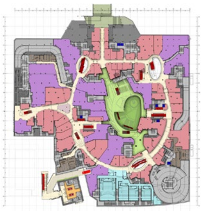




Figure 4. The appearance of the building, the ground floor, and the view of the central part of the complex, source: https://www.archdaily.com/791640/parc-central-benoy, 18.10.2024.

Parc Central is a retail building that is designed around an open parkland environment. Forming the heart of the complex (Figure 4.), the landscape, with its varying levels and forms of greenery, has created a place to socialise, rest, and relax. It is a 'Place to breathe' within the city centre zone. Much of the building has been placed underground to achieve this and preserve the ground-level environment.

The gardens, planted walkways, and living walls create an undulating green space that integrates not only with the complex itself but also with the surrounding streetscape [16]. The two buildings curve around the central gardens and are joined by a pedestrian bridge at one end. The design enables the complex to function as a multi-dimensional gathering space with convenient accessibility above, below, and at ground level.

Parc Central is a low-rise building, with two levels above ground and three levels underground. Being lower than the surrounding buildings, the architectural design called for an eye-catching and powerful visual expression. The geometry of the architecture is fluid. The roof canopies are supported by tree-like columns beneath which sit a series of gardens that extend the landscape element up the building. Large atriums punctuate the retail string and draw light into the arcades.

Sustainably designed, Parc Central's environmental performance is also enhanced through the addition of a rainwater collection system and low-E glass façades, and an EFTE roof.

2.4. Case studies from domestic architectural practice

Among the representative examples from domestic practice, the following prominent shopping center facilities were selected and analyzed: "Ušće" shopping center (New Belgrade, Serbia), “Ada mall“ center in (Belgrade, Serbia), and „Delta Planet“(Niš, Serbia), all of which reflect current trends in Serbian retail architecture.

2.4.1. “Ušće” shopping center/ Mihailo Janković, New Belgrade, 2009.

"Ušće" shopping center is one of the largest shopping centers in Serbia with an area of 130,000 m2. The building is located at the meeting point of the old city center and New Belgrade, which makes it equally distant from the city center as well as the new business center of the capital.

On 50,000 m2, there are over 135 shops, restaurants, bars, game rooms, supermarkets, as well as one of the most modern multiplex cinemas with 11 screens (Figure 5). It was built on four levels and has 1,300 parking spaces spread over two underground floors.

Figure 5. The appearance of the building, the ground floor, and the view of the escalators in the interior, source: https://www.gradnja.rs/tag/usce-trzni-centar/

The facility received the prestigious LEED certificate and thus became, in its time, one of the largest LEED-certified shopping centers in the region and Europe. In this way, it was confirmed that the facility applies the highest standards in five key areas related to environmental protection and human health, namely: sustainable development, water conservation, energy efficiency, adequate use of resources and materials, and the quality of interior space [17].

2.4.2. “Ada mall“ center/ Design International, Belgrade, Serbia, 2019.

The building of the shopping center has an irregular shape. Descending in a cascade, with its form and green terraces on two levels, it follows the movement of the surrounding terrain (Figure 6).

Figure 6. The ground floor and a view of the cascading descent of the building on the site, source: https://www.gtcgroup.com/en/portfolio/projects/serbia/ada-mall

Sales premises are located on the first three floors, while on the floors above, there are catering and recreational activities. All the premises and the movement of users are organized in a gallery style around a central, zenithally lit space.

The modernly designed building of 90,000 square meters stands out with facade brise soleils on large glass surfaces. The materials applied to the building are in accordance with the principles of environmental protection [18]. "Ada Mall" has a LEED Gold certificate for construction and design, which confirms that it was mostly built with materials of the local origin, optimized resources, and with minimum CO2 emissions.

2.4.3. „Delta planet“/ Delta Real Estate, Niš, Serbia, 2021.

The first Delta Planet in Serbia is located close to the city center of Niš, and it is well connected by traffic to other city areas. With the construction of this building, Niš has become a place of modern shopping experiences, offering visitors a large selection of domestic and international brands, restaurants, cafes, playrooms for children, and many other facilities (Figure 7). Very soon after its opening, Delta Planet Niš became a favorite destination for shopping and socializing.

Figure 7. Architecture of the building, ground floor and view of the upper galleries, source: https://www.projektinzenjering.com/projekat/delta-planet-nis-srbija/

The inspiration for the authentic design of the facade was found in the synergy of elements from the traditional Serbian carpet of South Serbia and the tangram, which is a feature of the logo of Delta Holding Company. Attractive architecture, state-of-the-art technical and technological solutions, and an environmentally conscious approach, including the heat pump system [19], have made Delta Planet one of the urban symbols of Niš.

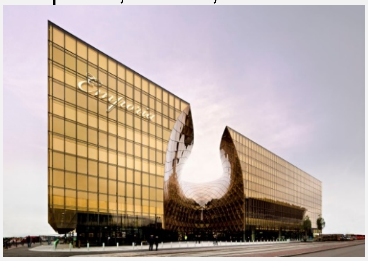
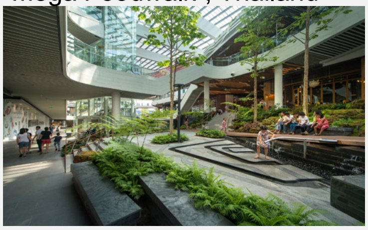
A major challenge during the execution of the works was in the area of the main entrance to the building, where the structure is practically suspended from the roof. This achieved an overhang at a height of 12 meters, which is a real rarity in architecture in the region.

3. RESULTS AND DISCUSSION

Both foreign and domestic experiences were examined through the analysis of characteristic shopping center examples as case studies.

Each of the distinctive buildings represents a unique and innovative approach to architectural design and materialization. The "Emporia" shopping mall, “Mega Foodwalk” and „Parc Central“ are attractive buildings with specific concepts. They are transforming shopping malls into urban public spaces with social features [20,21], aiming to enhance sustainability. These buildings are characterized by biophilic design [22], and offer an environmentally interactive experience within commercial spaces (Table 1).

Table 1. Characteristics of analyzed foreign examples (Source: Authors)

Selected example (foreign)	Characteristics
"Emporia", Malmö, Sweden 	• It has about 200 shops and includes administrative and business premises, as well as accommodation facilities; • petail is organized around a three-sided figure eight, and the rooftop park is designed as cultivated nature; • a structure with a strong visual identity; • a ramp on the north side of the complex leads to a garage with space for about 2,500 cars.
“Mega Foodwalk”, Thailand 	• Semi-open shopping mall; • an atmosphere similar to a natural valley, featuring green areas and canals; • a plaza with an amphitheater as the main social space for customers; • a hybrid of a marketplace and a public park; • every level is connected to a car parking structure.
„Parc Central“, Guangzhou 	• Large urban park retail; combined type • the architecture is characterized by fluid forms; • includes two levels above ground and three underground levels; • large atriums punctuate the retail area and draw light into the arcades; • the roof features canopies, under which a series of gardens pull the landscape elements up the building.

The research was initiated with the hypothesis that the continuous expansion of supplementary amenities beyond retail and hospitality is approaching its peak, resulting in the development of enormous architectural structures, including complexes and mega-structures. These new activities encompass offerings that cater to nearly all aspects of life and the diverse interests of visitors.

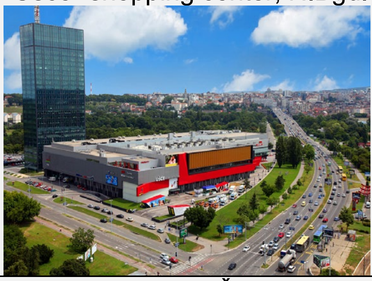
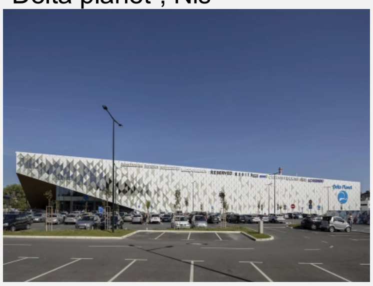
From this perspective, an emerging trend has been identified: the conceptualization of structures that integrate the external natural environment into their interiors, or, conversely, extend interior spatial qualities into the surrounding natural environment. This trend is exemplified by semi-open shopping centers or hybrid forms that combine enclosed and semi-open configurations.

A significant addition to these contemporary shopping environments, absent from traditional malls, is the inclusion of outdoor activities that are seamlessly interwoven with the shopping experience. Activities such as walking, resting, children’s play, outdoor social gatherings, and open-air events are conducted within a natural setting enriched by greenery and water features. The incorporation of natural elements and landscapes within these structures is no longer merely a response to sustainability principles but has become a strategy for enhancing the experiential quality and broaden the range of activities accompanying shopping.

Enclosed shopping centers, which are experiencing a decline in visitor numbers, are gradually being supplanted by hybrid and semi-open typologies that better align with evolving user preferences and behavioral patterns.

The buildings of domestic shopping centers are transitioning to multipurpose developments, combining retail with functions such as office spaces, fitness centers, apartments, commercial spaces, and event areas. Domestic shopping malls now aim to create socially engaging retail experiences by incorporating events, master-classes, job fairs, and a diverse retail mix. Another key characteristic is their adherence to sustainability principles, with many buildings obtaining LEED certification, reflecting their commitment to environmental protection and sustainable design practices (Table 2).

Table 2. Characteristics of analyzed domestic examples (Source: Authors)

Selected example (domestic)	Characteristics
"Ušće" shopping center, N.Bgd. 	• Over 135 shops, restaurants, bars, game rooms, supermarkets, and multiplex cinemas with 11 screens; • built across four levels, with 1,300 parking spaces spread over two underground floors.; • the building adheres to the highest standards of sustainable development, including water-saving, energy efficiency, resource optimization, and quality of interior spaces.
“Ada mall” center, Čukarica 	• Features an irregular shape with green terraces on two levels; • offers about 35,000 square meters of usable space, with three underground parking floors; • the first three floors house 100 shops, while the upper floors include catering and recreational activities; • organized in a gallery-style layout around a central, zenithally lit space.
“Delta planet”, Niš 	• Large selection of domestic and international brands, restaurants, cafes, playrooms for children, and other facilities; • destination for shopping and socializing; • features an authentic façade design, with the main entrance being a significant structural challenge; • utilizes state-of-the-art technical and technological solutions, including a heat pump system, to ensure environmental sustainability.

When it comes to domestic architectural practice, representative examples show that the closed form of shopping centers is dominant. Nature and elements of nature are represented only in certain buildings in the form of green roofs and terraces. The tendency to open is still in perspective, and modest forms of outdoor activities are extensions of cafes that expand from the inside of the premises to the outside when the weather is good.

Table 3. Summary analysis and systematization of results

Analyzed buildings	A	B	C	D	E	F	G	H	I	J	K
Foreign examples											
"Emporia"	**o**	o	o				o	o		o	o
“Mega Foodwalk”	o			o		o			o	o	o
„Parc Central“	o				o				o	o	o
Domestic examples											
"Ušće"	o		o				o			o	o
“Ada mall” center	o		o				o	o		o	o
“Delta planet”	o		o				o			o	o

Legend: A- Shops with additional activities; B- Mixed structure; C- Closed physical form; D- Semi-open physical form; E - Urban park retail-combined type; F- Linear spatial organization; G- Circular spatial organization; H- Park on the roof; I- More green areas; J- Aspects of social sustainability; K- Aspects of ecological sustainability (Source: Authors)

The results of the comparative analysis of the selected shopping centers are summarized and systematized in Table 3. The multipurpose character of these buildings was analyzed with respect to several different criteria such as physical form, spatial organization, the presence of elements of the natural environment, and aspects of sustainability. The results show that multipurpose correlated with circular spatial organization in closed physical forms of buildings contributes to social sustainability. In the case of semi-open and combined types of physical forms, the presence of more green areas and additional outdoor activities contributes to the ecological and social sustainability of these buildings.

4. CONCLUSION

Throughout history, trade took place in markets, fairs, and squares, and over time, clusters of trades emerged in central city areas. The appearance of shopping centers is primarily related to the development of the automobile industry and the emergence of the so-called "sales boxes" on the outskirts of cities, primarily in the USA, which later transformed into multifunctional spaces for entertainment, recreation, socializing, and spending leisure time. The emergence of new trends in the creation of shopping centers represents a desire to modernize their concepts, as well as to build modern buildings, unusual constructions, facades, and shapes that will impress visitors and lead them to spend as much as possible [23,9].

Through the development of shopping centers, various types of these buildings were created based on their position in urban areas. It has been proven that shopping centers have a significant influence on the quality of the urban environment in the surrounding area, in terms of the habits of visitors and the way they use the space [24].

Shopping centers that do not have spaces that people can perceive as their own, and where they feel comfortable spending time, are doomed to fail. That is why the shopping centers of the future must include smaller squares that bring a new spirit of "place" and thus grow into a public good. Therefore, shopping centers aspire to become new city centers. They will be the most visited "city squares", places to meet friends and combine shopping, entertainment, and enjoyment.

Respecting the context and integrating nature into shopping center buildings are key factors for their success and progress [22]. Consumer preferences have changed, and consumers favor relaxation in open spaces. "Lifestyle" centers appear as an answer. These centers feature extensive open spaces integrating shops, entertainment venues, parks, and business and residential buildings.

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GEOMORPHOLOGICAL, GEOLOGICAL, AND HYDROGEOLOGICAL FEATURES OF THE IMMEDIATE SURROUNDINGS OF SARAJEVO, BOSNIA AND HERZEGOVINA

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Žarko Grujić[3]

Abstract:

The Sarajevo depression and its surrounding area, from a hydrogeological perspective, represent an exceptionally complex system. In an area that was subjected to intense tectonic processes in geological history, due to the activity of specific climatic and hydrological conditions, a series of exogenous processes were activated, which, in morphological terms, reshaped this area and, consequently, influenced its hydrogeological properties. The area can be divided into two main units: the intensely folded and fractured mountainous region of the periphery and the Sarajevo field area, or the Sarajevo depression itself. The aim of this paper is to highlight the specific hydrogeological properties of the terrain, the particularities of individual blocks of the mountainous periphery, and the hydrogeological characteristics of the Sarajevo field area. The periphery of the Sarajevo depression is composed of powerful, predominantly limestone-dolomite deposits, which serve as hydrogeological conductors, and the underlying deposits of Lower Triassic age, known as the Sarajevo sands, which act as hydrogeological insulators. The key factors influencing the hydrogeological properties of the terrain include: hydrological conditions, terrain morphology, lithological composition, and structural characteristics. The aim of this paper is to present the most significant results of the mentioned research and to frame them into a unified whole, in order to provide a clear understanding of the hydrogeological properties of the terrain in the immediate surroundings of Sarajevo.

Key words: *Geomorphological, Geological and Hydrogeological properties, Sarajevo depression, Hydrogeological collectors, Hydrogeological insulators*

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1. INTRODUCTION

The environment of Sarajevo, specifically its mountainous part, is primarily composed of Mesozoic sediments, while younger Tertiary and Quaternary formations make up the lower periphery and the area of the Sarajevo-Zenica depression. Geological research initially began with informational prospecting, followed by regional geological surveys, and later detailed geological studies related to the implementation of specific projects. The first geological map of the wider Sarajevo area was created by E. von Mojssisovich, A. Bitner, and E. Tieze (1880). More detailed research was conducted by the Austrian geologist F. Katzer (1901–1918).

Between the two World Wars, more extensive research was carried out by B. Milojković (1929), Đ. Vasković (1931), and T. Jakšić (1931).

In the post-war period, notable works were done by I. Soklić, P. Stevanović, R. Milojević, P. Muftić, R. Jovanović, LJ. Rokić, E. Ramović, and others.

From a hydrogeological perspective, the oldest data dates back to the Ottoman period and is related to solving water supply issues. E. Ludwig and F. Katzer provided basic data on the occurrence of mineral and thermomineral waters in the Ilidža area [1].

Recent geomorphological, geological, hydrological, and hydrogeological research began in 1951 (Tilava) for the purpose of expanding the water supply network, while more extensive studies of the Sarajevo field and its outskirts aimed at defining the hydrogeological properties of this area started a bit later, and in some ways, continue to this day [5].

The goal of this paper was to present the most significant results of the aforementioned research and frame them into a cohesive whole in order to provide a clear understanding of the hydrogeological properties of the terrain in the immediate surroundings of Sarajevo.

2. RESEARCH METHODOLOGY

During the field research, for the purposes of constructing certain buildings, road infrastructure, as well as for the investigation and remediation of specific landslides, and during the supervision of the implementation of certain projects in the Sarajevo area and its surroundings, the authors collected all available documentation and used the results obtained from field research, as well as the results of laboratory tests. Based on these results, a synthesis was made, and this paper presents the basic geomorphological, geological, and hydrogeological properties of the terrain in the immediate surroundings of the city of Sarajevo.

Primarily, the results shown on the OGK SFRJ map of Sarajevo were used, as explained in the accompanying interpretation, along with available studies and works done in this field. A limitation is the absence of the OHGK Sarajevo map.

During the construction of certain buildings and the investigation and remediation of specific landslides, detailed engineering-geological mapping of the terrain was carried out at several locations for the needs of the project documentation, based on which numerous exploratory works were located, both in the design phase and additional exploratory works during the construction of the buildings themselves. A series of exploratory boreholes, excavation pits, and test trenches were made, certain geophysical investigations were applied, and a significant number of laboratory geomechanical, mineralogical, and petrological tests were conducted, as well as a number of engineering-geological and hydrogeological maps for specific parts of the terrain, depending on the construction issues of certain buildings, the remediation of landslides, or the resolution of stability conditions of certain slopes whose natural stability was disturbed either by the construction of new buildings or by some completely natural processes.

3. MORPHOLOGICAL PROPERTIES OF THE TERRAIN

Due to specific climatic and hydrological conditions, in an area previously subjected to strong tectonic processes, very active erosion-denudation processes have occurred, both before and during the glacial phase, as well as fluvioglacial processes that have acted over a long geological period and formed various and distinctive characteristic shapes in areas built by Mesozoic carbonate sediments, as well as Cenozoic carbonate-clastic and flysch sediments [1].

Basic structural forms, although transformed through various orogenic phases, have preserved elements of anticlinoria along the Romanija – Jahorina stretch and synclinoria along Bjelašnica – Igman. The morphogenetic forms resulted from the platy and radial movements, particularly affecting the rigid Triassic limestone-dolomitic plate, in relation to the plastic masses of the Verfens and partially towards the underlying Paleozoic rocks [3].

It is certain that in this area, where intense faulting processes took place, regional horsts and grabens were formed, which, through these basic structural forms, created special morphogenetic shapes. As a result, characteristic karst surfaces at various hypsometric positions were formed by the action of erosion-denudation processes, with periodic repetition of endodynamic movements, shaping primary morphological forms and giving them their present appearance.

Jovan Cvijić, regarding the relief development in central Bosnia, mentions that from the Sarajevo Field on the right side of the Bosna River, a series of long parallel valleys, tributaries of the Bosna River, are observed, which are inverse. It is believed that inverse valleys could not have originally been valleys of the present-day Bosna River, but rather belonged to another hydrological regime [9]. It is not excluded that the hydrological system developed several times and at different intensities in this area. Specific characteristics noted include preserved terraces at high altitudes, remnants of a lake basin that once filled the Sarajevo field. It is believed that the terraces of the Bosna River and other watercourses (Miljacka, Željeznica, Tilava) are up to 35 meters above their current beds [1].

Depression of the "Sarajevo-Zenica Basin" tends to sink unevenly towards the southwestern border compared to the northeastern. The river courses, Miljacka, Tilava, Željeznica, and Kasindolska River, have a Dinaric direction and are deeply incised into the Triassic sediments, which, in relation to the lake and Quaternary sediments, clearly indicate the oscillation of the depression. It is certain that the terraces of the upper courses correspond to lake development phases.

Glacial relief form, developed in the Bjelašnica area, and a large amount of glacial material was deposited and accumulated in the Veliko Polje area. A system of deep sinkholes with ponors formed in this area [1].

The sources of rivers below Bjelašnica and Treskavica developed intensively during the deposition of lake sediments, which caused a very deep erosional base to be reached in this area. The intensification of erosion-denudation processes resumed after the draining of the Oligocene lake in the Pliocene. It can be concluded that the surface of Igman was early karstified, but also that fluvioglacial deposits are found on its slopes.

The area of Trebević and Jahorina is not morphogenetically or hydrologically uniform, but represents a geomorphological form created by the high uplift of this part of the edge, as the Verfens sediments (T1) lie at high hypsometric levels, covered by relatively thin, variably oriented, radial and transverse faults, with fractured blocks of limestone-dolomitic plates. The parts of the limestone plates are relatively thin, so they do not allow for larger accumulations in the higher parts of Trebević, whose fragmented blocks gravitate towards the depression.

The narrower area of Paljanska and Mokranjska Miljacka, near the entrance to the Sarajevo basin, has specific morphogenetic forms. In this part, the Triassic limestone plates fractured, causing the limestone masses from the subsidized area to be the lowest and form the initial depression [12].

On the slopes towards Trebević and Hreša, an irregular slip of limestone blocks is evident, either towards the border of the internal depression or towards the initial depression in the Miljacka River valley. Notably, high terraces of the Miljacka River are preserved in this area, especially in the Bentbaša region.

The Romanija limestone surface actually represents the highest area in the southeastern surroundings of Sarajevo, in which the structure of the Middle Triassic (T2) limestone sediments lies over the Lower Triassic (Verfens) T1 clastic sediments.

4. HYDROLOGICAL PROPERTIES OF THE OBSERVED TERRAIN

The Bosna River, along with its larger and smaller tributaries in the wider Sarajevo area, covers a catchment area of nearly 1000 km^2. From the northeast to the southwest, the Vogošća, Koševski Potok, Mošćanica, and Mokranjska Miljacka flow as tributaries of the Miljacka River from its right side, while on the left side of the Miljacka, the tributaries include the Dobrinja River or Tilava, followed by the Kasindolska River, Željeznica with its tributaries, Presjenica, Bijela, and Crna rivers. The main hydrogeological collector is the outcrop from which the Bosna River originates. The source of the Bosna River is a typical karst spring, formed at the contact of Middle Triassic (T2) massive limestones as the hydrogeological collector and Verfens (T1) sandstones, known as the Sarajevo colored sandstones, which function as a hydrogeological isolator [2].

All the mentioned rivers are torrential in their upper parts, with varying intensities. Since the main valleys of these rivers are conditioned by structural morphological forms and pre-existing platy and particularly radial deformations, the valleys of these rivers are highly variable along their longitudinal profile, often alternating between wide sections and narrow gorges where these streams carve through blocks of Triassic limestone. Only upon entering the vast Sarajevo basin do they acquire the characteristics of lowland rivers.

The Bosna River is the main surface drainage collector of Sarajevo and its surrounding area. It springs at the foot of Igman, as a typical karst spring. The spring is a fragmented karst outcrop with a variable discharge regime, formed from a series of different springs along a stretch of about 550 meters.

The Večerica River is the first right tributary of the Bosna River. Its length is approximately 5 km. It is exclusively supplied by groundwater from the Igman-Bjelašnica block, as confirmed by hydrogeological studies [2].

The Željeznica River is a right tributary of the Bosna River, with the longest course (approximately 54 km). It springs beneath Treskavica and flows into the Bosna River at Osijek. The spring is located at an elevation of around 1200 m a.s.l., and the confluence is at an elevation of 491 m a.s.l., giving it an average gradient of 1.33%. The main tributaries of the Željeznica River are Crna River, Bijela River, and Presjenica. The average flow in the Krupaćki Rocks area is around 6 m^3.

The Kasindolska River is the second right tributary of the Željeznica River. In its upper and middle parts, it is incised into a gorge in the carbonate rocks of the Middle Triassic T2. Its length is about 25 km.

The Dobrinja River, or its constituent rivers, springs beneath Trebević and its length is around 17 km. This river is actually made up of two smaller streams, Lukavica and Tilava.

The Miljacka River is one of the largest tributaries of the Bosna River, originating from the Paljanska and Mokranjska Miljacka, which meet 6 km southwest of entering the Sarajevo urban area. The elevation at the confluence is 595 m a.s.l. The total length of the Miljacka is 53 km. The main tributaries of the Miljacka are Lapišnica, Mošćanica, and Koševski Potok. All of these tributaries are torrential in their upper courses. The Paljanska Miljacka springs as a typical karst spring at an elevation of 1020 m a.s.l. on the northern slopes of Jahorina, flowing northeast into the area of Pale where it meets with the Repešnica River, which collects water from the wider Pale and Ravna Planina regions. From the Pale area, where it flows almost as a lowland river, slightly upstream from the confluence with the Bistrica River coming from the slopes of Jahorina, it cuts into a deep gorge of Triassic limestone, where the elevation differences are several hundred meters. The gradient in the gorge areas is close to 40°, while the average gradient is 2.81%. After the confluence with Bistrica, the flow direction is Dinaric.

The Mokranjska Miljacka springs on the western slopes of Romanija at an elevation of 1060 m a.s.l. The length of the course to the confluence is about 15 km. In the Mokro area, before entering the limestone gorge near Ljubogošte, it is a lowland river, receiving tributaries from Ratkovac and Tabakovačka rivers. From Ljubogošte to the confluence with the Paljanska Miljacka, there is a high gradient of 31.7. Below Bentbaša, the gradient of the Miljacka is 2.98.

Zujevina is the most significant left tributary of the Bosna River in the Sarajevo basin. Its spring is located on the Quaternary watershed of Osenik. It receives the right tributary Krupa and the left tributary Rakovica. The length of the stream is around 20 km with a minimum flow of 0.2 m^3/sec. In addition to the mentioned karst springs of Krupa, the right tributaries represent smaller karst springs in the area between Pazarić and Hadžići. The waters of this river are connected to the depressed parts of the limestone-dolomitic block of Bjelašnica-Igman but are more directly related to the narrower area of the Osenik watershed, particularly to the karst springs around Zovik and Hadžići.

At the hydrometric station Plandište, from 1961 to 2016, the average flow rate of the Bosna River was 5.51 m^3/sec, with a maximum flow rate of 8.818 m^3/sec and a minimum flow rate of 2.45 m³/sec. At the hydrometric station Reljevo Reservoir, where the Bosna River receives all its tributaries in this area, the average flow rate is 28.8 m³/sec, the maximum flow rate is 44.2 m³/sec, and the minimum flow rate is 17.9 m³/sec, according to data from the Agency for the Watershed of the Sava River [13].

From the above, we can conclude that most of the right tributaries of the Bosna River generally follow a Dinaric direction, while only certain sections are conditioned by radial tectonics, influencing such flow directions.

5. GEOLOGICAL COMPOSITION OF THE TERRAIN

The geological composition of the terrain of the city of Sarajevo and its wider surroundings can be classified into four geological units as follows [4]:

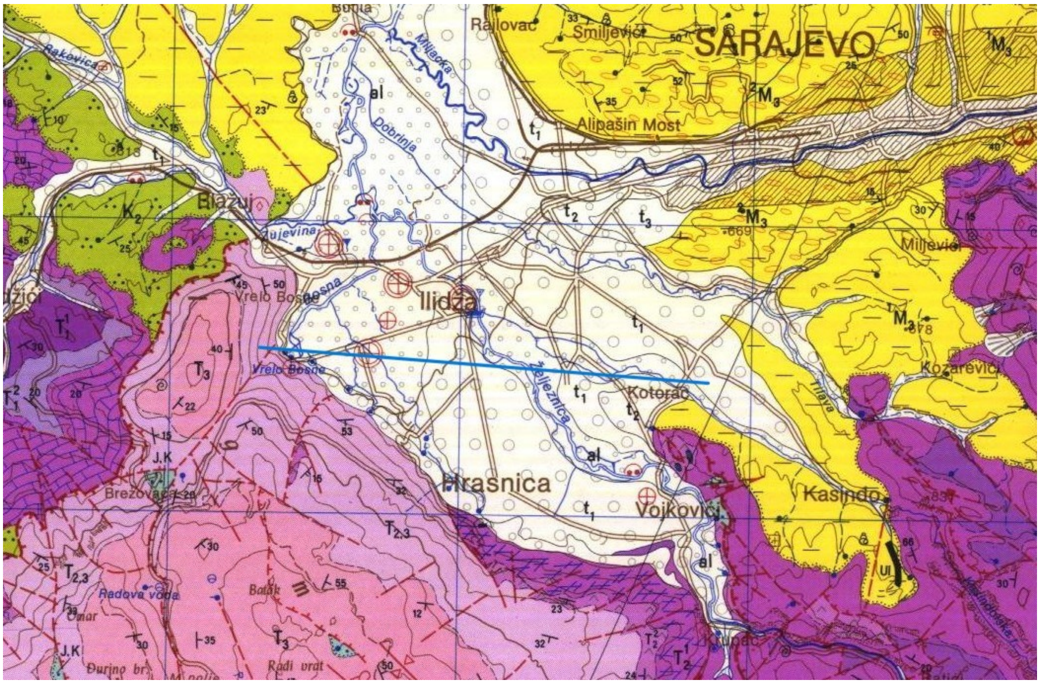

Fig. 1. Geological map of the studied area

- Lower Triassic or Verfenian sediments (T1), which can be subdivided into three lithological units:
  - A complex of sandstones, marls, and clays, which from a geotechnical perspective represents an unfavorable working environment, especially if the structural position is unfavorable relative to the slope. In terms of hydrogeological function, this lithological series acts as a hydrogeological isolator. In the geological past, it was exposed to strong tectonic processes and significant influences from exogenous factors, particularly denudation processes such as Sedrenik, northern slopes of Trebević, Pale, and Mošćanica. From an engineering geological aspect, it can be classified as rocks with unfavorable properties, where the terrain on gently inclined slopes is conditionally stable, while on steep slopes it is conditionally stable to unstable [7];

   - A complex of layered white and red sandstones (Sarajevo's colorful sandstones), which are more favorable from an engineering geological aspect compared to the previous lithostratigraphic unit, and the slopes composed of these sediments are stable to conditionally stable (Trebević, Sedrenik, Hreša, Pale, Mokro);
   - A complex of marls and thinly layered marl-limestone rocks which have a limited distribution and are found in the area of Kijevo, as well as sporadically on the northern slopes of Trebević. In terms of engineering geological properties, they are similar to pure limestone rocks;
- A complex of limestones and dolomitic limestones from the middle Triassic (T21,2):
   - Massive limestones of the Anisian stage of the middle Triassic (T21) form the lowest parts of the Sarajevo depression's boundary, characterized by a high degree of fracturing, with large systems of fissures along which significant block movements and displacements have occurred. As a working environment, these rocks are very favorable. These rocks can be used as quality construction materials, while the natural slopes are stable [12];
   - Banked to layered limestones of the Anisian and Ladinian stages of the middle Triassic are characterized by a high degree of karstification, with significant presence of fractures and larger fissures. At the base of these rock layers, screes have formed, and natural slopes are stable. As construction materials, these rocks are less commonly used due to the presence of dolomites;
   - Layered thin-bedded limestones and marls of the Ladinian stage are significantly folded and thrust. Natural slopes are conditionally stable to unstable. These rocks are rarely used as construction materials.
   - Volcanic sedimentary complex of the Ladinian stage, which, in addition to thin-bedded limestones with dolomites and marls, includes volcanic rocks such as tuffs and spilites. Depending on whether they are exposed or not, and the structure of the rock mass, they behave differently regarding erosion-denudation processes [4];
   - The first three formations function as conductors in hydrogeological terms, while the last formation acts as an isolator.
- Jurassic-Cretaceous J,K (Tithonian-Valanginian) flysch

  This lithostratigraphic unit is represented by breccias, brecciated limestones, marls, and clays that alternately change in the geological column, and each of the facies of this complex has its engineering geological and hydrogeological properties. In general, we cannot view them individually, but rather as a complex, concluding that this complex has different engineering geological, geotechnical, and hydrogeological characteristics that depend on the individual facies of this flysch complex. Locally, this lithological formation functions as a hydrogeological collector, and in some areas as an isolator. It is widespread along the perimeter of the Sarajevo depression and is found in localities such as Hreša, Ljubna, Koševski potok, Zujevina, Rakovica, and others.
- Tertiary complex of multifacial freshwater sediments

This complex of freshwater sediments is very diverse in hydrogeological terms, depending on which facies is dominant. In the area of the Sarajevo depression and its perimeter, three series are distinguished:

- A series of conglomerates, sandstones with thin layers of marls appears in the areas of Sedrenik, Vraca, Lukavica, and Kasindol. This series is characterized by a general dip towards Sarajevo field (west-southwest), so the stability of the slopes primarily depends on the orientation of the interlayer surfaces and the fissures that intersect them;
- A facies of loosely bound sandstones developed along the stretch from Podhrastovi - Veliki park - Mejtaš - Hambina carina. It has a pronounced collector function, which is crucial for the stability of slopes;
- A series of thin-layered marls, sandstones, and clays (Koševska series) forms the area of Koševski potok, Čengić Vila, Lukavica, and Kobilje Glave. The process of lithification is not completed, meaning these rocks occasionally transition to their unbound equivalents, so this series can be characterized as unfavorable from an engineering geological standpoint. In hydrogeological terms, different types of springs have formed in this formation.

➢ Quaternary cover is represented on the slopes mostly by thin, and less frequently by thicker deluvial cover, as well as by screes and alluvial sediments along the riverbeds.

6. HYDROGEOLOGICAL PROPERTIES OF THE TERRAIN

Hydrogeological Zoning of the Sarajevo Depression and Its Surroundings

The hydrogeological zoning of the Sarajevo Depression and its surroundings, based on major tectonic and structural units, can be divided into two completely separate parts [6]:

Intensively folded and eroded mountainous areas of the periphery, where several geomorphological and consequently hydrogeological units stand out:

- Bjelašnica-Igman
- Trebević-Jahorina
- Crepoljsko-Glog
- Narrow catchment area of the Miljacka River
- Kijevo-Ledići
- Zujevina area
- Sarajevo Basin as part of the unique "Sarajevo-Zenica coal basin."

In the area of the Sarajevo Field, completely different hydrogeological conditions prevail compared to its surrounding mountainous borders and previously listed regions. These structural-morphogenetic differences, along with the hydrogeological functions of the rocks in a lithofacial sense, directly affect all hydrological and hydrogeological phenomena, processes, dynamics, and groundwater regimes. Consequently, they influence the formation of springs, particularly large underground accumulations, their recharge, drainage, and hydraulic characteristics [8].

- Block Bjelašnica – Igman

This block is composed of limestone-dolomitic masses from the middle and upper Triassic, dominated by fissure porosity (T2,3), extending to cavernosity. The degree of karstification is very high. Below this formation, there are layers that serve as isolators, specifically Verfenian sandstones (T1), often referred to in literature as Sarajevo sandstones due to the unique development of this series. The length of the isolating layer is unknown, but it is spatially and morphologically clearly defined. The profile line in Figure 1. is marked in blue.

The mechanism of recharge and drainage of this block is conditioned by surface deposits and their drainage into the underground, mostly towards the Sarajevo Field.

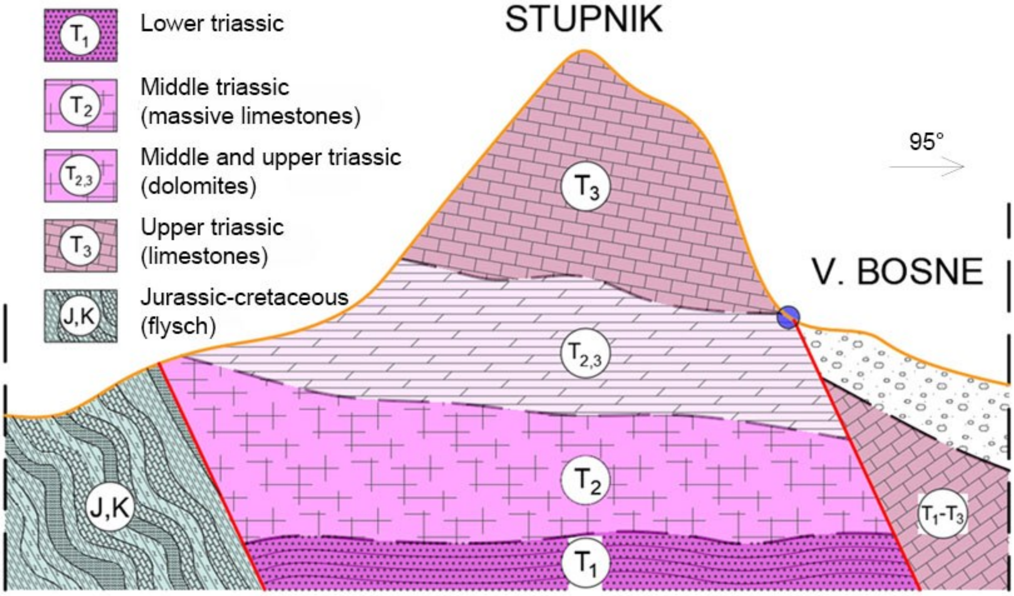

Figure 2. Geological Profiles in the Area of Vrelo Bosne

- Block Trebević - Jahorina

In the structure of the anticline Romanija – Jahorina, the southwestern part of the fractured wing that forms Trebević and Jahorina stands out, an area that contains several smaller hydrogeological units. This area morphologically represents the watershed between the Paljanska Miljacka river basin and the Crna River, Kasindolska River, and Tilava as tributaries of the Željeznica River. This area is divided structurally into several units (J. Josipović, 1969) [6], with most of the precipitation flowing over the surface or originating as springs of varying discharge in the tributaries of the Željeznica and Bistrica rivers. The underground water accumulation of Jahorina is fragmented, partially draining towards the source of the Prača River. The underground accumulations of Trebević partially drain towards the Miljacka River, or its basin, while part of the water drains towards Tilava and Lukavica.

- Block Romanija

The Romanija block is located at the far eastern limit of the Sarajevo Depression, marking the boundary of this geological unit. In this study, only the Kružlja spring can be mentioned, which feeds the Mokranjska Miljacka spring.

- Block Crepoljsko – Glog

This unit, both stratigraphically and structurally, morphogenetically, and hydrogeologically, represents the most complex part of the wider Sarajevo area. The composition of the morphological watershed mainly consists of relatively thin masses of Anisian and Ladinian limestones with roestones, beneath which Verfenian sediments appear in different facies. The limestone masses are separated by the discontinuous tectonic line Mrkovići-Faletići-Hreša, and intermittently where flysch zones occur, overlaid on the also fractured limestone masses of the Middle Triassic. Along this line, the springs of Mrkovići, Crnjilo, and Mošćanica appear.

- Block of the Middle Miljacka River

This area, which stretches deep into the limestone masses, is carved by the gorges of the Mokranjska and Paljanska Miljacka rivers, with tributaries such as Mošćanica and Lapišnica. In this area, a very small number of springs occur, with the most significant being the Sedrenik spring and the karst periodic spring in Ljubogošta.

- Block Sarajevo Field

The inner depression of Sarajevo Field can be considered a separate hydrogeological unit, particularly the part belonging to the open basin of Sarajevo Field, where the freshwater tertiary sedimentary complex is covered by Quaternary gravelly-sandy sediments of varying thickness. (Fig. 2)

It is believed that the thickness of the Quaternary sediments, especially in the depression area, is variable, with the upper gravelly horizons, from which groundwater is extracted, reaching depths of 40 meters, while the hydrogeological isolators reach depths of up to about 100 meters. Essentially, it can be concluded that in the upper parts of the depression, a compact aquifer has formed with a free level, while in the lower parts, the water is under pressure and appears as artesian aquifers [11].

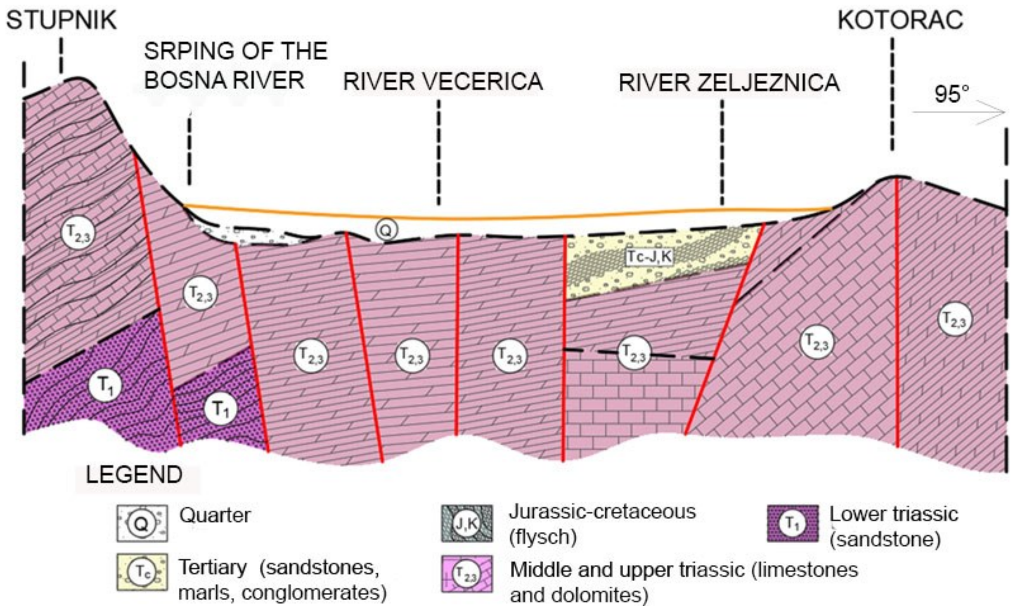

Figure 3. Projected Geological Cross-Section of the Stupnik – Kotorac Area

This arises from both structural-tectonic and morphological, as well as hydrogeological relationships. This area is composed of hydrogeological collectors – reservoirs with intergranular porosity and various hydraulic conditions present within them. A subsurface hydrogeological barrier along the Blažuj - Ilidža-Kotorac line separates this area from the Bosna river basin into a smaller, deeper part, while the higher part ends with the Tertiary "Reljevski threshold" in the Bosna valley.

7. THE OCCURRENCE OF THERMAL AND ACIDIC WATERS

The first observations on the occurrence of acidic and thermal waters were made by Austrian geologists A. Bittner, E. Tieze, and E. von Mojssisovics (1880), while F. Katzer significantly expanded the findings of his predecessors (1903) [12]. After World War II, the most significant works were done by Professor R. Jovanović, as well as many other geologists. Thermal waters, or their occurrence, are associated with the Ilidža area, while acidic waters are linked to the Kiseljak area. Based on data obtained from research throughout the 20th century, the following conclusions can be made:

The thermal water in the upper parts of the quaternary is spread in a relatively narrow zone with a northeast-southwest direction and is closely associated with the Željeznica River bed [14]. The measured surface temperatures of the thermal water range from 36°C to 38°C.

The area of the thermal spring's outflow is clearly limited by the occurrence of pure bigrovitic masses or aragonitic conglomerates, which have been identified in numerous exploration wells. In the zone of the so-called "Busovački Fault," extending from Sarajevo to the northwest, acidic waters, or Kiseljaci, appear. The best-studied spring is in the town of Kiseljak, from which it got its name. The captured well, drilled in 1971, where a bottling plant was built, has an output of 30 liters per second and represents one of the most prolific cold mineral water wells (13°C) in the former Yugoslavia [10].

8. DISCUSSION OF THE RESEARCH RESULTS

This paper presents the most significant geomorphological, geological, and hydrogeological characteristics of the terrain in the immediate surroundings of Sarajevo. In geomorphological terms, morphological units were identified, formed by the interaction of endogenous and exogenous processes that led to the creation of the current relief. The key factor in shaping the primary landforms was the continuous and intermittent river flows, whose action has been ongoing.

Based on the existing OGK SFRJ map of Sarajevo, as well as data obtained through terrain mapping at certain locations and available literature, the geological composition of the immediate surroundings of Sarajevo (lithological composition and tectonic properties) was analyzed and presented.

By analyzing geomorphological, geological, and hydrological data, hydrogeological blocks (areas with different hydrogeological properties) were identified. Special attention was given to the hydrogeological block of Bjelašnica - Igman, where the largest springs were formed, including the largest spring (Vrelo

Bosne). Figure 2. and Figure 3. show the specifics of this spring in both a broader and narrower sense.

9. CONCLUSION

The area of the Sarajevo depression and its wider surroundings, from a hydrogeological perspective, is divided into several different blocks, which are essentially limited by large dislocations created during previous tectonic activities.

From the southwest to the far southeast, along the broader perimeter of the Sarajevo depression, high limestone mountains dominate, broken and karstified by intense tectonic processes. A common characteristic of all these previously separated blocks is that the limestone sediments, predominantly of Middle Triassic age, function as hydrogeological collector-conductors and represent areas for large underground accumulations. Below them, with the role of a hydrogeological isolator, extends a layer of Verfen sandstones (T1), referred to in the literature as "Sarajevo sandstones." It is precisely at these contacts that large springs of high discharge are formed, such as the Vrelo Bosne, Paljanske and Mokranjske Miljacke, Bistrica, Željeznica, Crna Rijeka, Presjenica, Zujevina, and Tilava springs. The discharge of these springs is substantial.

In the area of the Sarajevo depression itself, fluvial sediments dominate on the banks of the Željeznica, Miljacka, and Bosna rivers, with thicknesses ranging from a few meters to several dozen meters. In the alluvial sediments, which are characterized by intergranular porosity, aquifers with free levels have formed, as well as some artesian aquifers. In addition to the springs used for the city's and its surroundings' water supply, water from the alluvial aquifers, such as the Stojčevec region, is also used for this purpose.

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

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