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3. Živković D.: Influence of front excavation on the state and deformity of montage lining of hydraulic pressure tunnels, Ph. D. University of Niš, 1988, pp. 95-108.
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Original Scientific Paper

PROPOSAL OF MODIFICATION OF EUROCODE 2 IN TERMS OF CALCULATION OF THE PUNCHING SHEAR CAPACITY OF RC COLUMN FOOTINGS

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Abstract. *The paper first presents the calculation of the punching shear capacity of concentrically loaded reinforced concrete column footings according to the current Eurocode 2, which can be carried out in two ways: by conducting an iterative procedure and by a simplified procedure applying the diagrams. By using these procedures, the punching shear capacity calculation was performed for the footings examined within the experimental research of the authors of this study, as well as for the footings that were considered by experiments conducted by other authors. Based on the conducted analysis of the calculation results and experimentally recorded results, a modification of the expression of the current Eurocode 2 with regard to the calculation of the punching shear capacity of concentrically loaded RC column footings is proposed. The proposed modification more realistically takes into account the influence of compressive strength of concrete and the reinforcement ratio in the footing, so that its application provides the results of punching failure forces that are closer to the results recorded by experimental tests.*

Key words: *RC column footing, Eurocode 2, punching shear, concrete compressive strength, reinforcement ratio*

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1. INTRODUCTION

The construction of monolithic reinforced concrete skeleton construction systems of buildings with floor structures in the form of flat slabs and foundations in the form of foundation slabs and column footings is very widespread. At the same time, there is a constant tendency to improve the calculation methods and the way of designing the mentioned structural elements in order to achieve savings in work and materials, i.e. to increase the economy of both these elements and the entire structure. On the other hand, we are witnessing a growing number of buildings in the world where damage has occurred, and even the collapse of the structure, which results not only in material damage, but, unfortunately, also in human casualties. Such events often occur due to exceeding the load-bearing capacity of individual columns or footings under them, which leads to their damage or, in certain situations, to failure. As a consequence, the forces are further redistributed to the adjacent columns and associated footings, thus causing significantly increased loads in them, which can cause their fracture, i.e. lead to a chain reaction and progressive failure of the entire structure. With all this in mind, in recent times, the attention of researchers is increasingly focused on increasing the resistance to progressive failure of buildings and structures in general, and thus their sustainability, reliability, and durability. Related to this is the growing number of studies with regard to the bearing capacity of foundations, in particular the punching shear capacity of column footings, as a type of unannounced failure. Control of foundations to punching shear is an obligatory part of the foundations design, primarily of column footings and foundation slabs, which are exposed to the action of concentrated forces in the columns. The behavior of these types of foundations under load will depend on the characteristics of the foundation and soil, as well as on the intensity of the load.

In most national and international regulations, an empirical method of calculating the punching shear capacity of concentrically loaded reinforced concrete foundations based on experiments conducted on flat floor slabs and foundations resting on a simulated subsoil has been adopted. When it is necessary to check whether the foundation is safe in terms of punching shear, for the known load and characteristics of the foundation, the calculation is based on first calculating the shear stress v in the critical section, at a certain distance from the column face, for a known force in the column. Then, the shear stress calculated in this way is compared to the punching shear resistance of concrete v_d. If $v < v_d$, then there is no risk of punching shear event, otherwise, the height of the foundations needs to be increased as well as the class of concrete, or the reinforcement to secure against punching shear needs to be designed. The critical section is the section along the effective depth of the foundation slab or footing and along the perimeter of the critical section which is at a certain distance from the column face (the so-called critical perimeter as presented in Fig. 1). Shear stresses in the critical section are calculated according to the expression:

$$v = \frac{V_{c,red}}{u_{cs} \cdot d} \tag{1}$$

where: $V_{c,red}$ – is the reduced force in the column,
u_{cs} – is the critical section perimeter, i.e. the length of the critical perimeter,
d – is the effective depth of the footing (a mean value for two perpendicular directions).

In most of the codes, the reduced force in the column is calculated by subtracting from the force in the column V_c a part of net reactive soil pressures σ_n (without the effect of the footing dead weight) inside a considered critical perimeter having the area A_0:

$$V_{c,red} = V_c - A_0 \cdot \sigma_n = V_c - A_0 \frac{V_c}{A} = V_c \left(1 - \frac{A_0}{A}\right) \qquad (2)$$

where A is the area of the footing base. Finally, the punching shear capacity of footings is expressed through the ultimate force in the column in terms of the punching shear:

$$V_c = \frac{V_{c,red}}{1 - \frac{A_0}{A}} \qquad (3)$$

On the other hand, the punching shear resistance of concrete v_d depends on multiple parameters, which reflect the characteristics of the footings such as the column and footing dimensions, compressive strength of concrete, as well as the implemented reinforcement ratio and the quality of the reinforcement. For calculation of parameter v_d, the existing codes to a smaller or larger extent take into account the mentioned footing properties. Thus:

- Eurocode 2 (EC2) [1] takes into account the compressive strength of concrete, the reinforcement ratio of footing and the size-effect coefficient that depends on the effective depth of the footing;
- Current ACI 318-19 [2] takes into account only the compressive strength of concrete and the size-effect coefficient that depends on the effective depth of the footing;
- *fib* Model Code 2010 [3] takes into account the compressive strength of concrete, the reinforcement ratio of footing and the size-effect coefficient that depends on the effective depth of the footing;
- BS 8110-1:1997 [4], likewise EC2, takes into account the compressive strength of concrete, the reinforcement ratio of footing and the size-effect coefficient that depends on the effective depth of the footing;
- СНиП-84 [5] takes into account the design strength of concrete to axial tension, which is calculated depending on the concrete class, with the corresponding working conditions coefficients (types of load, environment in which the element is situated, and the method of concreting).

The method of critical section in the control of punching shear capacity does not reflect the true nature of punching, but when the properties of the footing affecting its punching shear capacity are taken into account in the appropriate correlation, the acceptable results of prediction of the footing punching shear capacity are obtained.

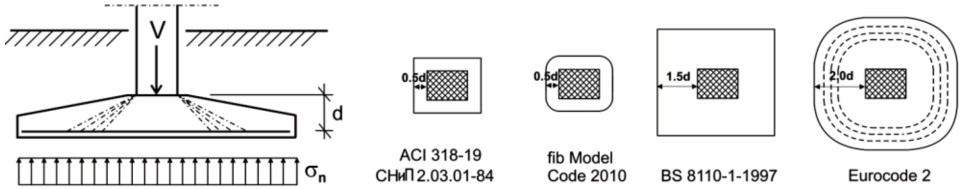

Fig. 1 Possible critical perimeters in some codes (ACI 318-19, СНиП2.03.01-84, *fib* Model Code 2010, BS 8110-1:1997, Eurocode 2) mainly based on the effective depth of the footing *d*.

Bearing in mind that in Serbia Eurocode 2 has been adopted as a code in the field of design of reinforced concrete structures, in the following part the attention is paid to determining the punching shear capacity of footings according to this standard, and to evaluation of standard expressions based on the experimental research of column footings on a real soil, both of the authors of this paper and of other researchers.

2. Calculation of the Punching Shear Capacity of Concentrically Loaded RC Column Footings According to Eurocode 2

Calculation of punching shear of column footings and foundation slabs according to Eurocode 2 (EC2) is mostly based on the calculation concept provided in *fib* Model Code 1990. According to this code, it is necessary to check the shear stresses in two sections. The first section is the cross-section of the footing along the column perimeter, while the position of the second section is not directly determined, but is determined using the iterative procedure. Namely, unlike other codes where the position of the critical section is defined in advance, in Eurocode 2 the calculation of punching shear is performed in several control sections, and the finally adopted control section is a critical section. Thus, in order to determine the ultimate force in the column, it is necessary to consider several control perimeters within a distance of 2*d* from the edge of the column (which is the so-called basic control perimeter according to Fig. 2) and by iterative procedure to determine the position of the critical perimeter resulting in the ultimate force in the column in terms of punching shear.

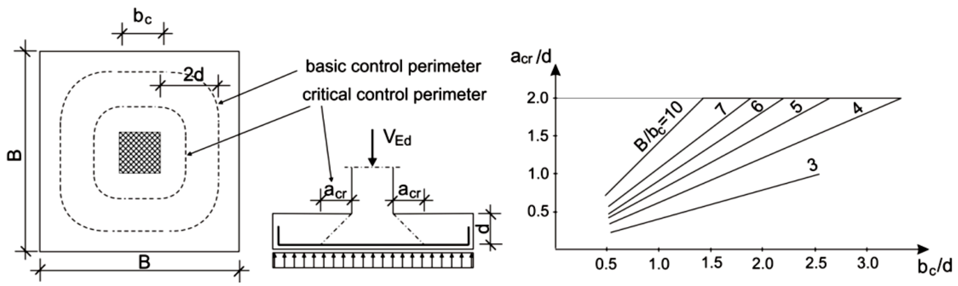

Fig. 2 Position of the critical perimeter according to the European Concrete Platform [6]

When an unknown concentric force of punching shear of the footing is to be determined for a footing of known characteristics, it is necessary to first calculate the punching shear resistance of concrete v (marked $v_{Rd,c}$ in EC2) for each control section considered, as follows:

$$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_t \cdot f_{ck})^{1/3} \cdot \frac{2d}{a_{EC2}} \geq v_{min} \frac{2d}{a_{EC2}} \quad (4)$$

where:

$C_{Rd,c} = 0.18/\gamma_c$ – the empirical factor which takes into account the partial safety coefficient for concrete γ_c (1.5),

d – effective depth of footing (in mm),

$k = 1 + \sqrt{200/d} \leq 2.0$ – coefficient depending on the effective depth of footing,

$\rho_t = \sqrt{\rho_{tx} \cdot \rho_{ty}} \leq 0.02$ – average value of the reinforcement ratio in two orthogonal directions taken at a width equal to the width of the column increased for the distance 3d on each side of the column,

f_{ck} – characteristic value of compressive strength of concrete for a standard cylinder,

$v_{min} = 0.035 \cdot k^{3/2} \cdot f_{ck}^{1/2}$ – the minimum punching shear resistance of concrete,

a_{EC2} – distance from the edge of the column to the observed control section.

In the following step, on the basis of the calculated value of concrete punching shear resistance $v_{Rd,c}$ and expression in Eq. (1), for each considered control section of perimeter u, a reduced force in the column is calculated (in EC2 marked as $V_{Ed,red}$) in the following way: $V_{Ed,red} = v_{Rd,c} \cdot u \cdot d$. Also, for each considered control section it is necessary to calculate A_0, i.e. to determine area inside the considered control perimeter, and then using Eq. (3) calculate ultimate punching shear force, in EC2 marked as V_{Ed}. Since the described calculation procedure is performed in several chosen control sections, several values of ultimate punching force are obtained, the relevant being a force which is minimal in terms of its value. The distance of the critical control section determined in this way in relation to the edge of the column is marked as a_{cr} (Fig. 2).

Apart from the described iterative procedure, the position of the critical section can be determined somewhat more simply, based on the diagram derived from the parametric studies and presented in the European Concrete Platform – ECP [6]. The diagram for determining the position of critical section a_{cr} based on the dimensions of the cross-section of the column (b_c) and geometry of the footing (B and d) is provided in Fig. 2.

As already mentioned, Eurocode 2, in addition to the critical section defined by the iterative procedure or using the diagram in Fig. 2, also requires checking the shear stresses in the footing cross-section along the perimeter of the column. In the process, for the force in the column reduced for the part of soil reaction beneath the column footing, shear stress v_{Ed} along the column perimeter u_0 is calculated, and it must not exceed the value of the maximum punching shear stress $v_{Rd,max}$, i.e.:

$$v_{Ed} = \frac{V_{Ed,red}}{u_0 \cdot d} \leq v_{Rd,\max} \quad (5)$$

where:

$v_{Rd,max} = 0.5 v f_{cd}, \ v = 0.6(1 - f_{ck}/250)$,

$f_{cd} = \alpha_{cc} \cdot f_{ck} / \gamma_c$ is the design value of compressive strength of concrete,

α_{cc} is the coefficient of long-term effects on the compressive strength of concrete (1.0).

For the final conclusion on the punching shear capacity of column footings, of the two considered sections (section within a distance of 2d from the edge of the column and the section along the perimeter of the footing column) is relevant the one that results in a lower value of punching shear force.

Yet, more recent research conducted by Hegger et al. [7–9], Siburg et al. [10], Ricker and Siburg [11], indicate that expression $v_{Rd,max}$ is not the most adequate for determining the values of maximum stress at punching shear, regarding that it is only a function of the compressive strength of concrete. Therefore, in the German national annex of Eurocode 2, the calculation of the punching shear force for the section along the perimeter of the column is considered obsolete and is not taken into account. Therefore, in the analyses conducted in this paper, the calculation of the punching shear force for the section along the perimeter of the column is omitted.

3. Analysis of Experimental Research Conducted Previously

Although the number of studies on the punching shear capacity of column footings has been growing recently, unfortunately, a larger number of experimental tests still relate to footings that rely on some kind of simulated subgrade (springs, presses, line support). An overview of previous experimental tests of concentrically loaded reinforced concrete column footings in terms of the punching shear capacity, according to the available technical literature, is given in Table 1.

Table 1 An overview of previous experiments on reinforced concrete column footings

Author(s)	Type of support	Number of tested footings	Geometry of footing		
			Form	Dimensions [mm]	Effective depth [mm]
Zhang et al. (2019) [12]	Rubber – wooden composite blocks	3	Square	1200×1200	140
Simões et al. (2016) [13]	Hydraulic jacks	8	Square	1950 and 2120	497–516
Shill et al. (2015) [14]	Stabilized soil	1	Square	1524	212
Siburg and Hegger (2014) [15]	Hydraulic jacks	13	Square	1200–2700	400–590
Urban et al. (2013) [16]	Linear support	9	Octagon	1948–2344	118–318
Mordich et al. (2007) [17]	Sand	3	Square	2200	132–272
Hegger et al. (2006, 2007, 2009) [7–9]	Sand / Hydraulic jacks	22	Square	900–1800	150–470
Timm (2003) [18]	Linear support	10	Square	760–1080	172–246
Hallgren et al. (1998) [19]	Linear support / Hydraulic jacks	14	Square and rectangle	850–960	273–278
Tetior and Djakov (1989) [20]	Sand	6	Square and rectangle	1500×1000	125
Dieterle and Rostásy (1987) [21]	Sand	13	Square	1500–3000	320–800
Kordina and Nölting (1981) [22]	Hydraulic jacks	11	Rectangle	1500–1800	193–343
Dieterle and Steinle (1981) [23]	Hydraulic jacks	6	Square	1800–3000	700–740
Rivkin (1967) [24]	Hydraulic jacks / Clay	3 / 6	Square	650 and 1000	95
Richart (1948) [25]	Springs	149	Square and circle	610–3000	200–740
Talbot (1913) [26]	Springs	20	Square	1520	250

Experimental tests have shown that the punching shear capacity of column footings is significantly higher in the case of footings rested on a real subgrade soil compared to footings in which the subgrade is simulated. Therefore, when analyzing the influence of concrete compressive strength and reinforcement ratio on the punching shear capacity of column footings, only footings supported on the ground are taken from Table 1. In addition, the analysis included the footings examined during specially designed and constructed experimental setup in Niš, Serbia, where many tests were performed (more data can be found in Bonić et al. [27]).

Table 2 Punching failure forces of footings rested on the ground according to experiments and EC2

Mark (1)	B [mm] (2)	b_c [mm] (3)	d [mm] (4)	f_{ck} [MPa] (5)	ρ_t [%] (6)	V_{test} [kN] (7)	$V_{EC2(i)}$ [kN] (8)	V_{test} / $V_{EC2(i)}$ (9)	$V_{EC2(ECP)}$ [kN] (10)	V_{test} / $V_{EC2(ECP)}$ (11)
Bonić et al.										
F1	850	175	175	30.37	0.40	1001	776	1.29	786	1.27
F2	850	175	125	30.37	0.40	1050	396	2.65	400	2.63
F3	850	175	100	16.83	0.40	430	208	2.07	210	2.05
F4	850	175	150	16.83	0.40	656	468	1.40	476	1.39
F5	850	175	125	15.28	0.40	451	315	1.43	318	1.42
F6	850	175	125	7.92	0.40	440	254	1.73	256	1.72
F7	850	175	125	15.83	0.27	527	266	1.98	282	1.87
F8	850	175	125	15.83	0.48	645	325	1.98	342	1.89
F9	850	175	125	15.83	0.91	720	401	1.80	423	1.70
Rivkin (1967) [24]										
R1	1000	200	95	16.67	0.25	180	158	1.14	191	0.94
Hegger et al. (2006, 2009) [7],[9]										
DF1	900	150	150	20.20	1.03	551	638	0.86	607	0.91
DF2	900	150	150	22.00	1.03	530	656	0.81	625	0.85
DF4	900	150	250	24.50	0.62	1251	1403	0.89	1410	0.89
DF5	900	175	250	17.60	0.73	1130	1467	0.77	1475	0.77
DF6	1200	200	395	19.00	0.87	2836	3255	0.87	3282	0.86
DF7	1400	200	395	20.90	0.87	2569	3080	0.83	3090	0.83
DF8	1200	200	250	22.50	0.88	1203	1532	0.79	1583	0.76
DF10	1200	200	250	38.10	0.91	1638	1847	0.89	1908	0.86
Shill et al. (2015) [14]										
S1	1524	200	212	13.47	0.56	640	747	0.86	736	0.87

Experimentally recorded values of punching failure forces of the analyzed footings V_{test} are provided in Table 2, column (7). Using the expression for calculation of the punching shear capacity of column footings according to Eurocode 2 in the iterative procedure, for the mentioned footings resulted in the values $V_{EC2(i)}$ that are provided in column (8), and the ratio of experimental and calculated punching shear forces $V_{test}/V_{EC2(i)}$ in column (9). In addition, for comparison, in column (10) are presented the design values of punching shear force $V_{EC2(ECP)}$, determined by using the diagram shown in Fig. 2 according to the European concrete platform (ECP, 2008), and in column (11) ratio of these forces in comparison to the experimentally recorded punching shear forces $V_{test}/V_{EC2(ECP)}$. What can be observed by comparing the values in columns (8) and (10), i.e. in columns (9) and (11), is that the extensive iterative procedure and simplified procedure using the diagram result in approximately identical results.

4. EFFECTS OF CONCRETE COMPRESSIVE STRENGTH AND REINFORCEMENT RATIO TO THE PUNCHING SHEAR CAPACITY OF CONCENTRICALLY LOADED RC COLUMN FOOTINGS

Effects of compressive strength and reinforcement ratio to the punching shear capacity of concentrically loaded RC column footings was considered on two series of footings tested by the authors of this study according to Table 2 (Bonić et al.). In each of them, all characteristics of footings, except that whose effect was considered, were approximately identical. For the analysis of the effects of considered characteristics on the punching shear capacity of column footings, the footing deflection was observed in the function of the increase of load in the footing column. There, footing deflection comprises the difference between the registered soil settlements under the column and the angle of the footing.

The first series consisted of three footings made of concrete, whose compressive strengths (average values of multiple tested specimens, on a cylinder of standard dimensions) varied and amounted to f_{cm} = 7.92 MPa (footing marked as F6), f_{cm} = 15.83 MPa (footing F8) and f_{cm} = 30.37 MPa (footing F2), whereas the remaining characteristics were approximately the same. In the other series of the tested footings, the used reinforcement ratios were 0.27% (footing F7), 0.48% (footing F8) and 0.91% (footing F9), whereas the other characteristics were again approximately identical. Qualitative effects of considered characteristic on the punching shear capacity of column footings are illustrated on the diagrams in Fig. 3.

In Fig. 3(a) it can be observed that the effects of compressive strength of concrete to punching shear force of the footings is considerable, because the recorded punching shear forces of the footings with markings F2, F6, and F8 were respectively 1050 kN, 440 kN, and 645 kN. Such a result was expected and it is in agreement with the previous research (Hegger et al. [7–9]; Siburg and Hegger [15]; Simões et al. [13]). Moreover, in the diagram can be seen that the footings with a lower concrete compressive strength (F6 and F8) exhibit much more ductile behavior under load.

In Fig. 3(b) it can be observed that effects of the reinforcement ratio are not as prominent as the previously observed effect, whereby the recorded punching shear forces of the footings F7, F8, and F9 were 527 kN, 645 kN, and 720 kN, respectively. This result was expected and in accordance with the previous research (Hallgren et al. [19]; Menetrey [28]). In terms of ductility, these footings showed relatively similar behavior.

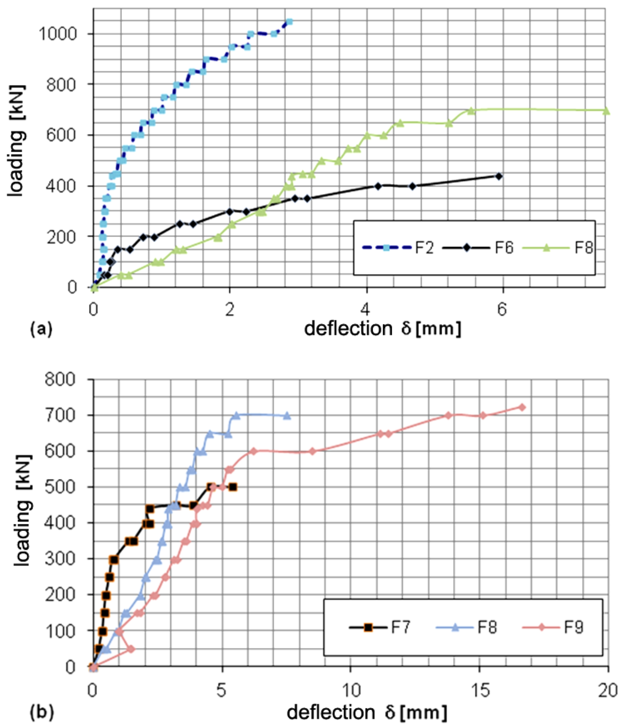

Fig. 3 Load–deflection diagrams of the footings: (a) for different compressive strengths of the concrete, (b) for various reinforcement ratios of the footings

The stress in concrete at punching shear v_{test} for the registered force of punching shear during the experiment V_{test}, was calculated in the critical cross section of the foundations with a goal of determining the quantitative impact of compressive strength and reinforcement ratio:

$$v_{test} = \frac{V_{test}\left(1 - \frac{A_0}{A}\right)}{u \cdot d} \tag{6}$$

where the designations from the previous expressions are retained.

The values used in the iterative calculation procedure according to EC2 (calculation provided in columns (8) and (9) of Table 2) are used for A_0 and u.

Fig. 4 shows the punching shear stress in concrete at the moment of punching, v_{test}, for the footings which were rested on a real subsoil (according to Table 2), depending on the compressive strength of concrete (f_{ck}) and reinforcement ratio (ρ_l) of tested footings.

The conducted regression analysis, Fig. 4(a), shows that the stress in concrete at punching shear v_{test} is proportional to the compressive strength of concrete with the exponent of 0.50. This corresponds with the conclusions of Hallgren et al. [19], which state that the punching shear capacity of slabs having a low shear slenderness, such as column footings, is proportional to the compressive strength of concrete in a ratio of 0.76, whereas the tests with thin slabs by Braestrup and Gardner (according to [19]) showed that this impact is smaller and amounts from 1/3 to 1/2.

According to Fig. 4(b), punching shear stress in concrete at the moment of punching v_{test} increases with the reinforcement ratio with the exponent of 0.23, which also agrees with the research by Hallgren et al. [19]. On the basis of this, it can be concluded that the reinforcement ratio has a smaller influence on the concrete punching shear resistance than the compressive strength of concrete. The obtained results indicate that Eurocode 2, which in the expression of Eq. (4) includes the impact of these two parameters with the same exponent (1/3), on the one hand underestimates the impact of compressive strength of concrete, whereas on the other hand overestimates the impact of reinforcement ratio on the punching shear capacity of RC footings.

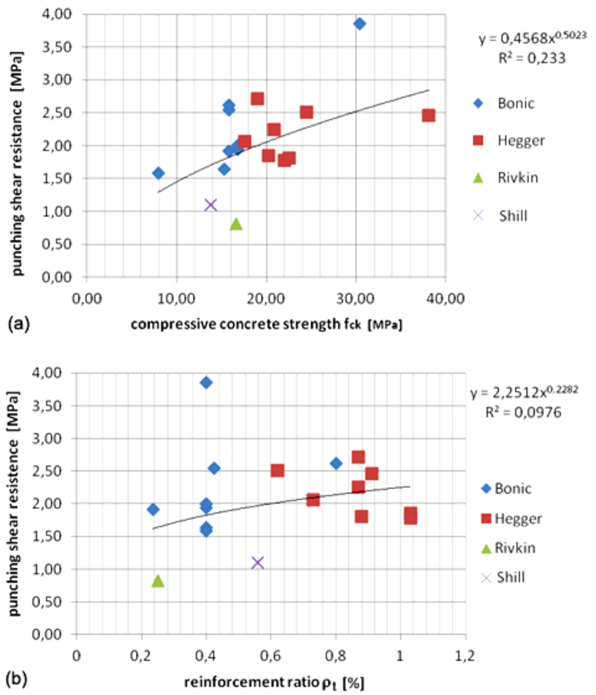

Fig. 4 Dependence of the punching shear resistance of concrete v_{test} on: (a) concrete compressive strength (f_{ck}), (b) reinforcement ratio (ρ_t)

Considering the mentioned differences in the results provided by the standing EC2 in comparison to the experimentally obtained results, in agreement with the conclusions based on the diagrams in Fig. 4, a modification of Eq. (4) for the punching shear resistance of concrete is proposed having the form:

$$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (f_{ck})^{1/2} (100 \cdot \rho_t \cdot)^{1/4} \cdot \frac{2d}{a_{EC2}} \geq v_{min} \frac{2d}{a_{EC2}} \tag{7}$$

where the coefficient k is also modified and is calculated according to the expression $k = \sqrt{200/d}$, whereas other designations and method of calculation are the same as in the expression of Eq. (4).

Finally, for the footings given in Table 2 the procedure of calculation of the ultimate punching shear force according to Eurocode 2 was repeated, but with implementation of the proposed calculation modification, provided by Eq. (7). As the relevant critical section (α_{EC2} in Eq. (7)) was taken the section determined using diagrams provided in the European concrete platform – ECP [6], i.e. according to Fig. 2.

The obtained results are provided in Fig. 5. As previously observed, the iterative procedure and procedure using the ECP diagram result in almost identical values. By comparing the results according to the standing Eurocode 2 and to the proposed solution, it can be seen that the proposed solution provides the results which are considerably closer to the experimentally registered values. For the footings F1 to F9, the proposed modified solution gives the values of V_{test} / V_{calc} that are significantly less conservative (closer to 1.0) compared to the current Eurocode 2. On the other hand, for the remaining footings from Figure 5, for which the original Eurocode 2 gives the ratio V_{test} / V_{calc} lower than 1.0 (which is an undesirable situation), by the proposed modified solution values equal to or greater than 1.0 are achieved, which is on the safety side.

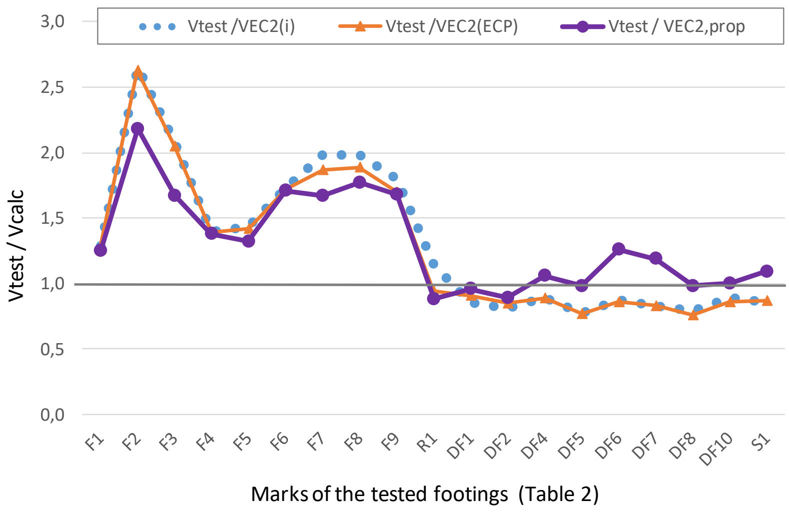

Fig. 5 Comparison of the ratio V_{test} / V_{calc} for different methods of calculation considering the experimentally tested footings

5. Conclusion

Based on the performed experiments of concentrically loaded RC column footings rested on real soil and conducted analyses related to the punching shear capacity of footings, the following conclusions can be drawn:

- Recommendations for determining the position of the critical perimeter based on the diagram proposed by the European concrete platform – ECP yield almost the same results as the calculation which identifies the minimum punching force inside the area bounded by the basic control section (iterative procedure). Therefore, the use of this diagram can be recommended instead of a complicated iterative procedure;
- The conducted regression analysis of the footings rested on the real soil indicates that the punching shear capacity is more affected by the compressive strength of concrete than reinforcement ratio, even though Eurocode 2 takes them in the calculation in the same measure. It is proposed to calculate the compressive strength of concrete and reinforcement ratio with the exponents of 1/2 and 1/4 respectively, when calculating punching shear capacity of footings, instead with the same exponent of 1/3 for both characteristics;
- The proposed calculation modification according to Eurocode 2, which in a different way takes into consideration the impact of the size-effect coefficient (k), reinforcement ratio (ρ_t), and compressive strength of concrete (f_{ck}), provides the results which are considerably closer to the experimental results in comparison to the current Eurocode 2.

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PREDLOG MODIFIKACIJE EVROKODA 2 U POGLEDU PRORAČUNA NOSIVOSTI AB TEMELJA SAMACA NA PROBIJANJE

U radu je najpre predstavljen proračun nosivosti centrično opterećenih armiranobetonskih temelja samaca na probijanje prema aktuelnom Evrokodu 2, koji se može sprovesti dvojako: sprovođenjem iterativnog postupka i primenom zamenjujućih dijagrama. Primenom ovih postupaka, urađen je proračun nosivosti pri probijanju za temelje ispitivane u okviru sopstvenih eksperimentalnih istraživanja, kao i za temelje koji su bili sagledani eksperimentima sprovedenim od strane drugih autora. Na osnovu sprovedene analize rezultata proračuna i eksperimentalno registrovanih rezultata, predložena je modifikacija izraza aktuelnog Evrokoda 2 u pogledu proračuna nosivosti centrično opterećenih AB temelja samaca na probijanje. Predložena modifikacija realnije uzima u obzir uticaj čvrstoće na pritisak betona i procenta armiranja temelja, tako da se njenom primenom dobijaju rezultati sila probijanja koji su bliži rezultatima registrovanim tokom eksperimentalnih ispitivanja.

Ključne reči: *AB temelj samac, Evrokod 2, probijanje, čvrstoća na pritisak betona, procenat armiranja*

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Original Scientific Paper

SUSTAINABILITY OF POST-SOCIALIST URBAN DESIGN TREATMENT OF PUBLIC OPEN SPACES IN MULTI-FAMILY HOUSING AREAS: CASE STUDY OF NIŠ, SERBIA

UDC 728.2:625.712.43(497.11)
316.323.72:711.4(497.11

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Abstract. *This research focuses on the treatment of public open spaces (POS) in multi-family housing areas in post-socialist Central and Eastern European (CEE) countries. The aim is to evaluate their quality and sustainability and to identify all important impact factors influencing their properties. A case study was conducted on a representative sample of four multi-family housing sites in Nis, Serbia. Determining the interconnection between urban planning parameters and the realized quality of POS is one of the primary objectives that could lead to forming recommendations for future multi-family housing development, including more usable and sustainable POS in the current social and economic context. The models for improvement of POS quality and sustainability are defined as a research result.*

Key words: *sustainability, multi-family housing, public open spaces, urban planning, post-socialist*

1. INTRODUCTION

Many Central and Eastern European (CEE) countries undergone more or less difficult transition in recent decades, from communist to capitalist political system, and from centrally planned to market based economy. Changes in political and economic system largely conditioned social changes. Stratification of population and impoverishment are the results of these changes. In this, newly formed social and economic context, urban planning and architectural design framework inevitably changed.

Transition to democracy (systemic political change), markets (systemic economical change) and decentralized system of local governance were identified as a major drivers of

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urban change (Tsenkova, 2006), and government and markets are the two key determinants of social and spatial processes in this new environment (Nedovic-Budic, 2001).

While many other countries successfully finished transition process, some south-eastern European countries are still trying to make considerable progress in this complex process. Political instability and conflicts are the main reason why this region is behind other CEE countries.

It appears that in Serbia, these reforms have been driven by a number of post-socialist ideological and political dogmas (e.g., privatization, marketization, liberalization), rather than a society-wide, rational, consensus-building process. As a result, Serbian society has found itself in a severe social, economic, and political crisis, which has been further deepened by the global recession (Nedovic-Budic et al., 2012).

These processes had considerable spatial implications. Urban planning framework in Serbia became investor and market-driven, with disregard to any public interest. General financial crisis in the country reflected on the lack of big investments. Low financial potency of the investors caused the fragmentation of housing development. Multi-storey extensions (MSE) of existing multi-family buildings were dominant housing development model at the nineties (Kuzmanov 2009; Vranic et al., 2015) as they required small-scale investments. Further development of housing market in Serbia in the first decade of 21st century focused mainly on small private plots. Small multi-family housing buildings were built on sites where property and legal issues could be resolved, and agreement with plot owners could be reached. Large-scale investments in housing neighbourhoods were very rare.

Unlike previous socialist planned housing development system, this new market oriented system in Serbia completely disregarded public interest and housing quality. The profit of the investors was primary driving force in this process. That was possible because of severe political, social and financial crisis. Corruption and the absence of clear legislative, combined with urban planning documents that often were unclear and of poor quality were the factors that created this investor-oriented housing market environment. Impoverished, uneducated and non-selective user population, whose primary concern was to satisfy basic bio-physiological needs, was another factor that facilitated the development of such low competition housing market.

Despite the fact that the quality of public open spaces (POS) is very important factor in overall housing environment quality (Vasilevska, 2012), they were often neglected in this new investor-driven urban housing development context. The aim of this research is to evaluate their quality and sustainability and to identify all important impact factors influencing their properties, as well as to form recommendations for overcoming identified problems and improving overall POS quality. POS environmental and social sustainability is of great importance because of the great influence on housing quality and urban planning sustainability in general.

2. METHODOLOGY

A case study was conducted on a representative sample of four multifamily housing sites in Nis, Serbia. Determining the interconnection between urban planning parameters and the realized quality of POS is one of the primary objectives of the analysis, as well as the evaluation of POS in terms of their social and environmental sustainability. The developed evaluation method is based on previous research of several authors (Vasilevska et al., 2014; Mitkovic, Bogdanovic, 2004; Dinić, 2006). Mitkovic and Bogdanovic focus on the contents and activities at different urban levels, urban equipment, arrangement level and hygienic conditions. Vasilevska et al. developed complex evaluation method of the quality of POS in multi-family housing areas, analysing large set of parameters to determine the quality of POS from different time periods.

This research is primarily focused on the environmental and the parameters initiating social interaction between tenants, thus indicating potential for socially and environmentally sustainable POS design. Following indicators of POS quality are identified and analysed as relevant:

- Occupancy level (site coverage, the percentage of the plot covered by physical structure)
- Housing density (plot ratio, ratio between total gross area of the building and area of the plot, also implies higher number of apartments and users, greater housing density)
- Percentage of green area (ratio between greenery and total plot area)
- Parking solution (ratio between number of parking spaces in open parking lots and garages, lower ratio leaves more POS area for other purposes)
- The amount of urban equipment (the amount of urban equipment implies the amount of spaces for social interaction, including children's playgrounds)
- Social interaction and usage level (the data on social interaction level are gathered by field research, and include the number of users and the amount of time they spend in the open spaces).

First four parameters are usually defined by the GRP or DRP. The hypothesis is that all these parameters are mutually interconnected and influence one another and thus overall POS quality and sustainability. They were systemized in Table1. that was used for analysis.

Table 1 Parameter evaluation table

Parameter	Value			GRP or DRP value
	Low	Medium	High	
Occupancy level (site coverage)				
Density (plot ratio)				
Percentage of green area				
Parking solution (open parking lot/garage ratio)				
The amount of urban equipment				
Social interaction and usage level				

3. Conducted Research

Nis is the third largest city in Serbia, and is selected as a typical framework to represent these spatial processes. In socialist period it was one of the main industrial centres in Serbia, characterized by large increase of population. The result of this process was great need for new apartments and mass housing development in certain city areas. In post-socialist period, despite crisis the increase of population continued. Refugees and economical migrations from rural areas were the main reason for this process. The need for new apartments still exists, but the local and state authorities were not interested in solving problems of providing dwelling for this population because of transition to market oriented economy and cutting of public expenses. This is where private investors saw the opportunity to enter unregulated market and maximize their profit. In this process POS were neglected and treated by the investors as unnecessary expense. Four multi-family housing areas were selected, as a representative sample for research of POS treatment (Fig. 1).

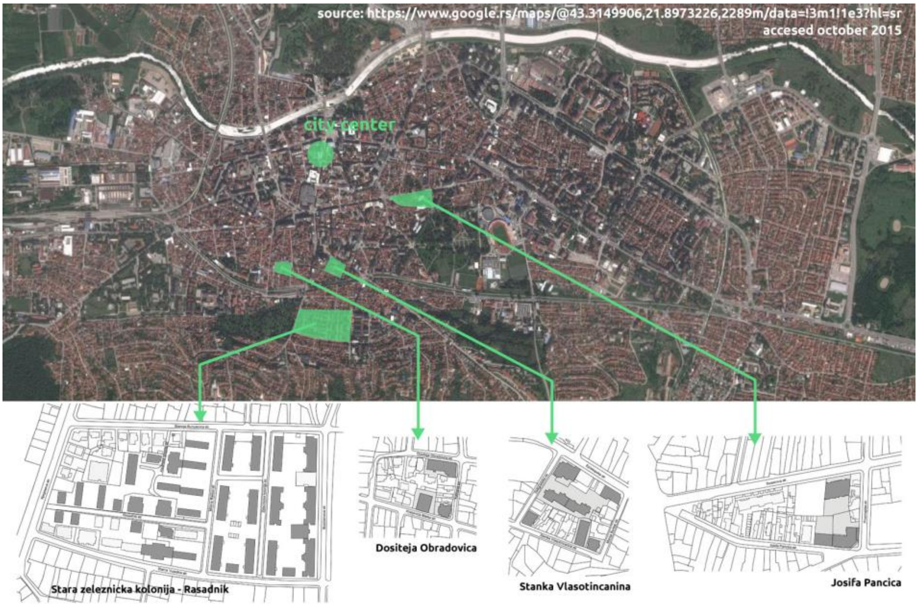

Fig. 1 Central city area of Nis with studied housing development sites (authors drawings)

3.1. Josifa Pancica Area

Urban city block between Dusanova and Josifa Pancica streets is located in central city area. The physical structure of the block was a mixture of architectural structures of different type and from different time periods. Dominant building type were low-storey family housing units from different time periods (pre-WWII to socialist period). Two larger multi-family buildings from socialist period were integrated into block physical structure. Both of these buildings undergone multi-storey extension process in the nineties, and their number of storeys was increased from four to six. Due to the position of this urban block within the central city area most of the ground floors were converted to commercial use. New housing development within this block was initiated according to Detailed Regulatory Plan of "Cair- Center" complex from 2006. DRP classified this block as a mixed used area with possible multi-family housing development. Three new high-storey multi-family housing buildings (9 storeys high) with about 20% of commercial space were constructed in last few years (Fig. 2).

Fig. 2 Josifa Pancica area (authors drawings)

POS use in these complexes is rudimentary. They are used as a parking lots, without any urban equipment, developed green areas or places for social interaction between tenants (Fig. 3, J1-2). Only a small amount of greenery is present on these plots (Fig.3, J3-4).

Table 2 Dusanova-Josifa Pancica evaluation table

Parameter	Value			GRP or DRP
	Low	Medium	High	value
Occupancy level (site coverage)		√		80%
Density (plot ratio)			√	3.6
Percentage of green area	√			-
Parking solution (open parking lot/garage ratio)		√		min. 70/30%
The amount of urban equipment	√			-
Social interaction and usage level	√			-

Fig. 3 Josifa Pancica area – photo-documentation (photos by S. Kondic)

3.2. Dositeja Obradovica Area

Dositeja Obradovica block is within old single-family housing area. In recent years it is being transformed to multi-family housing development, in accordance with DRP „Obilicev venac" of 2003. Three multi-family residential buildings were constructed so far on three plots (Fig. 4). In two cases POS are used only as open parking lots, without any green areas or spaces for socialization of tenants (building No. 1 and 2, Fig. 5, D3-4). Despite that fact parking space remains a great problem in this area. In case of building No. 2 parking space is small and insufficient (Fig. 5, D3). The original design of building No. 1 had almost 50% of parking places in garages on the ground floor, so it formally complied with DRP requirements. But in practice, most of these garages were transformed to illegal commercial spaces, so parking place problem remained unsolved (Fig. 5, D5). Unlike previous two cases, building No. 3 has an underground garage and few parking places on the plot. But in this case POS had been usurped by the investor and sold to the users of the ground floor apartment as private courtyard. Even some additional illegal physical structure – extension of the apartment, was constructed subsequently. Although in this case there is enough green area on the plot, it is not used as POS but as a private garden (fig. 5, D2).

These sites are characterized by high site coverage and density. DRP regulated number of storeys was four, but despite that five and even six storey buildings were constructed (Fig.5, D1). Public green area percentage is low, and urban equipment and places for social interaction are non-existing (Table 3).

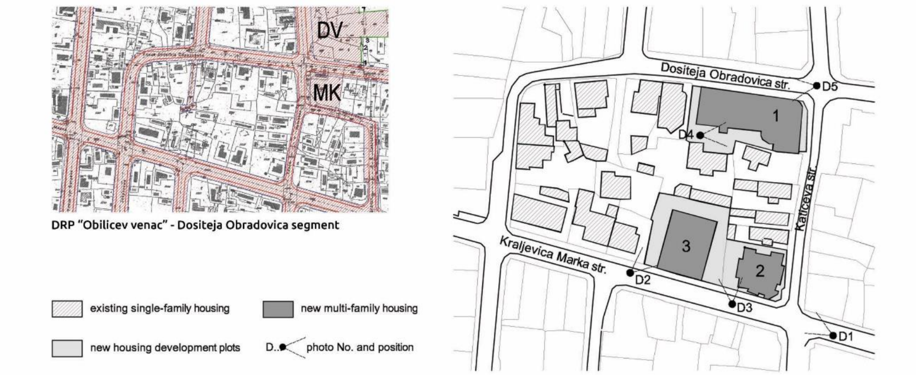

Fig. 4 Dositeja Obradovica area (authors drawings)

Table 3 Dositeja Obradovica evaluation table

Parameter	Value			GRP or DRP value
	Low	Medium	High	
Occupancy level (site coverage)			√	70%
Density (plot ratio)			√	2.4
Percentage of green area	√			-
Parking solution (open parking lot/garage ratio)		√		-
The amount of urban equipment	√			-
Social interaction and usage level	√			-

Fig. 5 Dositeja Obradovica area – photo-documentation (photos by S. Kondic)

3.3. Stanka Vlasotincanina Area

Stanka Vasotincanina block is within mixed inherited housing area and new development is regulated by DRP "Stanko Vlasotincanin" of 2003 (Fig. 6). Four different housing development types can be identified within this area: existing single or multi-family housing, existing housing with MSE development, first period post-socialist housing development (nineties, buildings No. 1, 2 & 3), and second period post-socialist housing development (post 2000, buildings No. 4, 5 & 6).

Fig. 6 Stanka Vlasotincanina area (authors drawings)

Table 4 Stanka Vlasotincanina evaluation table

Parameter	Value			GRP or DRP value
	Low	Medium	High	
Occupancy level (site coverage)			√	70%
Density (plot ratio)			√	3.0
Percentage of green area	√			-
Parking solution (open parking lot/garage ratio)	√			-
The amount of urban equipment	√			-
Social interaction and usage level	√			-

Existing socialist period housing was not the subject of the analysis. It is mostly single-family housing that is being replaced by higher density multi-family housing, in accordance of the increase of land value in the central city area.

First post-socialist period was characterized by the absence of strict legislative and regulations. Despite that fact development in this period provided certain amount of usable POS, used as open parking plots (Fig. 7, S3) or greenery with socialization areas (Fig. 7, S4). The reason for that could be found in closeness to socialist period planned development characterized by higher degree of public awareness.

Fig. 7 Stanka Vlasotincanina area – photo-documentation (photos by S. Kondic)

Second period is the period of unregulated and investor profit-driven development. Even basic urban parameters were often exceeded. This is the case of building No. 4 (Fig. 7, S1), with site coverage of 83% (DPR defined max. 70%) and plot ratio of 4.0 (DRP defined max. 3.0). This development is characterized by the absence of any useable POS, and even any parking spaces. Open spaces are small and unarranged, without adequate green areas, urban equipment or social interaction sites (Fig. 7, S2).

This housing area is a great example of chaotic post-socialist urban development in Serbia without any regard for public interest.

3.4. Stara zeleznicka kolonija – Rasadnik Area

Stara zeleznicka kolonija – Rasadnik area is a specific city area where MSE of existing multi-family buildings was dominant type of housing development in post-socialist period. The existing socialist period physical structure was already developed to the extent that made demolition and construction of new buildings economically unjustified. That is why MSE was the most viable development model for this area. It would increase economical sustainability and housing density, without the increase of site occupancy level. This model was adopted and defined by DRP “Stara zeleznicka kolonija-Rasadnik” from 2007 (Fig. 8).

Fig. 8 Stara zeleznicka kolonija - Rasadnik area (authors drawings)

Table 5 Stara zeleznicka kolonija – Rasadnik evaluation table

Parameter	Value			GRP or DRP value
	Low	Medium	High	
Occupancy level (site coverage)	√			50%
Density (plot ratio)		√		3.2
Percentage of green area			√	-
Parking solution (open parking lot/garage ratio)	√			-
The amount of urban equipment		√		-
Social interaction and usage level		√		-

The existing structures are dominantly single and multi-family buildings, with a small amount of public and commercial facilities (kindergarten, health care centre…). Before the extensions most of the multi-family structures in this area were low-storey (two or three storey) buildings. Through the MSE process another two or three storey were added, so that current physical structure consists mainly of four and five storey buildings (Fig. 9, R1, R2). This model increased housing density without diminishing POS area, so that higher plot ratio was achieved with low occupancy level. This fact was very favourable for the POS quality. Only in this area within the scope of this research large percentage of arranged and unarranged green areas and children playgrounds were identified (Fig. 9, R3-R4). This had been achieved although DRP does not define minimal green area percentage.

Fig. 9 Stara zel. kolonija - Rasadnik area – photo-documentation (photos by S. Kondic)

Larger POS and green area is followed by the presence of urban equipment and higher social interaction level then in other observed areas (Fig.10, R5-R6). Even some aspects of multi-family housing individualization were observed, like individual ground floor apartment entrances, independent from the main building entrance (Fig. 10, R7). This improves apartment and housing concept quality (Stoiljkovic, Jovanovic, 2010; Stoiljkovic, Petkovic, 2012).

Parking space, a great problem in the other analysed areas, does not represent a significant problem in Stara zeleznicka kolonija - Rasadnik. Most of the parking spaces are on the open parking lots, and there are a few garages in the central part of SZK area. Although there is a large POS area, considering the amount of increase of housing density greater problem with providing sufficient parking space was expected than observed. But even now there is not a clear differentiation of greenery and parking spaces, and some of the green areas are being destroyed by vehicles (Fig. 10, R8).

This is the only area with medium social interaction level observed. It clearly is stimulated by the existence of adequate social interaction spaces with urban equipment and green areas. Parking solution parameter was not of great influence in this area because there is no deficit of green areas, and maximum DPS defined plot ratio was not exploited.

Fig. 10 Stara zel. kolonija - Rasadnik area – photo-documentation (photos by S. Kondic)

4. Results & Discussion

Analysis results confirm the hypothesis that all of the considered parameters are interconnected. This is clearly visible through the evaluation tables. Higher occupancy level and density imply lower percentage of green area and the amount of urban equipment. Smaller available POS area is conditioned by higher site coverage. On the other hand, higher housing density requires more parking space. For economic reasons the tendency of the investors is always to maximize the use of open spaces for parking lots, leaving less space for greenery and places for social interaction. If the GRP or DRP does not define minimal percentage of green area and minimal percentage of garage parking spaces it can be expected that the POS will dominantly be used as open parking lots, without greenery and spaces for social interaction.

Economic interest of the investors was obviously primary driving force in housing development. In some cases even urban parameters are not in accordance with DRP defined values. These cases are identified in Stanka Vlasotincanina area. Larger number of storeys and housing density than DRP permitted are identified both in Stanka Vlasotincanina and Dositeja Obradovica areas.

Also, there often is a problem of providing adequate number of parking spaces in almost all of the considered areas. Nominal garages and parking areas are often illegally converted to commercial spaces or private gardens. Even illegal subsequent construction of additional physical structure and the extension of original ground floor area, thus the reduction of available POS area, is sometimes present (Dositeja Obradovica area). This implies corruption or the lack of local authorities control over the construction process. On the other hand, Stara zeleznicka kolonija – Rasadnik area, as dominantly MSE model of housing development, does not have the problem of the increase of the site coverage. Thus total POS area from original socialist period development remained undiminished. This is the only studied area where children's playgrounds are present, and places for social contacts and greenery percentage are adequate. But even in this area the problem of providing adequate number of parking spaces is expected. Since the increase of housing density was not compensated by adequate increase of parking spaces capacity green areas are partially used as illegal parking space and therefore destroyed. The age structure of the population in this area is very specific. Most of the original structures are inhabited by older population that in most cases does not use cars. Increase of younger population in housing extensions initiated parking space problem, and it can be expected to intensify over time, following the change of tenant age structure.

Based on the analysis of evaluation tables following conclusions on parameters interconnection can be drawn:

- Occupancy level (site coverage) is always inverse parameter to the percentage of green area, the amount of urban equipment and social interaction and usage level. In all of the observed areas this connection was determined. Larger site coverage has very negative effect on POS quality.
- Plot ratio and housing density are also inverse to percentage of green area, amount of urban equipment and social interaction and usage level. This connection is not as rigid as in the case of site coverage. Larger density negative effects can be minimized by adequate urban planning and architectural design. It can be achieved by larger number of floors that could allow smaller site coverage. From the aspect of POS quality this is favourable model of achieving greater housing density, as the analysis of Stara zeleznicka kolonija – Rasadnik area proved.
- Percentage of green area is rarely defined in DRP-s. This parameter is very important from the aspect of sustainability, and larger required green area percentage would stimulate smaller site coverage level, and therefore higher degree of social interaction, based on the previous discussion.
- Parking solution (open parking lot/garage ratio) is not always a parameter of great importance, but in some cases it can be crucial for POS quality. High housing density requires large numbers of parking spaces on confined plot. If DRP requirement is to provide larger percentage of parking spaces in the garages more of the POS area is left to the greenery and social interaction sites.

These conclusions could provide guidelines for the recommendations how to improve POS quality and sustainability in post-socialist multi-family housing areas.

5. Conclusion

To determine overall sustainability of POS it is necessary to evaluate all of its aspects: environmental, social and economic. Although environmental and ecological aspect of sustainability are usually most exploited, social aspect is also very important because it determines use value and therefore durability of POS in multi-family housing, and also housing in general. On the other hand, housing development must be economically sustainable, so that the investors would not lose interest in further development. That is why all of the models for improving sustainability of POS must consider all of these sustainability aspects.

Public authorities in Serbia were not very interested in the investments and maintenance in POS, especially within new multi-family housing blocks, and as a private property they were left to the investors to arrange them. Due to the corruption and lack of control by local authorities POS are often left uncompleted and in poor condition by the investors.

Following models for improvement of POS quality and sustainability in post-socialist multi-family housing areas can be determined:

- Better control of the development process by local authorities and reduction of corruption level. This is not within the scope of this research nor architectural profession, and represents a much wider society problem. Beside other benefits, further progress in this area would have positive effect on housing development process.
- User’s education to form a more competitive housing market. Uneducated and non-selective users easily adopt low quality housing. Increase of the awareness of the users through education would increase the need for competition in the housing market, and therefore overall quality of housing development.
- Correction of urban planning documentation (GRPs and DRPs). It is necessary to define certain urban parameters more precisely in urbanistic plans that condition construction and housing development. As opposed to recent years tendency of urban planning regulations in Nis to limit number of storeys and increase housing density by the increase of site coverage, from the aspect of POS quality and sustainability increase of buildings height and reduction of site coverage percentage is more viable solution. Increase of the minimal green area percentage is also very important parameter. Larger greenery percentage that would include all of the permanent green areas on the plot and on building open spaces (terraces, roofs…) would make a great contribution to housing quality and sustainability. Development of economic models of stimulation of the investors to use these principles (subsidies, exemption from payment of municipal expenses…) is of key importance in this process. Parking solution, defining ratio between number of parking spaces in open parking lots and garages is very important in large density housing areas. Lower ratio (larger percentage of parking spaces in the garages) leaves more POS area for greenery and socialization of tenants, improving overall housing quality and sustainability.
- Land Readjustment (LR). This is one of potentially best methods of resolving the problem of POS deficiencies. One of the primary problems of high quality and sustainable urban development of the city is the absence of efficient land management instruments. (Obradovic, 2012). Irregular plots form and undisputed private property rights prevent urban planners and architects from finding the most economical and efficient design. LR proved to be a viable solution for more efficient and economic

land management and urban development, increasing overall housing development quality and sustainability (Yilmaz, Demir, 2015). The general idea of LR is the exchange of the plots in the project area. All of the plots are added together to a so-called land readjustment-mass. Out of this total land readjustment mass all areas designated in the urban development plans for public spaces can be excluded and allocated to the municipality. The remaining mass is the so-called redistribution mass that has to be redistributed to the original landowners (Müller-Jökel, 2004). That way POS area is excluded from the original investors plot and they are conditioned to provide POS area. For this solution to be viable it is necessary to respect investor's economic interest, to condition them to finance POS arrangement, but at the same time to increase plot ratio parameter in order to compensate their plot area loss and provide much better and economic plot shape.

Implementation of these models could increase quality and sustainability of POS, as well as overall urban development quality. Further research should provide more detailed guidelines for their implementation and simulation of potential positive results.

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ODRŽIVOST POSTSOCIJALISTIČKOG URBANISTIČKOG TRETMANA SLOBODNIH PROSTORA U ZONAMA VIŠEPORODIČNOG STANOVANJA: STUDIJA SLUČAJA – NIŠ, SRBIJA

Ovo istraživanje je fokusirano na tretman slobodnih prostora (SP) u zonama višeporodičnog stanovanja u postsocijalističkim centalno i istočnoevropskim zemljama. Cilj istraživanja je da oceni njihov kvalitet i održivost, kao i da identifikuje sve bitne uticajne faktore značajne za njihova svojstva. Sprovedena je studija slučaja na reprezentativnom uzorku od četiri područja namenjenih višeporodičnom stanovanju u Nišu, u Srbiji. Jedan od osnovnih ciljeva istraživanja je utvrđivanje međuzavisnosti između urbanističkih parametara i realizovanog kvaliteta slobodnih prostora. Ovo bi moglo da vodi do formiranja preporuka za buduću višeporodičnu stambenu izgradnju, uključujući i upotrebljivije i održivije otvorene površine u savremenom socijalnom i ekonomskom kontekstu. Kao rezultat istraživanja definisani su i modeli za unapređenje kvaliteta i održivosti slobodnih prostora.

Ključne reči: *održivost, višeporodično stanovanje, otvorene površine, urbanističko planiranje, postsocijalističko*

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Original scientific paper

INFLUENCE OF GEOMETRICAL AND STRUCTURAL IMPERFECTIONS ON THE BEHAVIOR OF STEEL PLATE GIRDERS

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Abstract. *The girders or parts of the girders are not ideally flat in terms of their geometry. The deviations that occur are defined as geometric imperfections. Also, in the material from which the girder is made, a certain deviation may occur during factory production or for some other reason, which is known as structural imperfection. This paper presents the analysis of the behavior of plate girders (welded steel I girders), with and without material stiffening and loaded with patch loading. The results were obtained by numerical simulation in the ANSYS for models with included geometric imperfections. The model was performed in accordance with the recommendations for different behavior curves of materials from Eurocode 3. The limit load obtained by numerical simulation corresponded to the experimental results from the literature. Stress values for girders with and without geometric imperfections for the same load value were compared.*

Key words: *geometric imperfections, structural imperfection, plate girder, steel girder*

1. INTRODUCTION

The behavior of plate girders (welded steel I girders) under the patch load is very complex. The complexity of this problem lies in the fact that, on the one hand, there is a localized buckling of the girder in the web. On the other hand the load due to buckling does not match the limit load.

In practice, this case is encountered during the assembly of bridges, the process of launching the bridge to its final position over temporary or permanent supports. The influences which occur may exceed the load of the structure in certain points due to the patch loading. As no complete theoretical solution to this problem has not been found yet, there is a need for a more detailed analysis. With that kind of problems, in order to perform

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their design, it is necessary to consider the geometry of the girders and the characteristics of the materials from which they are made. The way to its solution requires a combination of experimental research and numerical analysis, to which special attention is paid in this paper. Especially in cases of numerical simulations where numerical models are formed, it is very important to include imperfections of girders.

When analyzing the behavior of plate steel girders, in the beginning, the models were composed of ideally flat plates. It is clear that real constructions are not ideally flat, but that they have initial imperfections before applying the load. These irregularities have become an unavoidable part of the analysis and it has been shown that in some cases their impact is not negligible.

The importance of this problem is also shown by the fact that in the European regulations EN1993-1-5 in Annex C [1], as well as ENV 1993-1-1 [2], recommendations are given for the method of setting the initial imperfections. Cases of research on the influence of real imperfections on the size of the limit load are represented in the literature in a smaller number. Within the commentary of EN1993-1-5, a suggestion was given that studies of the impact of real imperfections should be continued in order to improve the calculation recommendations. Girder analysis was performed in the ANSYS program. Girders without longitudinal stiffener and girders with longitudinal stiffener near the loaded upper flange were tested. We analyzed the influence of the length of the uniformly distributed load on the loaded flange, and in the plane of the web, known as patch loading and the behavior of the girder in the nonlinear domain, as well as the ultimate load which was manifested as progressive increase of registered deformations of flanges and the web and strains without further increase of force. Tests were performed using numerical simulations and they relate to the behavior of the girder model and the values of the ultimate load for different material models in the plastic domain with the aim of choosing the one that gives the closest results to the real model. Also, in terms of stress analysis, the results of girders with and without geometric imperfections were compared.

Geometric imperfections mainly occur during the construction and operation of the structure. Globally, imperfections are divided into geometric imperfections, ie. imperfections concerning girder geometry and structural imperfection, ie. imperfections related to material imperfections. When determining the ultimate load capacity of steel plate structures by numerical analysis, in case the reduction factor is not taken, the initial imperfections must be included. However, no matter how precisely the imperfections are defined, they represent only a replacement for the real imperfections of the girder. Accordingly, it is clear that there are certain differences in the results of numerical simulations in relation to the results obtained by experimental research. In this regard, it is impossible to precisely define the inhomogeneity of the material, the effect of the load or the definition of boundary conditions, but appropriate substitutions must be found in the formation of the numerical model.

2. IMPERFECTIONS OF GIRDERS

This section will provide an overview of girder analysis involving imperfections and a brief overview of this issue that can be found in the literature.

2.1. Geometric imperfections of girders

The initial deformations are predicted to include the corresponding model imperfections. Their choice is such that due to the load, the least resistance of buckling is obtained. Imperfections can also be divided into: local imperfections within which individual elements are analyzed and global imperfections that apply to the entire structure.

According to the method of setting the initial geometric imperfection, they can be divided into real imperfections, imperfections according to their own modes, equivalent geometric imperfections and imperfections according to the fracture shape.

2.1.1. Real imperfections

The setting of imperfections in this way is used in the testing of concrete carriers or during serial production. Setting imperfection in this way is used in testing specific girders or during series production. In numerical modeling, this type of imperfection is usually replaced by some other imperfections, which are easier to model. In this paper, real imperfections on numerical models are given. There is not much data in the literature about systematic measurements of initial deformations, that is, real imperfections used in the experiments, which was an additional incentive for the authors of this paper to research.

Speaking about the experiences of researchers who assigned real initial imperfections on their numerical test models, specifically in [3], the girder in the ABAQUS software package was modeled. The shape of the precise girder geometry was obtained using a 3D measuring device. The measured web geometry was transferred to the model for numerical analysis, while it was estimated that the measured geometry of the flanges, i.e. its imperfections should be neglected, so the flanges of the model are taken as ideally flat. It was concluded that the results of girders with real imperfections lead to a satisfactory ultimate load compared to the experimental results. In addition to the real imperfections, the structural imperfections of the girder were also included.

2.1.2. Imperfections according to buckling modes

This type of imperfection is defined on a mathematical-numerical basis, by analyzing the bending of the girder at its eigenvalues. After determining the eigenmodes, the shape of the eigenmodes is assigned to the geometry of the girder model. Such girder geometry should be considered as the initial geometry with appropriate boundary conditions.

One of the first researchers to include the influence of initial imperfections in his research of patch-loaded girders was Bergfelt [4]. He concludes that if the shape of the initial imperfection of the girder is similar to the shape of its own buckling mode, then the ultimate bearing capacity is lower than if this is not the case. The amplitude, the shape of its own mode, the slenderness of the element and the type of stiffening of the web to flange should be taken into account.

Graciano [5] analyzed the girders loaded with patch loading by setting the initial imperfections according to eigenmodes in the ANSIS software package. The models were previously tested experimentally. The cases for the first three basic buckling modes shapes of the girder were examined (Fig. 1), as well as for the case of the sum of the first three buckling modes.

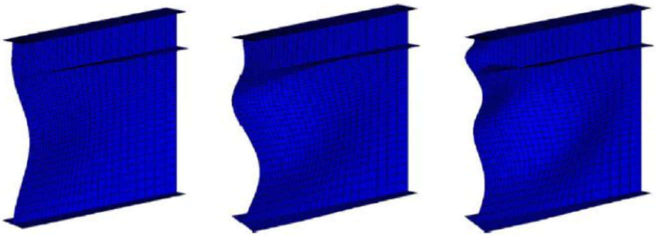


Fig. 1 The first three buckling modes respectively [5]

The conclusion of this research is that the shape of the initial imperfection that results in the lowest strength for a girder differs for each size of imperfection and stiffener location. It is also pointed out that the initial imperfections for girders under patch loading can be modeled using a shape similar to the first eigenmode or sine wave in order to obtain satisfactory results.

In the EN 1993-1-5, Annex C [1], it is proposed that Geometric imperfections may be based on the shape of the critical plate buckling modes with amplitudes given in the National Annex, as well as to recommend 80% of the geometric fabrication tolerances. In the case of greater distances of transverse stiffness, in global imperfections for longitudinal stiffening the eigenmodes consist of two or more half-waves. Therefore, care should be taken that the assumed imperfections have a certain number of half-waves, because the relevant form of imperfection is the one that gives the least ultimate load.

In the work of Chacon [3], the girder geometry, based on its eigenmodes, is given in accordance with the regulations EN1993-1-5, with an amplitude w = 80% of the factory tolerance. Structural initial imperfections were also taken in all girders. Four types of girders with different initial geometries were examined (girder length was varied). It was concluded that satisfactory results were obtained according to the first two eigenmodes, while setting the shape of higher eigenmodes does not give less resistance as provided in EN 1993-1-5.

2.1.3. Equivalent geometric imperfections

The initial geometric imperfections of a girder that are represented in the form of a mathematical function, for example a sine function, and follow the form of real geometric imperfections, are called equivalent imperfections. European regulations [1], [2] provide rules for assigning geometric imperfections. Equivalent imperfections can be used in all cases where no more precise analysis is performed. The table with recommended values of amplitudes and shapes of imperfections in relation to the width and length of the support already exist. It is also noted that equivalent geometric imperfections can be replaced by appropriate fictitious forces.

In the work of Granath [6], satisfactory results were obtained by assigning equivalent imperfections (in the form of a sinusoidal function similar to the form of the first buckling mode) for the girders without stiffening.

In [7], equivalent imperfections of the sinusoidal function were used. Although these imperfections did not represent the most unfavorable case for predicting the lowest resistance, satisfactory results were obtained. The conclusion was: the shape of imperfections becomes relevant only for non - square plates, while for square plates the difference in imperfections according to their eigenmode and equivalent imperfections in the form of sinusoidal function becomes negligible.

In [8], the imperfections given on the basis of the buckling shape that was previously obtained experimentally are considered. With such given imperfections, the lower ultimate strength was obtained in comparison with other cases of imperfections. The authors suggested that this be included in the regulations as a better way of setting imperfections.

2.2. Structural imperfections

Structural (material) imperfections of the carrier refer in most cases to imperfections of materials that occurred during factory production or for other reasons. These imperfections are residual (residual) stresses in the material. These stresses occur during the welding of the girders, which reduces their load-bearing capacity [9]. Structural imperfections must be taken so as to cause the most unfavorable case of buckling, which is achieved by including residual stresses in the model in FEM. EN 1993-1-5 highlights the use of a combination of structural imperfections with one of the geometric imperfections. Residual stresses can sometimes be considered as fictitious, additional initial deformations [1].

In paper [3], it is stated that each residual stress is atypical and that each specific case can cause different implications. It is stated that the introduction of patterns for residual stresses gives somewhat more precise results, but that their influence does not play a decisive role.

Simplified patterns for residual stresses, proposed by the Swedish regulations for steel girders, were used in [10] and [11].

Note that the presence of geometric and material nonlinearity must be observed simultaneously.

3. Geometric Characteristics of the Girder and Numerical Model

Within this paper, a numerical model was formed which confirmed the results of N. Marković's experiment, taken from the literature [12]. The model included the geometric characteristics of the girders with imperfections, and during the testing, within the material characteristics, several different σ-ε curves were taken, which correspond to the tested material samples from which the experimental models were made [13]. The geometry of the girder model with all dimensions is shown in Fig. 2. Four girders of the same dimensions were tested, two are without longitudinal stiffening, and two with longitudinal stiffening. The girder span is s=500 mm, web depth h=500, web thickness t_w=4 mm, flange with b_{fl}=120 mm, flange thickness t_{fl}=8 mm, stiffening depth h_{st}=30 mm, stiffening thickness t_{st}=8 mm, distance from the upper flange to the longitudinal stiffener h_1=100 mm. The length of application of the load l differed. Two girders lengths of patch load is l=50 mm and for the other two is l=150 mm. Web panel aspect ratio is s/h=1.

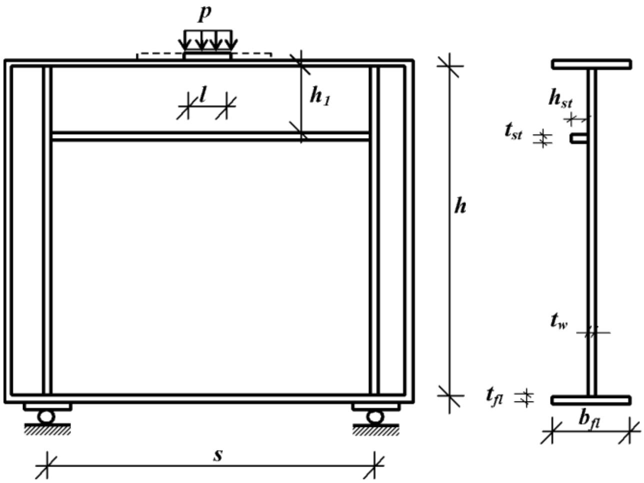


Fig. 2 Model of girder [14]

The aim of this research is, among other things, to examine the influence of real geometric imperfections of the girder web on the stress state, so that the girder models for computer simulations were taken as girders without and girders with imperfections.

Defining the initial shape of the girder for a numerical model was based on the precise geometry of the examined experimental model. In the experimental models, the initial geometric imperfections of the web were measured at a number of points (Fig. 3) with a measuring device. Imperfections of flange and stiffeners were not considered. Numerical models were formed and their geometry corresponded to the girders from the experiment. Figure 4 shows the shape of the initial geometric imperfections before applying the load. The values are given with magnification to highlight imperfections.

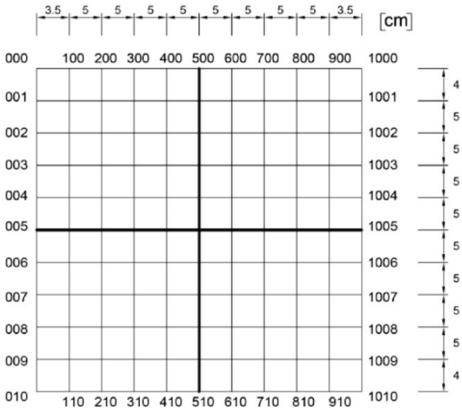


Fig. 3 Points on the web where the initial imperfections are given [15]

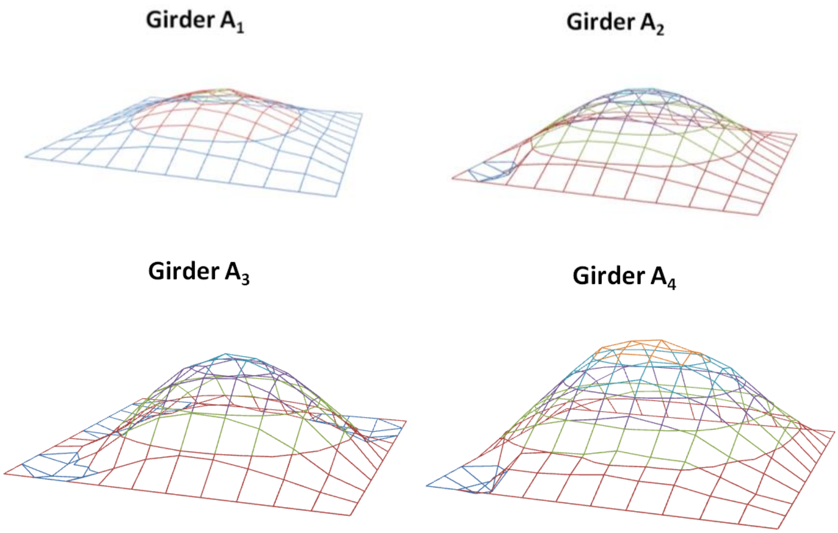


Fig. 4 Initial imperfections of the webs before loading for all type of girders

To obtain relevant data, for a numerical model, it is of great importance to represent the exact behavior of the material. Precise tests of the material properties of the girders were performed and the obtained results were used to form nonlinear models of materials used in numerical analysis.

According to European standards, in cases where material data are not available, the yield stress is assumed theoretically as a horizontal line to the achieved yield stress or its slope is defined with the value E / 10000, where E is the modulus of elasticity of that material.

Another case is the approximation of the E / 100 slope curve where the reinforcement of the material is considered and, in the case of a more realistic representation, it is possible to approximate the real curve in such a way as to obtain a multilinear curve that will best show the material characteristics. All variants of curves will be used in this paper. Bilinear curves with tangent modulus Et = E / 10000, Et = E / 100 will be used as well as a multilinear curve corresponding to the actual σ-ε material curve (Fig. 5).

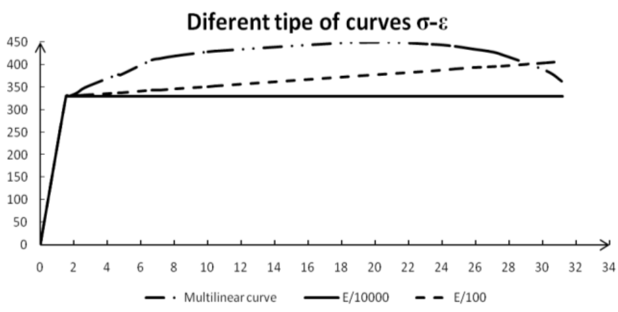


Fig. 5 σ-ε curves used in numerical model

The boundary conditions of the girder are defined so that the girder in the static sense is simply supported. In numerical analysis, the own weight of the girder is included in the calculation. The load of the girder is given as an equally distributed load over the entire width of the flange, and with certain lengths *l* on the upper flange. The girder load was applied through the load plate as in the experiment, and it was permitted to move only in vertical direction.

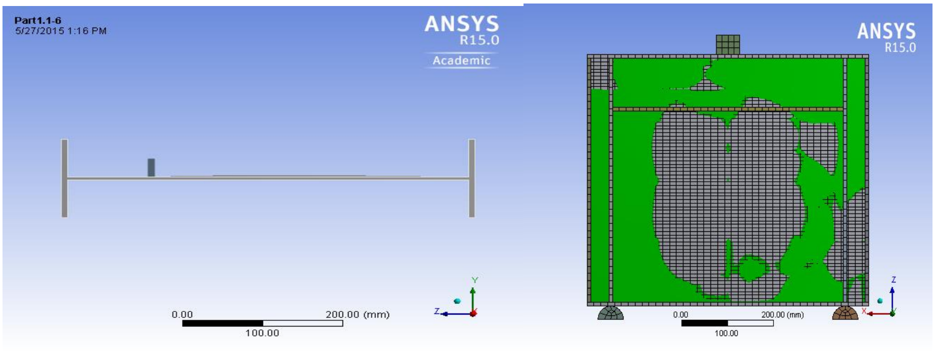


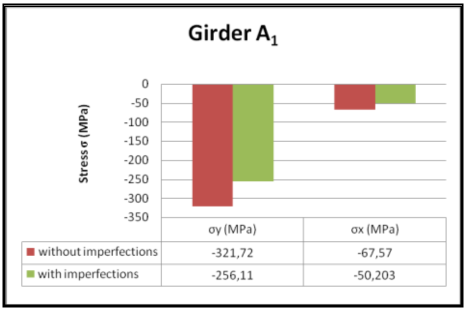
Fig. 6 Numerical model with initial imperfections

Based on the geometry of the girder, the numerical model of the girder was discretized by dividing it into finites element mesh. From the database of elements of the software package ANSYS Workbench 15, elements of the SOLID type were selected. A finite element size of 15mm was adopted.

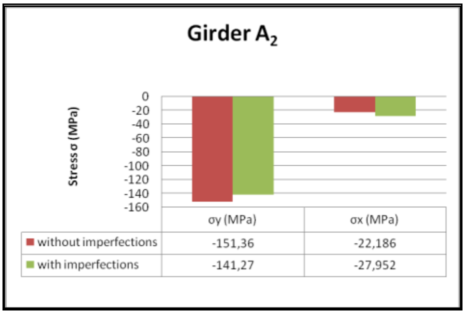
Figure 6 shows a beam with a finite element mesh before loading and on which geometric imperfections are clearly visible.

4. Results and Discussions

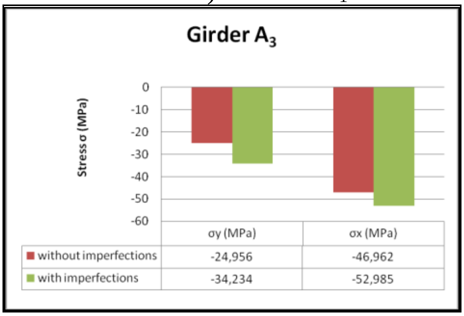
The actual models for numerical simulation of girder behavior allow inclusion of initial deformations-imperfections into the calculation on the basis of the actual girder model. In the numerical simulations of the model, the form, character and course of the deformation process as well as the buckling were identical as in the experiments with actual models, for each concrete sample [15]. Based on that, this numerical models can be used for further analysis. Figure 7 shows the stress diagrams σ_x and σ_y for girders without imperfections and for girders with real imperfections for all types of girders A_1, A_2, A_3 and A_4. The influence of real imperfections in numerical simulation on stress values σ_x and σ_y at one of the measuring points for the same load value is presented (100 kN).



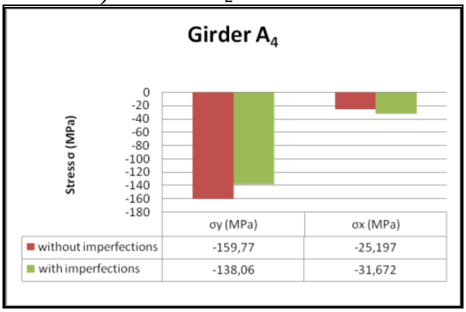
a) Girder A_1



b) Girder A_2



c) Girder A_3



d) Girder A_4

Fig. 7 Influence of real imperfections in numerical models of girders on stress values σ_x and σ_y for force of 100 kN [15]

One of the main goals of this modeling is to monitor the ultimate bearing capacity of the girder. The obtained values were compared with the ultimate load obtained experimentally. Table 1 shows the ultimate load values in kN for all four types of girders (A1, A2, A3 and A4) obtained experimentally (experiment), as well as obtained by numerical simulation for different values of curved σ-ε materials (multilinear curve, E/10000 and E/100).

The difference between the ultimate load of numerical models and the ultimate load obtained experimentally is shown as a percentage. The last column shows the mean value of the deviation expressed as a percentage for each of the given behaviors of the material curves.

Table 1 Ultimate load values for all types of girders and deviation in relation to experimental results

	A_1	A_2	A_3	A_4	%
Experiment	165	215	183	255	Mean value
Multilinear curve	178,174	216,9275	188,5	274	
%	7,98%	0,90%	3,01%	7,45%	4,84%
E/10000	172	235,406	176,962	299,407	
%	4,24%	9,49%	-3,30%	17,41%	8,61%
E/100	180,5	238,637	185,5	302,438	
%	9,39%	10,99%	1,37%	18,60%	10,09%

Table 2 shows the increase in ultimate load with increasing patch loading length from 50 mm to 150 mm for non-stiffening girders (A_1 and A_2) and with stiffening (A_3 and A_4). The results obtained experimentally and numerically by simulation were compared and presented in percentages.

Table 2 Influence of "patch loading" on ultimate load

	Without stiffener	*With stiffener*
	A_1 and A_2	A_3 and A_4
Experiment	23,26 %	31,20 %
Multilinear curve	17,86 %	59,66 %
E/10000	26,93 %	40,90 %
E/100	24,36 %	38,67 %
Mean value	22,56 %	43,56 %

Table 3 shows the effect of longitudinal stiffening on the ultimate load capacity for girders with load length l = 50 mm (A_1 is without stiffening and A_3 is with stiffening) and load length l = 150 mm (A_2 is without stiffening and A_4 is with stiffening).

Table 3 Influence of longitudinal stiffening on the increase of ultimate load capacity

Load length	*l=50 mm*	*l=150 mm*
	A_1 and A_3	A_2 and A_4
Experiment	9,84 %	15,69 %
Multilinear curve	5,8 %	20,83 %
E/10000	2,88 %	21,38 %
E/100	2,77 %	21,10 %
Mean value	2,99 %	22,10 %

5. Conclusions

The behavior of plate girders under the patch loading is very complex and depends on various parameters. The appearance of plasticization occurs already after 50% of the ultimate load. The deformations that occur then do not have to be significant. The Plastification develops on the most loaded part of the web, first, only on the surface and then spreads along the thickness of the web. This behavior depends on many parameters, and it can be quite complex due to the variable stress field.

The influence of geometric imperfections of the web in the girders (without flange and stiffening imperfections) was included and a comparison with girders without imperfections was performed within the numerical simulation, in order to monitor the development of stresses.

Stress values for the same load values for the observed girders were obtained. The obtained results were compared for girders with geometric imperfections of the webs on one side and girders without geometric imperfections on the other side. In Figure 7 we can see that by including imperfections in the calculation, deviations in stress values occur. It is necessary to keep in mind that within our model, the effects of imperfections of flanges and stiffening, possible deviations in defining the boundary conditions that correspond to the real girder, etc. were not taken into account.

The ultimate load for all types of girders were calculated and the obtained values were compared with the experimental results (shown in Table 1). The values for different σ-ε curves in accordance with European regulations were calculated separately. In all cases of the given material behavior diagrams, the results are satisfactory. The best agreement with the experimental results was given by the material behavior curve corresponding to the multilinear curve of real material and this deviation averages 4.84%.

With the increase of patch load length, there was an increase in the ultimate load capacity in both stiffened and unstiffened girders, with included imperfections (see Tab. 2). The presence of longitudinal stiffeners also increases the ultimate load capacity, which is shown in Table 3.

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UTICAJ GEOMETRIJSKIH I STRUKTURNIH NESAVRŠENOSTI NA PONAŠANJE ČELIČNIH PLOČASTIH NOSAČA

Nosači ili delovi nosača nisu idealno ravni u pogledu svoje geometrije. Nesavršenosti koje se javljaju definišu se kao geometrijske imperfekcije. Takođe, u materijalu od kojeg je napravljen nosač može doći do određenog odstupanja tokom fabričke proizvodnje ili iz nekog drugog razloga, što je poznato kao imperfekcija materijala. Ovaj rad predstavlja slučaj pločastih nosača (zavareni čelični I nosači) sa i bez ukrućenja i opterećenih patch loading-om*. Dobijeni su rezultati numeričkom simulacijom u programu ANSYS za modele sa uračunatim geometrijskim imperfekcijama. Formiranje modela izvršeno je u skladu sa preporukama za različite krive ponašanja materijala iz Evrokoda 3. Granično opterećenje dobijeno numeričkom simulacijom odgovaralo je eksperimentalnim rezultatima iz literature. Upoređene su vrednosti napona za nosače sa i bez geometrijskih imperfekcija za istu vrednost opterećenja.*

Ključne reči: *geometrijske imperfekcije, imperfekcije materijala, pločasti nosač, čelični nosač*

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Original Scientific Paper

TOWARDS FLEXIBLE HOUSING: BASIC DESIGN PRINCIPLES

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Abstract. *In times of radical social transformations, the demand for flexibility of space can be identified as one of the strategic priorities of maintaining the urban environment. In the context of social, economic and environmental sustainability, housing must imply an integrated ability to respond to programme changes, which can be achieved through the concept of flexibility. By identifying and applying certain design principles, it is possible to prevent the problem of functional obsolescence and unsuitability of the living environment that modern cities are facing. The apartment as an immediate living environment is the most direct indicator of the degree of adaptability of the physical surrounding to modern human needs. The analysis of basic design principles, using an example of flexible apartment, examines the spatial correlations and laws of the relationship between elements of the plan, which provides the basis for the authors to draw the conclusions about the reality of applying this concept in practice.*

Key words: *apartment, housing, flexibility, design principles, sustainability*

1. INTRODUCTION

Progressive socio-economic development, advances in information and communication technologies, the state and conditions of the living environment create a climate for constant and continuous changes, setting new conditions and requirements in the field of architecture. The evolution of housing leads to new conceptual solutions and new standards and principles of design. Programme changes in the field of housing are conditioned by numerous phenomena occurring in the modern society, among which are particularly noteworthy the accelerated population growth, emphasized social diversity, transformation of household typology, tendency of cohabitation of non-residential and residential functions, etc.

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In the existing urban areas, the number of abandoned buildings that are in a state of devastation and obsolescence is growing. The problem is further complicated by the fact that in the age of progressive growth of the world population, upgrading the housing environment in already defined and densely populated urban patterns is recognized as an imperative measure of sustainability. The sustainability of the urban environment in the conditions of progressive social development requires strengthening the functional immunity of all urban layers, from basic constitutive elements to the complex formations of the dynamic spatial system. Physical and functional adaptability to technological, environmental, economic and social trends requires the definition of sustainable housing models that will respond to programme and content modifications. Housing that actively corresponds to the continuous changes in society is therefore required to conceptualize in accordance with the general principles of flexibility, which within the appropriate spatial framework enable the acceptance and functioning of the different housing concepts.

Flexibility represents a political and social imperative, which is based on people's differences rather than on their similarities. These differences are recognized in informal patterns of space exploitation that flexibility formalizes through its principles [1]. Decisions made at the earliest stage of design, which relate to the spatial and functional characteristics of the plan, largely determine the course and potential modalities of housing exploitation. The main goal of the research is to improve the quality of living space by affirming conceptual models of flexibility through its basic design principles. In accordance with the basic goal and the selected methodology, the paper defines the apartment as theoretical and physical framework of the research, along with an analysis of human needs issue within it. The main starting point in the research is the assumption that implementation of the certain design principles ultimately increases the level of plan flexibility. Perceiving and understanding the interdependence of specific physical aspects is a necessary precondition for optimizing the space exploitation. In this regard, appropriate spatial correlations formulated through the basic principles of flexibility are identified. After systematization and formulation of the principles, their interdependence is examined and the possibilities of implementing this concept in practice are evaluated.

2. THE APARTMENT AS A FLEXIBLE FRAMEWORK OF MODERN SOCIETY

The apartment represents a basic physical, but also psychological framework for satisfying complex human needs that it incorporates and links to its multi-valued functions [2]. The relationship between human and the environment should be perceived as a two-way process, in which the exploitation mode represents the basic determinant of this relationship and the source of knowledge about the housing needs and peculiarities of human nature. This relationship, usually called "the apartment exploitation", is in fact not exclusively of an exploitative nature. Namely, humans use a living space by giving it signs of their engaged presence [3]. Satisfaction of housing needs is the basic measure of an apartment use value. The design quality depends on the extent to which the apartment can respond to the dynamics and diversity of life processes within it. By correlation of numerous factors, created housing environment puts a dweller in a role of an active participant or passive observer, on the basis of which the measure of "humanization of space" [4], i.e., "visibility" of users in space is determined.

The diversity and complexity of housing functions stems from the individual developmental variation within different household models. Changes in the modern way of living, under the dominant influence of advanced information technologies and current movements of globalization and sustainability, transform the classical perception of the family and affect the development of new household typologies. Along with the globalization process, movements of liberalization and individualization are also developing, transforming inherited traditional and dogmatic values within the concept of modern society. Social movements and the evolutionary progress of society create demand for reconceptualization of contemporary housing and research of new developmental models and housing typologies. The range of individual and common needs is constantly getting more complicated, and thus the potential patterns of space exploitation. The traditional monothematic family, which once represented the dominant unit of society, is now becoming just one of many typological forms of households. The dominant primacy of the individual over the collective, in the current conditions defined by the modern society creates the programme diversity on the housing market. Greater efficiency and mobility of information technology transform the classic housing concept, requiring its programme redefinition. The dynamism of life and the technological revolution initiated new tendencies in housing development, where flexible mechanisms are the basic instrument of amortization of programme changes. The unpredictability and dynamism of life circumstances, the weakening of socially predetermined roles, traditional and marital norms, the postponement of starting the family, the expression of the individual over the collective lead to the gradual replacement of the institution of marriage with alternative forms of single life and living together in cohabitation. The increasing degree of tolerance and freedom in self-decision and self-determination, as well as the weakening of previous ties with tradition and inherited social values, result in structural diversity and heterogenization of lifestyles.

The living environment should in the most appropriate way respond to the socio-psychological specificities of human needs. A rigid and unadaptable housing can leave serious consequences on personal identity and cause psychological and sociological conflicts in a family or non-family group. Flexibility of an apartment is a dynamic category that, given the complexity of human needs, can significantly improve the exploitation potentials [5]. In this regard, it is necessary to define the basic design principles which will support the concept of flexibility and its dynamic performance.

3. Architectural Principles of Flexibility

Considering the results of previous research on the topic of flexibility [2], the basic design principles are presented in seven major categories. These principles which can serve as recommendations for improving the methodology of architectural design can be expressed and classified as follows:

1. principle of stratification
2. principle of coherent grouping
3. principle of polyvalence and neutrality
4. principle of openness
5. principle of modularity
6. principle of division and integration
7. principle of spatial reserves.

Figure 1 shows an example of a flexible apartment within Neuwil residential development in Wohlen (Switzerland) designed by Metron-Architekten AG. The basic idea of the designers was that the apartment, owing to its flexible potentials in the open plan, responds to the changing needs of one family group, i.e., the changing lifestyle of future generations. The centrally positioned technical core contains a sanitary block, a kitchen and a staircase, and only its function and position are predefined. The use and arrangement of surrounding space is not predetermined, but the tenants are left with the possibility to organize it individually. As the convenience of orientation, quality and size of the space facing the east and west facades are almost identical, it is possible to create different spatial arrangements by exchanging the functions. As part of the project, the architects also prepared the brochure in which they presented the potentials of space flexibility through appropriate 2D and 3D drawings. Thus, among other, the possible position of the partitions in the modular grid of 30 cm is indicated in analyzed apartment. As this apartment contains all the previously mentioned principles, they will be individually presented through the schematic drawings by the authors of this paper.

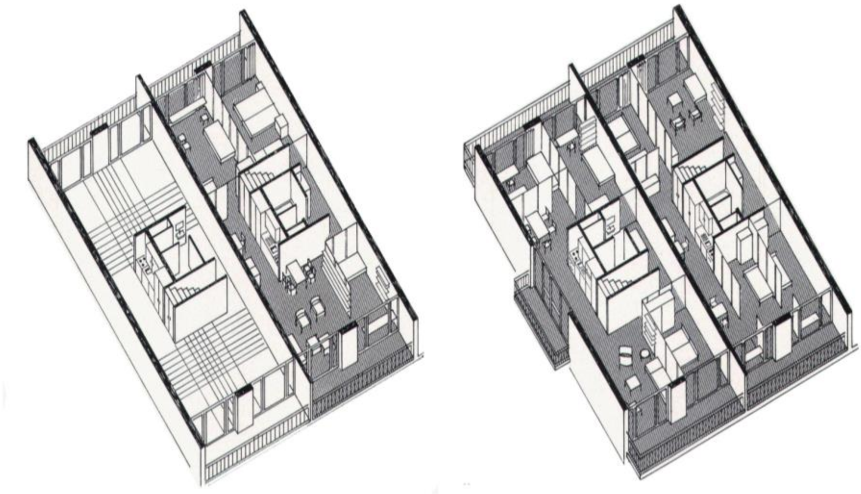

Fig. 1 The example of flexible apartment, Neuwil, Switzerland, Metron-Architekten AG (M. Pestalozzi, “Flexibilitätsexperiment im Freiamt”, 29. August 2016, [Digital image], https://www.swiss-architects.com/de/architecture-news/meldungen/flexibilitatsexperiment-im-freiamt)

3.1. Principle of stratification

Differentiation of spatial characteristics based on their determination in the plan is the initial step in conceptualization of a flexible housing model (see Fig. 2). Systematic spatial decomposition into static and dynamic components or, according to the classification of relevant authors, into “structure and infill” [6], i.e., “frame and generic space” [7], actually means that in the initial stage of design it is necessary to define a constitutive platform that will, in a later phase, adequately accept upgrading and variability of the system. In this regard, a thorough analysis of the aspects that permanently and irreversibly define the morphology and modalities of space exploitation is extremely important for the study of flexibility.

Immutable, fixed plan determinants include all constructive, dispositional and installation components that are permanently defined in the plan. Variable aspects represent spatial characteristics in free interpretation which are, in fact, direct indicators of the achieved degree of flexibility.

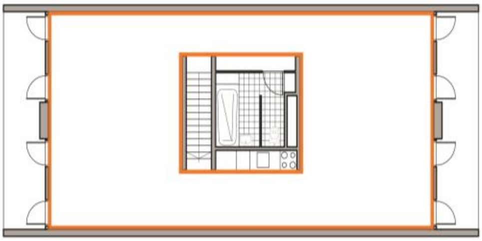

Fig. 2 The principle of stratification with designated “frame and generic space”

3.2. Principle of coherent grouping

The way of structuring determinants in the plan is one of the important factors of flexibility. The grouping of related functions into residential zones is replaced by the grouping of coherent contents and elements of the plan according to the principle of permanence and variability in space-time frameworks. As the installation blocks and bearing elements of the structural system represent the most inflexible parts, it is necessary to thoroughly consider the possibilities of their grouping in the plan (see Fig. 3). By integrating the determinants into a meaningful grouping, the surrounding space is relieved of physical constraints, thus achieving a greater degree of free zone variability. If the construction design envisages the positioning of the bearing elements within the plan, it is desirable to position the installation blocks in the immediate vicinity of these elements, in order to clearly separate the so-called “frame” of “generic space”. It is also desirable to group auxiliary rooms that do not require natural lighting and ventilation within this zone. Coherence and compactness instead of the fragmented concept of determinants in the plan is, therefore, one of the principles of flexibility.

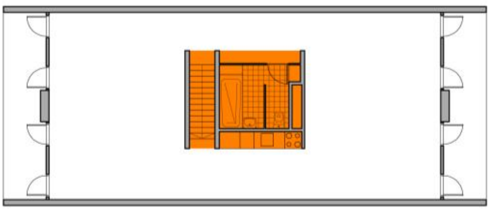

Fig. 3 The principle of coherent grouping with designated core of determinants

3.3. Principle of polyvalence and neutrality

Universality of space organization represents a response to the unpredictability and uncertainty of programme contents that housing unit accepts over time. The creation of neutral spaces that correspond to multiple purposes and functions is one of the principles that leads to the prolonged housing exploitation (see Fig. 4). The concept of undefined and polyvalent space transcends conventional housing models, in which the functional and spatial differentiation of contents is conducted according to a strict schematic pattern. Unlike the classical system of rooms of predetermined function, the advanced programme concept defines typical units of approximately same size and dimensions, which become independent entities suitable for different social and programme scenarios. Polyvalence and ambiguity in use require standardization and implementation of a unified model of space structuring and organization. Differences of spatial requirements are overcome by superimposing functions in the plan or by meaningful division of typical units.

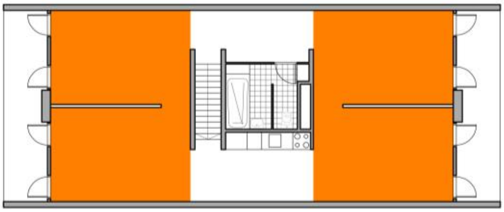

Fig. 4 The principle of neutrality and polyvalence with indication of universal rooms

3.4. Principle of openness

An open plan designed with a certain degree of incompleteness and contents that organically permeate and are connected with each other, is one of the possible concepts of flexibility (see Fig 5). The openness of the plan is stimulated by the designer's intention to leave tenants the opportunity to independently organize the space, according to their own needs and desires. The incompleteness of the spatial system that leads to freedom of interpretation, however, requires a certain professional orientation. The potentials of space partitioning can be represented by suggesting the possible position of the walls in the interior (dashed lines). The openness of the space should have its limitations. Due to the complexity of human needs, it is desirable that, in addition to sanitary facilities, there is the possibility of physical separation of at least two more zones with alternative functions, in order to avoid conflict between them.

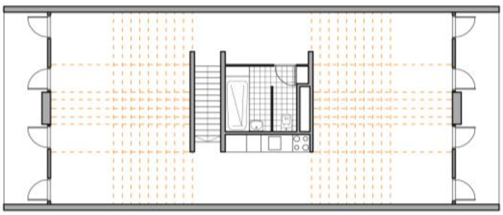

Fig. 5 The principle of openness with indication of the possible partitioning options

3.5. Principle of modularity

Openness, neutrality and polyvalence are closely related to the principle of modularity. Similar to a traditional Japanese house, in which the size of the rooms and the positioning of the pillars correspond to the tatami's module, the plan should be based on a universally adopted and standardized system of measures (see Fig. 6). Designing within a single system of modular coordination is essential to the concept of flexibility because universality which lies at the core of thinking leads to programmatic diversity. In this manner, a balance is established between the conflicting demands for standardization in construction and programme diversity in exploitation. Unification of the structural platform ultimately results in greater freedom of "generic space". Coordination of construction elements with the architectural design should enable variability in the organization and multifunctional use of space. In this regard, in the design phase, it is necessary to anticipate possible spatial and functional scenarios and dimensional frameworks of potential housing functions in the appropriate design module.

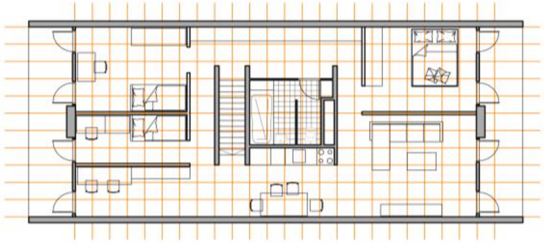

Fig. 6 The principle of modularity with the possible space division in a modular grid

3.6. Principle of division and integration

Flexibility is based on the criteria of elementary ambivalence of social life, which equally treats human's need for isolation and togetherness. The possibility of organic connection of spatial units within a meaningful functional entity of higher level, i.e. the possibility of entity's division into segments of lower level, while preserving the spatial and functional integrity of space, is one of the elementary principles of flexibility (see Fig. 7). The degree and modality of changes in fragmented-integrated relationship depends on the applied design concept. It can be based on a permanently defined or controlled pattern of use. The application of flexible equipment that enables a regulated connection between individual spatial units is a suitable solution for dynamic programme concepts, in which changes are manifested intensively, often on a daily basis. Preferences in relation to the degree of space division depend on personal affinities, structure and type of household.

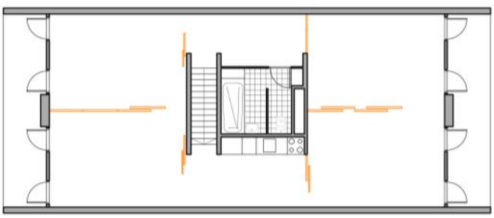

Fig. 7 The principle of division and integration with presented application pattern

3.7. Principle of spatial reserves

The floor area is a crucial criterion for conceptualization of the flexible plan. The reduced area irreversibly limits the possibilities of variable organization and room upgrading within the unit. Defining the optimal apartment area is an essential issue that cannot be solved exclusively on the relation between the household structure and the structure of the unit (number of bedrooms). As the floor area of living space increases, structural characteristics become a minor criterion for meeting unexpected or forecasted housing needs over time. In this regard, it is desirable for space to be to some extent oversized. In this manner, the spatial reserves in the comfortable phase of exploitation will be activated and used in the most crowded phase of family development (see Fig. 8). For reasons of economic acceptability, in the case of a nuclear family household, housing standards in the initial phase of household development would correspond to the area maximum, while in the mature phase of development they would correspond to the area minimum. The adopted normative standards of the lower structure correspond to the minimum spatial standards of the higher structure.

Fig. 8 The principle of spatial reserves with possibilities of plan arrangements

4. Discussion

Some of the presented principles are closely interrelated, some can be individually implemented or combined with other principles, depending on the degree of built-in flexibility. Stratification of space into layers is essential for understanding and applying the concept of flexibility. Within the system, the spatial criteria that are being the subject of physical changes and those that are permanently defined are identified. Researching the correlative relationship between determinants and elements in a free interpretation can introduce certain spatial directions on the basis of which the other principles of flexibility are further defined. The stratification of space into variable and immutable components is, therefore, the first step in the formation of a sustainable system and a prerequisite for all other stated principles. Grouping the determinants in the plan is a desirable, but not always possible option, which depends on the broader spatial picture and technical and constructive conditions, as well as the requirements of the space functionality. Central positioning of determinants in the core, while the surrounding space remains free and allows circular communication, requires a certain spaciousness of the apartment. The conceptual design of the plan that characterizes the system of rooms without a clearly defined purpose is directly related to the principles of modularity and plan openness. The openness of the plan also requires spaciousness, multiple exits to the facades and a concept that enables optional space partitioning. Openness, neutrality and polyvalence require standardization and implementation of a modular system of measures, because the unification of the structural platform ultimately results in greater programme variability. Modularity, however, must be supported by further design decisions that allow for optional partitioning, without endangering the functional and structural relationships as well as the ambient space qualities. The concept of functionally neutral spaces, as well as the application of flexible elements in the plan that can be periodically opened or closed, are not particularly applicable solutions in architectural practice. Movable elements make construction more expensive and require special sound insulation standards. The movement of elements in the daily mode is mainly a consequence of necessity, and not a desire to reconfigure the living environment. The floor area of the apartment is a key parameter of flexibility. The larger the apartment and the surface reserves within it, the greater are the potentials of rearrangement. An oversized apartment, however, is an "economic unreality" [8]. Even in practice an undersized apartment is often preferred, with standards of subsistence minimum. The area of the apartment should be adjusted to the number of their tenants in the most crowded stage of development, while remaining within the limits that are socially and economically acceptable [9]. Considering the concept of flexibility is a complex and multi-layered problem and requires certain professional skills and design experience in anticipating future programme scenarios. The application of these principles requires adequate education of designers and raising awareness within them about the importance of flexibility for housing sustainability.

5. CONCLUSIONS

The paper systematizes and presents the basic design principles of flexibility. The principle of stratification into static and dynamic layers actually means that in the initial phase of design it is necessary to define a constitutive framework that will, at a later stage, adequately accept upgrading and variability in the system. The principle of coherent grouping implies the integration of related content according to the principle of permanence and variability in the plan, which achieves greater flexibility of space in free interpretation. The formation of neutral spaces that correspond to multiple purposes and functions is also one of the principles that leads to the prolonged exploitation of the apartment. An open plan, designed with a certain degree of incompleteness, leaves enough space to tenants to rearrange and organize the space themselves, according to their own needs and desires. Openness, neutrality and polyvalence require standardization and implementation of a modular measures, because the unification of the system ultimately results in greater program variability. The initial increase in the floor area within economically acceptable limits enables the spatial reserves present in the comfortable phase of exploitation to be activated and used in the most crowded phase.

Implementation of flexible programmes and spreading awareness of the importance of systemic reforms in housing among professionals are desirable measures for improving the quality of the living environment. It is necessary to emphasize that the flexible potentials of the plan are the result of the correlation of numerous, interdependent spatial determinants, which by their joint action affect the quality of the offered design solutions. Anticipating programme scenarios is an important precondition for realization of the concept of flexibility because the implementation of the principles requires a multifaceted view of the spatial relationships among key architectural elements. If some of the individual conditions are not applied adequately, it can lead to the complete inapplicability of the principle of flexibility.

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O FLEKSIBILNOM STANOVANJU: OSNOVNI PROJEKTANTSKI PRINCIPI

U doba korenitih društvenih transformacija, zahtev za fleksibilnošću prostora može se identifikovati kao jedan od strateških prioriteta održanja urbane sredine. U kontekstu socijalne, ekonomske i ekološke održivosti, stanovanje mora podrazumevati integrisanu sposobnost da reaguje na programske promene, što se može ostvariti kroz koncept fleksibilnosti. Identifikacijom i primenom određenih projektantskih principa moguće je predupredititi problem funkcionalne zastarelosti i nepodobnosti stambene sredine sa kojima se suočavaju savremeni gradovi. Stan kao neposredno životno okruženje je najdirektniji indikator stepena prilagodljivosti fizičke sredine savremenim potrebama čoveka. Analizom osnovnih projektantskih principa na primeru fleksibilnog stana preispituju se prostorne korelacije i zakonitosti odnosa elemenata plana, na osnovu čega se donose zaključci o realnosti primene koncepta u praksi.

Ključne reči: *stan, stanovanje, fleksibilnost, projektantski principi, održivost*

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Original Scientific Paper

REVITALIZING SMALL URBAN STREAMS AS AN INSTRUMENT OF URBAN PLANNING IN CREATING RESILIENT CITIES

UDC 502.171:546.212
627.152.15:711.4

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Abstract. *Small urban streams are an important element of blue-green infrastructure that is often underused, especially regarding stormwater management. In addition, small streams in dense urban areas often seem to be polluted and devastated, or even buried underground. This paper discusses the problems and challenges that occur in urban areas regarding small streams and creeks, and explores how their revitalization can help in shaping more resilient communities. The study explores two cities, Graz and Oslo, and their best practice examples in revitalizing urban watercourses. As a valuable natural "blue" capital, small streams can reduce the city's risk of flooding from intense rainfall and strengthen the ecosystem. At the same time, small urban streams are cost-effective, proactive and attractive elements of urban landscape. Research identifies the benefits that the process of revitalization of small urban streams brought about to the selected case studies regarding the environment, public health, social interactions, land use and adaptation to climate change. Furthermore, the research establishes urban planning guidelines for revitalization of watercourses that could help in setting up policy framework for adapting inherited urban settings to climate change.*

Key words: *deculverting, renaturation, water quality, flood protection, blue-green infrastructure, recreation*

1. INTRODUCTION

Throughout urban planning history, towns and cities were developed along waterways in order to enable access to drinking water, dispose of wastewater/sewage and provide transportation routes. Aside from large rivers, which are the most visible watercourses, urban areas often have a very rich water potential in small streams and creeks. They are

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vitally important sources of clean water and habitat for wildlife and biodiversity. On the other hand, healthy river ecosystems also provide significant social, economic, and environmental benefits [1]. Even though small urban watercourses represent a very important element of blue-green infrastructure (BGI), they often seem to be polluted, neglected, devastated and forgotten [2]. In some cases, they have even been hidden in culverts and pipes and buried underground, to make way for new developments and expansion of urbanized areas.

This paper discusses the problems and challenges that occur in urban areas regarding small streams and creeks, and explores how their revitalization can help in achieving more resilient communities. Cities around the world are nowadays increasingly attempting to revitalize small urban watercourses and particularly to restore buried streams. The process of deculverting – reopening streams is often referred to as "daylighting". Daylighting consists of exposing some or all of the flow of a previously buried stream by creating a new streambed, and may include the creation of ponds, wetlands or estuaries [3]. Deculverting projects decrease the environmental effects of urbanization by re-establishing natural stream structure and enabling the colonisation of aquatic fauna and flora [4]. Some of the benefits that the overall revitalization of streams brings include reducing flood risk, reducing pollutant concentrations, improving water quality, renewing river ecosystem, improving the ecology and biodiversity of the area, and creating a recreational amenity for the local community. Many cities are exploring possibilities to use small urban streams as a BGI element that would strengthen the ecosystem and reduce the risk of flooding from intense rainfall, and thus improve the resilience of urban areas. In order to better illustrate the benefits of stream revitalization, the paper explores two cities, Graz and Oslo, and their best practice examples in revitalizing watercourses.

The initial hypothesis of this research, which stems from contemporary urban planning theory and practice, is that revitalizing existing small watercourses in dense urban areas can help in increasing the resilience of cities. Therefore, the main goals of this paper are: (1) to determine the benefits that the process of revitalization of small urban streams brought about to the selected sites in Graz and Oslo; and (2) to establish urban planning guidelines for revitalization of watercourses that should help in adapting inherited urban settings to climate change.

2. Materials and Methods

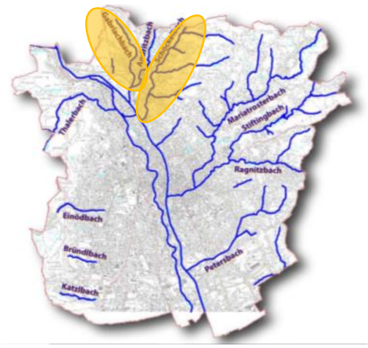
This paper explores the process of revitalization of small urban streams in the cities of Graz and Oslo, by using empirical research and literature review. The research methodological framework is conceptualized on description and analysis of the selected cases of stream revitalization, with the synthesis of study findings presented within established key benefits and implementation guidelines.

The cities of Graz and Oslo were selected as study areas because they are currently implementing comprehensive programs and various projects for the restoration of their urban watercourses, in an attempt to address climate change challenges, such as Streams of Graz Program in Graz, Oslo Reopening Waterways Project and Urban Ecology Program in Oslo. Four small urban streams were analyzed: Schöckelbach and Gabriachbach in Graz, and Hovinbekken and Alna in Oslo. These particular watercourses were chosen based on two criteria: (1) extensive revitalization works along the stream already completed, so that their effects can be evaluated; and (2) size of watercourse catchment area 10-100 km^2, so that they are considered small urban streams according to the size typology of the Directive 2000/60/EC [5].

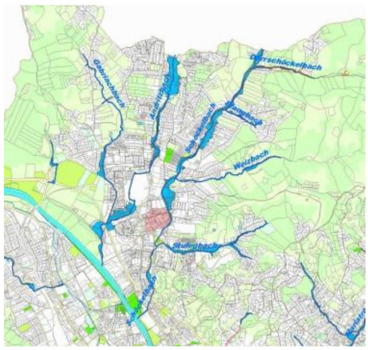
3. Learning from Best Practice Examples

3.1. Streams of Graz Program

The City of Graz has 52 streams and numerous small channels and ditches, with a total length of about 270 kilometres [6]. Out of that, 125 km of small urban watercourses are located within the urban area, with approximately 70 km^2 catchment area lying within the city (Fig. 1A). With development of the municipal sewer system in Graz, streams were mostly encased, piped or fed into the sewers in central city areas. On the outskirts these streams remained largely open, thereby creating a mix of naturally flowing sections and concrete channels. Densification of urban area brought about new developments along small urban streams, thus narrowing their riverbeds and increasing the risk of flooding. Urban area of Graz was flooded by small urban streams several times in the last 50 years. Discharge measurements performed in 1997 showed that more than 1000 buildings in the urban area of Graz would be endangered in the event of a flood with a return period of 100 years [6]. A particularly dramatic flood event occurred in August 2005, resulting in vast damage to populated areas that amounted to 5 million euros [7].



A. Streams in Graz urban area, with the position of Schöckelbach and Gabriachbach.
https://docplayer.org/79587336-Das-sachprogramm-grazer-baeche-hochwasserschutz-fuer-die-stadt-graz-ein-integraler-ansatz.html



B. Schöckelbach and Gabriachbach with floodplains.
https://geodaten1.graz.at/WebOffice/synserver?project=baeche

Fig. 1 Waterways in Graz.

These floods have led to the creation of a special program Streams of Graz, a project of the Federal Ministry of Agriculture and Forestry, Environment and Water Management, the Provincial Government of Steiermark and the City of Graz. The program was designed to run for a period of ten years (2006-2015), with three main goals to be achieved [6]: (1) provide flood protection for endangered zones in Graz based on a catalogue of measures, coordinated with spatial planning; (2) improve the ecological quality of streams; and (3) turn the streams and their adjacent space into recreational areas for the population, in order to improve their quality of life. Flood protection measures involve: linear measures, such as widening of the streambed, raising the embankment or the adjacent terrain, removing discharge obstacles and pruning streamside vegetation; and retention measures, which imply the construction of retention structures.

The implementation of actions envisioned in the program on how streams and their catchment areas can be improved to prevent flooding, is illustrated in the examples of two streams, Schöckelbach and Gabriachbach (Fig. 1B). Relevant data on the selected streams, including stream characteristics and main issues of concern regarding the stream and flood events, is provided in Table 1.

Table 1 Schöckelbach and Gabriachbach streams datasheet

	Schöckelbach	Gabriachbach
General data	▪ catchment area 34km2; ▪ llength 12km (4,8km in urban area); ▪ flows into the River Mur.	▪ catchment area 2,6km2; ▪ length 6,8km; ▪ flows into the Andritzbach stream.
Main issues	▪ buildings and high-value infrastructure developed close to the stream, no available space to safely retain the floodwater; ▪ partly elevated stream bed aggravates the floodwater to flow back into the channel.	▪ along the stream there are more than 30 residential buildings at risk of flooding.
Flood events	▪ flooded the district centre of Andritz in 2005, 2009.	▪ flooded residential buildings along the stream in 1989, 1996, 1998 and 2005.

Schöckelbach stream revitalization project. Schöckelbach stream is located in the north of Graz, in the Steiermark province. Its lower course has a small capacity, which often results in flooding of nearby areas (Fig. 2A). Main aims of the revitalization project were to maintain or extend the existing retention spaces/floodplains, and to improve the capacity of flood discharge downstream, by implementing linear and retention flood protection measures. Project activities involved the renaturation stream of the segment from Andritzer Maut tram stop to Rotmoosweg road (2013), and the construction of a flood retention basin Weinitzen 2 Höfbach outside of the urban area (2012) [8]. Future actions that are now in the planning stage include the linear expansion of a 2 km section of the stream from Rotmoosweg road to city limits, as well as the construction of one additional flood retention basin Weinitzen 1 outside of urban area of Graz.

Revitalization of the 2,7 km long stream section Andritzer Maut – Rotmoosweg was implemented in three phases and involved widening the stream bed (Fig. 2B) and raising the terrain and embankment level. A variety of actions were implemented in the project [7]. Suitable native trees and shrubs were planted along the stream and a flower meadow was sowed in order to create to create a colourful habitat. In the zone where the stream's bed has been widened a children's playground was built, and the stream was allowed to develop its own channel. New habitats for fish, insects and birds were created in the stream itself, by using elements such as wood and rocks.

Retention basin Weinitzen 2 Höfbach has a capacity of 215.000 m^3. It is supposed to reduce the incoming flood discharge peak of Schöckelbach stream by almost 50% [9]. After the retention basin was completed, renaturation measures were carried out, including planting the embankment areas with site-specific greenery (Fig. 2C), planting riparian wood fringes and developing wet areas.

Besides active flood control measures, the following planning activities were also conducted [7]: (1) developing water management plans; (2) developing flood forecast models, warning and alarm plans; and (3) developing residual risk analyses and contingency plans. Accompanying procedural measures included negotiations with land owners regarding purchasing their land [8]. Revitalization project also engaged the local community, with the following goals [7]: (1) informing the local population of different projects; (2) raising awareness on the significance of the stream; and (3) introducing personal responsibility of each individual who might be affected and promoting protective measures, such as constructing flood adapted buildings, using mobile flood-protection measures, preparing personal contingency plans and buying flood protection insurance.

A. Flooding of Schöckelbach in Andritz district, Graz in 2005. *https://www.wetterzeugen.at/hochwasser-in-graz-andritz-2005/*

B. Widening the stream bed in the area of the Gasthof Pfleger. *http://www.freiland.at/de/hws_schoeckelbach/*

C. Retention basin Weinitzen 2 Höfbach.*https://www.graz.at/cms/dokumente/10278073_8028812/dccbe8b0/Fotodokumentation%20RHB%20Weinitzen%202.pdf*

Fig. 2 Schöckelbach Revitalization Project.

Gabriachbach stream revitalization project. Gabriachbach is a very small stream that is also located in the north of Graz, in the Steiermark province. Despite its size (Fig. 3A), the stream can reach a water level of several meters in just a few hours during heavy storm events. Therefore, the risk of flooding nearby areas is severe. Main aims of stream revitalization were to address protective water management, landscaping and ecological issues, and to create a recreation area along the watercourse [7]. Revitalization project involved the construction of two flood retention basins Untere Schirmleiten and Am Eichengrund (2007), and renaturation of the stream in the Schleppgleistrasse area (2014) [8]. Linear expansion of about 0,8 km of the stream along Hoffeldstrasse road is planned for the third construction phase.

In the first phase of the project, flood retention basins Untere Schirmleiten and Am Eichengrund were built, with a total capacity of 40.000 m^3, and a section of the stream of about 120 m was opened. The retention basin Am Eichengrund is particularly interesting because it is located in a landscape protection area. Therefore, the project activities were accompanied by a nature conservation expert [9]. When designing the retention basin, special attention was given to planning, in order to keep the interference in the bank vegetation of the Gabriachbach low. Landscaping involved planting of 1200 woody plants, which are native and suited to the site. Also, the emphasis was placed on keeping the visual axes of the valley free, while natural vegetation along the brook was largely preserved and retained all the way to the dam [7]. Dam slopes were kept as gentle as possible and connected to the surrounding terrain (Fig. 3B). The project created a wet biotope at its lowest point, thus providing a habitat to numerous plant and animal species [7]. Food retention basin is replenished permanently with drainage water.

The second phase implied linear expansion of 0,6 km of the stream in the Schleppgleistrasse area, from mouth to the Andritzbach stream to Andritzer Reichsstraße. Ecological upgrade of the stream was carried out, involving the removal of former concrete half-shells and the creation of a meandering low water channel with wooden pilots (Fig. 3C). An accompanying footpath and cycle path with drainable special surface and new lighting were also provided. Diverse bank planting included 20 new tree locations and 600 riparian trees, thereby creating a natural zone along the stream [10]. Recreation zone with greenery and seating was established, and a suitable stream access for children was enabled. This comprehensive renaturation project enabled a connection to the Andritzbach stream at the same riverbed level, which allowed unimpeded migration for aquatic organisms, particularly fish [7].

Accompanying activities involved negotiating with land owners regarding redemption, securing funding through grants from the federal and state governments, and conducting necessary tender procedures [8]. A very important aspect of the project was educating the young population on the significance of urban streams. When planting the retention basin Am Eichengrund, pupils of the local elementary school were engaged, thus educating them on water ecology.

A. Gabriachbach stream before revitalization. *https://www.graz.at/cms/dokumente/10278073_8028812/4ae10ab1/Pressemappe_Gabriachbach.pdf*

B. Retention basin Am Eichengrund. *https://www.wasserwirtschaft.steiermark.at/cms/beitrag/10857450/4570277/*

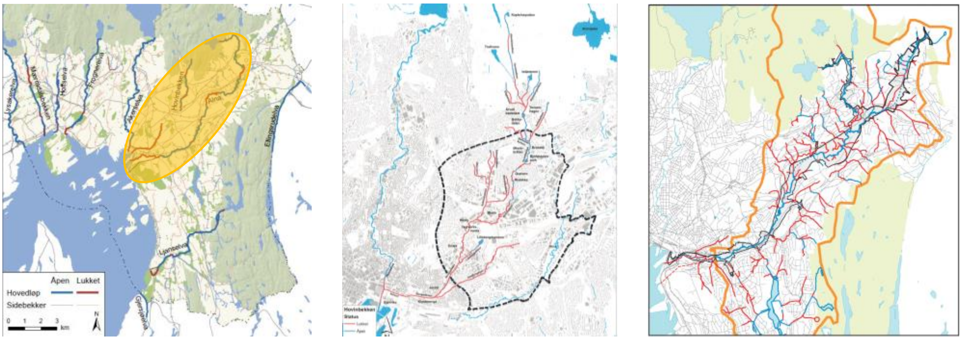
C. Meandering low water channel. *https://www.graz.at/cms/dokumente/10278073_8028812/4ae10ab1/Pressemappe_Gabriachbach.pdf*

Fig. 3 Gabriachbach Revitalization Project.

3.2. Oslo Reopening Waterways Project

The City of Oslo has ten main waterways in the urban area, which have numerous tributaries (Fig. 4A). Total length of rivers and streams amounts to 354 km [11]. Many watercourses in Oslo area were diverted underground during “the big closing” of rivers in 1879, and remained largely in culverts and pipes until the late 1990s. Until the 1980s, rivers and streams were considered problematic due to leakages from the sewage system and heavy pollution, and were viewed as an impediment to urban development and efficient use of land. Culverted watercourses have limited capacities to manage water, which can cause urban flooding problems in extreme weather events.

The City of Oslo decided to reopen closed rivers and streams wherever possible, as an integral part of climate change adaptation plan to make the city resilient to flood risk [11], and started the project Oslo Reopening Waterways in 2002. Relevant municipal agencies have, in collaboration, developed a management document that outlines the principles for reopening projects, including a list of prioritised projects [12]. In an attempt to achieve a green profile, the City has developed "Urban Ecology Program 2011-2026", which defines the goals for improving both the quality of life and the ecology of urban environment. These goals include deculverting as many streams as possible, creating blue-green corridors and preventing pollutants from entering waterways [13]. In line with this, 2.810 m of streams were already reopened, while long-term plans envision opening up of additional 8 km of waterways [11]. Today, the City of Oslo's main goal is to create blue-green corridors throughout the city, where living rivers form a city web, binding everything together into an organic, logical, functional and attractive whole [14].



A. Ten main waterways in Oslo, with the position of Hovinbekken and Alna. *https://rm.coe.int/16806f5e75*

B. Hovinbekken with tributaries. *https://hovinbekken.org/2015/02/12/innspill-til-strategisk-plan-for-hovinbyen-fra-hovinbekkgruppen/*

C. Alna with tributaries. *https://docplayer.me/docs-images/39/19839266/images/6-0.png*

Fig. 4 Waterways in Oslo.

Some of the principles for the projects of reopening waterways in Oslo that are outlined in the program are illustrated in the two examples of Hovinbekken stream and Alna River (Fig. 4B and Fig. 4C). Relevant data on the selected streams, including stream characteristics and main environmental issues of concern regarding the stream and flood events, is provided in Table 2.

Table 2 Hovinbekken stream and Alna River datasheet

	Hovinbekken	Alna
General data	▪ catchment area 10km2; ▪ length 8,5km; ▪ flows into Akerselva river.	▪ catchment area 69km2; ▪ length 17km; ▪ flows into the Oslo Fjord.
Main issues	▪ one of the most culverted streams in Oslo; ▪ poor water quality, with high nutrient levels and organic load.	▪ large sections of the river are culverted; ▪ highly polluted river, used as a sewer drain to receive runoff from the sewer and traffic areas.
Flood events	▪ increased risk of flooding due to the increase in rainfall, increase in population density and intensive urbanisation along the stream.	▪ increased risk of flooding due to paved surfaces of the third of the catchment area, and completely/partially closed tributaries; ▪ flooded Kværnerbyen area in 2015.

Hovinbekken stream revitalization project. Hovinbekken is one of the most culverted streams in Oslo (Fig. 5A). The stream was gradually hidden until the 1960s, in order to hide pollution, to expand the city and make way for new infrastructure and housing. Nowadays, the stream is being reopened throughout urban area, thereby connecting the forest with the fjord, and linking different parts of the city. The restoration project was initiated with the main goal to improve the water quality downstream, by implementing natural self-purification of water through planted wetlands and pools [13]. Secondary aims included adapting to a changing climate, strengthening urban ecology, increasing possibilities for recreation and improving public health [15]. Reopening of the Hovinbekken and creating a more “natural” look involved the following completed projects of various stream segments [16]: Bjerkedalen Park (2013), Teglverksdammen (2015), and the segments in the neighbourhoods Ensjø (2019) and Jordal (2020). Reopening of the stream is also planned for the stretches in Oslo’s parks Klosterenga and Grønlandspark.

Bjerkedalen Park is situated along Hovinbekken stream in Bjerke neighbourhood, in the middle of a residential urban area that used to have few public spaces. Restoration project involved reopening of 300 m of the formerly culverted stream, with the main aim of improving water quality, preventing floods and creating new green areas [15]. Several elements of blue-green infrastructure were implemented in park design. Native trees and plants were planted along the river, and open grassy areas and trees were provided on the slopes of the park. Bjerkedalen Park features 36.000 m2 of natural meadows, perennial flower beds, and paths made of permeable material [17]. Blue features such as the stream, canals and pond were also installed. Habitats for various aquatic and land species were provided. This park adjacent to the waterway plays an important role in stormwater management, since it functions as a retention basin during extreme weather events. These actions improved the overall urban landscape and created an attractive recreational area with various facilities for outdoor activities, hiking trail, bathing pond, small stage, café and playground. The project also brought about social and health benefits to the residents, such as the improved access to urban green space, increased opportunities for social interaction and gained amenities for recreation and exercise [15].

Reopening of the second section of Hovinbekken in Hasle neighbourhood called Teglverksdammen involved deculverting 650 m of the stream. Teglverksdammen is both a large-scale biological cleaning system and a spectacular recreational space [18] (Fig. 5B). In order to achieve water purification for the downstream section, a natural cleaning system to filter incoming waters was designed and developed. It consists of several sedimentation basins, a small lake Teglverksdammen, three dams, streams with rapids, and high-density native vegetation in shallow waters [11]. Native plants also act as a wetland. Within this system, the sediments settle and the water is filtered through rocks and vegetation. The City of Oslo monitors water quality at Teglverksdammen after reopening the stream, and the results indicate the potential for purification [13]. Long-term monitoring should determine how the natural system matures and develops, in order to enhance the knowledge database and provide insight into how future projects may be improved. This restoration has enabled the development of a clean habitat to native species and rejuvenation of biodiversity. Consequently, the naturalization of urban landscape resulted in an appealing recreation zone with a park environment. A pedestrian trail was placed along the restored stream segment.

Restoration of the part of Hovinbekken stream in Ensjø neighbourhood was initiated within urban regeneration of this area, with the goal to improve water quality in the newly created residential zone. Former industrial area Ensjø, located at the margins of Oslo's inner city, was redeveloped with an emphasis on high residential density, high frequency transit services, and path improvements to encourage walking and cycling. Reopening of the third section of Hovinbekken covered 400 m of stream along Gladengveien Street, until the newly created Ensjø Square. Streambed is a 4 m wide concrete duct, which was filled with stone, earth and plants in order to create a nature-like creek [18] (Fig. 5C). Access to the stream was improved with stairs leading to the water itself. Seating facilities were placed along the sidewalk, thereby creating an appealing linear setting. The burble from the stream helps to curb traffic noise and makes it more attractive to stay, exercise, and rest along the city street [18].

Reopening of 600 m of Hovinbekken stream in Jordal neighbourhood occurred with the construction of a new Jordal amphitheater. The Municipality of Oslo has created a new Jordal Sports Park that is open to everyone and has organized seating. New trees were planted along the stream and in the park, while more activities on naturalization and beautification of open space are expected in the future [19].

A. Culvert of Hovinbekken under the subway at Risløkka.
https://hovinbekken.org/vandring/

B. Teglverksdammen project.
https://commons.wikimedia.org/wiki/Category:Teglverket_skole

C. Hovinbekken in Ensjø.
https://arkitektur-n.no/prosjekter/gjenapning-av-hovinbekken-hasle-ensjo

Fig. 5 Hovinbekken Revitalization Project.

Alna River revitalization project. Alna River is the longest watercourse in Oslo. On its flow towards the fjord, the river formed a biological and blue-green spine of the Grorud Valley [14]. This valuable natural resource was endangered by culverting the stream until the 1980s (Fig. 6A). Alna is the most polluted river in Oslo, as it runs through industrial areas Groruddalen and Alnabru, and is also affected by recent urban densification. After the turn of the Millenium, the Municipality acknowledged this issue and developed plans to restore the Alna as a central element of Oslo landscape. Main aims of reopening the river were reducing the risk of flooding and improving water quality through nature's own self-cleaning processes. Reopening and environmental enhancement of Alna River was implemented at various sites, in two phases along the watercourse: Hølaløkka Waterpark (2004) and Grorud Valley, which encompassed creating the Alna Trail (2011) and the Grorud Park (2013).

Hølaløkka Waterpark is a site located between an industrial business park and a housing estate, where a 300 m section of formerly culverted Alna River was reopened. The aim of the project was to combine a technical water management system, where ecological and hydrological needs are met, with a design that maximizes the potential of an appealing outdoor space [20]. The newly created riverbed of Alna is widened at one point to create a natural settling basin in a corner of the park. Then, the river moves through small waterfalls and flows into an open swimming pond, which holds back flood waters. In the middle of the park a water mirror is located (Fig. 6B), with the adjacent meadow serving the double purpose of an informal relaxing area and a flood meadow [20]. A new wetland with detention capacity is developed in the eastern park zone, to treat polluted stormwater from traffic and industrial areas. This run-off is first conveyed via surface drainage to a cleansing biotope, before the water is released to wetland area for final cleansing. Water management concept implies directing rainwater into an open canal, returning water to the surface, cleansing it and releasing back into the Alna [20].

Grorud Valley Project was developed for a 10-year period (2007-2016) in cooperation of the National Government and the City Government. Roads, industrial areas and railway lines represented some of the main barriers for pedestrians and cyclists in the Grorud Valley. The main aim of the project was oriented towards sustainable urban development, environmental upgrades and improvement of the quality of life [14]. Blue-green measures in redevelopment area of Alna River had the priority in realization of project activities.

Within the Grorud Valley Project, Alna Trail was developed as part of the efforts to strengthen Alna River and provide options for recreation in the river landscape. One of its segments is a 900 m long section through the Svartdalen nature area. A unique feature of this project is a 250 m long boardwalk bypassing the geological phenomenon of Ekeberg escarpment [14]. Prior to the construction of the trail, the area was inaccessible and littered. By the Nygård waterfall, one of the biggest waterfalls in the Alna, the trail crosses a new suspension bridge, and creates opportunities for a close encounter with nature (Fig. 6C). The construction of the 40 m long underpass Haugen Gate beneath the railway lines has enabled strolling along the Alna Trail. Leir Waterfall, one of Alna's biggest waterfalls, which used to be hidden behind a concrete dam, was also reopened, and the access to it was significantly improved. Alna Trail now represents the longest stretch of inter-linked walking trails and green spaces along the course of Alna River.

A. Culvert of Alna at Kvaernerfossene.
https://www.skiforeningen.no/marka/bilder/?poi_id=1912

B. Hølaløkka Park.
http://www.alnaelva.no/nyhet094.php

C. Suspension bridge along Alna, Svartdalen.
https://no.wikipedia.org/wiki/Svartdalen#/media/Fil:Alna.jpg

Fig. 6 Alna Revitalization Project.

Grorud Park was inserted into the existing green corridor along reopened Alna River. The park is designed around a swimming pond close to the Grorud sports grounds, with seating facilities established near the river. Now, the entire path system along this section of Alna creates a nature and parkland area of high quality. A lighting plan was created for the entire area, with the goal of improving public safety and enabling the recreation after dark. The water in the park is being treated through sedimentation, detention, infiltration and cleansing before it reaches the Alna River, and also creates good biotopes for animals and plants [21].

4. Discussion and Conclusion

Cases of revitalization of small urban streams that were examined in this paper point towards a very important role that watercourses play in urban landscape, particularly regarding the resilience of cities. In line with the first research aim, it can be stated that the revitalization of small urban streams brought numerous benefits to Graz and Oslo, thus providing valuable contribution to the environment, public health, social interactions, land use and adaptation to climate change.

In Graz, a holistic planning approach to stream revitalization resulted in these key benefits: (1) *flood remediation of settlement areas*, by implementing both linear and retention measures, thereby preventing million costs in flood damage; (2) *improvement of stormwater management* to the current integrated approaches that implement BGI elements and wetland areas, and thus relieving the city's sewer system; (3) *restoration of the streams' ecological function*, by planting native, site-specific vegetation and creating new habitats for fish, insects and birds; (4) *improvement of the quality of life* of urban residents, by creating nearby recreational areas and strengthening the connection with nature; (5) *enhancement of the watercourses' positive image* in people's consciousness, by raising awareness on the significance of streams, improving the experience of users and enhancing the safety for the population.

In Oslo, extensive reopening of culverted watercourses provided the folowing main benefits: (1) *flood mitigation*, by developing sustainable solutions for stormwater management, and thus decreasing pressure on the city watershed, reducing the risk of flooding and preventing damages; (2) *improvement of biodiversity*, by developing BGI, planting native vegetation and creating new aquatic and terrestrial habitats for flora and fauna; (3) *provision of new recreational space*, including parks, walking/hiking trails and playgrounds, which represent valuable amenities for the community and improve public health; (4) *improvement of water quality*, by developing natural cleaning systems with self-cleaning processes, which include sedimentation basins, water rapids and shallow waters with dense vegetation for filtering pollution from the water; and (5) *improvement of urban landscape*, by adding aesthetics of water surfaces and attractive greenery.

Regarding the second research aim, several elements of urban design and key planning activities can be identified as those that enhance the retrofitting of small urban streams into the existing urban fabric, and contribute to creating resilient communities. Certain guidelines for the urban planning framework that are established in this research are summarized below, around the following crucial points:

(1) *Flood protection*. Implementing linear and retention measures along the stream; Deculverting enclosed/piped streams; Implementing contemporary integrated stormwater management approaches, along with elements of blue-green infrastructure; Developing wetlands and parks in retention basins.

(2) *Strengthening urban ecology*. Creating new habitats in revitalized watercourses and adjacent urban green spaces; Planting native, site-specific vegetation and introducing new aquatic species; Developing natural self-cleaning systems, where natural soils and plant life improve water quality by filtering pollution.

(3) *Creating recreational areas*. Developing nature-like zones for both active and passive recreation for all user categories; Providing adequate lighting to enable recreation in the evening; Enabling easy access to the stream itself; Creating opportunities for social interaction by implementing various amenities for outdoor activities.

(4) *Appealing urban landscape*. Improving the overall aesthetics of space to enhance the experience of users, by creating a park environment; Implementing diverse types of greenery within meadows, open grassy areas, flower beds and parks, as well as a variety of water features such as lakes, ponds, dams, canals, rapids and waterfalls.

(5) *Sustainable mobility*. Developing bicycle and pedestrian pathways made of permeable material along the streams in order to promote healthy transportation options, and inter-linking them to the city transportation network.

(6) *Community engagement*. Raising awareness on the significance of the streams, along with creating a positive image with the local population; Educating local population on different projects; Promoting healthy lifestyles, such as walking, cycling, exercising and establishing a contact with nature, along the revitalized streams; Designating streams as potential research polygon for local schools.

(7) *Risk management*. Performing risk analyses, developing forecast models and early warning plans, and integrating them into urban planning documents; Promoting protective measures based on personal responsibility; Enhancing the safety for the population.

It can be concluded that rivers and streams must be given a new strategic significance in urban planning, within a holistic planning approach that includes spatial, functional, social and environmental aspects of revitalization. Only the open watercourses with natural character that are integrated into a dynamic blue-green web can indeed serve as a planning instrument in adapting inherited urban settings to climate change.

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REVITALIZACIJA MALIH URBANIH VODOTOKA KAO PLANSKI INSTRUMENT U KREIRANJU OTPORNIH GRADOVA

Mali urbani vodotoci su važan element plavo-zelene infrastrukture koji je često nedovoljno iskorišćen, posebno u pogledu upravljanja atmosferskim vodama. Pored toga, potoci u gusto izgrađenim urbanim područjima su često zagađeni i devastirani, ili čak zakopani pod zemljom. Ovaj rad razmatra probleme i izazove koji se javljaju u urbanim sredinama u vezi sa malim vodotocima i istražuje kako njihova revitalizacija može pomoći u oblikovanju otpornijih zajednica. Studija istražuje dva grada, Grac i Oslo, i njihove primere dobre prakse u revitalizaciji urbanih vodotoka. Kao vredan prirodni „plavi“ kapital, mali potoci mogu da smanje rizik od poplava u gradu usled intenzivnih padavina i ojačaju ekosistem. Istovremeno, mali gradski vodotoci su isplativi, proaktivni i atraktivni elementi urbanog pejzaža. Istraživanje identifikuje benefite koje je proces revitalizacije malih urbanih vodotoka doneo odabranim studijama slučaja u pogledu životne sredine, javnog zdravlja, socijalnih interakcija, namene zemljišta i prilagođavanja klimatskim promenama. Osim toga, istraživanje uspostavlja smernice urbanističkog planiranja za revitalizaciju vodotoka koje bi mogle pomoći u uspostavljanju okvira javnih politika za prilagođavanje klimatskim promenama nasleđenih urbanih područja.

Ključne reči: *otvaranje kanala, renaturacija, kvalitet vode, zaštita od plavljenja, plavo-zelena infrastruktura, rekreacija*

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SHEAR STRENGTH OF FIBRE REINFORCED POLYMERS (FRP) USED AS INTERNAL REINFORCEMENT FOR REINFORCED CONCRETE (RC) BEAMS

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004

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Abstract. *The main aim of the study was to perform selection procedure in order to find the optimal predictors for the shear strength of fibre reinforced polymers (FRP) used as internal reinforcement for reinforced concrete (RC) beams. The procedure was performed by adaptive neuro fuzzy inference system (ANFIS) and all available parameters are included. The ANFIS model could be used as simplification of the shear strength analysis of the FRP-RC beams. MATLAB software was used for the ANFIS application for the shear strength prediction of the FRP-RC beams. The results from the searching procedure indicated that "beam width" and "effective depth" form the optimal combination of two input attributes or two predictors for the shear strength prediction of the FRP-RC beams. This selected two predictors could be used effectively to estimate the strength of the FRP-RC beams.*

Key words: *FRP; predictors; shear strength; reinforced concrete; ANFIS.*

1. INTRODUCTION

Steel reinforcement corrosion represents one of the main issues for the deterioration of reinforced concrete (RC) structures. In order to solve the issue, fiber reinforced polymer (FRP) has been included into the RC structures as internal reinforcement instead of the conventional steel. FRP members have high resistance to corrosion and high ratio strength to weight. However, the FRP members have lower modulus of elasticity than conventional structures.

In paper [1] has been presented the use Machine Learning (ML) techniques to study the behavior of shear-deficient reinforced concrete (RC) beams strengthened in shear with

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side-bonded and U-wrapped fiber-reinforced polymers (FRP) laminates and results indicated that the ML with the selected parameters was capable of predicting the FRP shear capacity more accurately. Based on the comparison of different performance evaluators in article [2], it can be concluded that the present ANFIS model has better performance in the prediction of the shear contribution of FRP. A parametric study was also conducted to study the effect of individual parameters on the shear contribution of FRP composites. The accuracy of the soft computing models is quite satisfactory as compared to experimental results for modeling of strength enhancement of FRP (fiber–reinforced polymer) confined concrete cylinders [3]. In the case of FRP-confined concrete cylinder with a strain-hardening response, it is found that the ultimate Poisson's ratio of FRP-confined concrete trends to an asymptotic value [4]. FRP-confined steel-reinforced concrete (FCSRC) column with high strength concrete (HSC) is a promising type of hybrid structural element that enables effective utilization of both HSC and high-performance FRP [5]. Compressive behavior of FRP-confined (FRP)-confined recycled glass aggregate concrete (RGAC) is comparable to that of FRP-confined normal concrete when the replacement ratio of RGAs is not large than 50%, although the compressive behavior of RGAC has a notable decrease with increasing replacement ratio of recycled glass aggregates (RGAs) [6]. Using large rupture strain FRP (LRS-FRP) significantly improved the ductility and ultimate strength of the confined concrete compared to small rupture strain FRP (SRS-FRP) confined concrete [7]. The results obtained in this study [8] showed that expansion of shear zone for unconfined concrete is more localized than FRP-confined specimens. In paper [9], a 3-dimensional geometrical approach is proposed to interpret the general theory of analysis-oriented models based on three general equations. FRP composites have been widely used in the retrofitting of earthquake-damaged concrete structures [10].

In this study is performed a selection procedure for optimal predictors for shear strength of fibre reinforced polymers (FRP) used as internal reinforcement for reinforced concrete (RC) beams. To perform the selection procedure data set was collected and arranged from published literature. Adaptive neuro fuzzy inference system (ANFIS) [11] is used for the selection procedure of the data samples.

2. METHODOLOGY AND MATERIALS

2.1. Experimental procedure

To study the behavior of FRP-RC (Fibre Reinforced Polymers (FRP) used as internal reinforcement for Reinforced Concrete (RC) beams and check the performance of the proposed ANFIS model. Data samples are collected and arranged from literature [12]. Table 1 shows input and output data samples. The used inputs are: concrete compressive strength (fc (MPa)), beam width (bw (mm)), effective depth (d (mm)), beam shear span (a (mm)), shear span to depth ratio (a/d), reinforcement ratio of longitudinal FRP bars (ρf (%)), and modulus of elasticity of the reinforcing bar (Ef (GPa)). The output represents the shear strength (Vexp (KN)) of FRP-RC beams.

Table 1 Experimental data samples [12]

In1	In2	In3	In4	In5	In6	In7	output
fc (MPa)	bw (mm)	d (mm)	a (mm)	a/d	ρf (%)	Ef (GPa)	Vexp (KN)
36.3	229	225	914	4.1	1.11	40.3	39.1
36.3	229	225	914	4.1	1.11	40.3	38.5
36.3	229	225	914	4.1	1.11	40.3	36.8
36.3	178	225	914	4.1	1.42	40.3	28.1
36.3	178	225	914	4.1	1.42	40.3	35
36.3	178	225	914	4.1	1.42	40.3	32.1
36.3	229	225	914	4.1	1.66	40.3	40
36.3	229	225	914	4.1	1.66	40.3	48.6
36.3	229	225	914	4.1	1.66	40.3	44.7
36.3	279	225	914	4.1	1.81	40.3	43.8
36.3	279	225	914	4.1	1.81	40.3	45.9
36.3	279	225	914	4.1	1.81	40.3	46.1
36.3	254	224	914	4.1	2.05	40.3	37.7
36.3	254	224	914	4.1	2.05	40.3	51
36.3	254	224	914	4.1	2.05	40.3	46.6
36.3	229	224	914	4.1	2.27	40.3	43.5
36.3	229	224	914	4.1	2.27	40.3	41.8
36.3	229	224	914	4.1	2.27	40.3	41.3
40	1000	165	1000	6	0.39	114	140
40	1000	165	1000	6	0.78	114	167
40	1000	161	1000	6.2	1.18	114	190
40	1000	162	1000	6.2	0.86	40	113
40	1000	159	1000	6.3	1.7	40	142
40	1000	162	1000	6.2	1.71	40	163
40	1000	159	1000	6.3	2.44	40	163
40	1000	154	1000	6.5	2.63	40	168
50	250	326	1000	3.1	0.87	128	77.5
50	250	326	1000	3.1	0.87	39	70.5
44.6	250	326	1000	3.1	1.24	134	104
44.6	250	326	1000	3.1	1.22	42	60
43.6	250	326	1000	3.1	1.72	134	124.5
43.6	250	326	1000	3.1	1.71	42	77.5
40.5	200	225	600	2.7	0.63	145	47.2
40.5	200	225	800	3.6	0.5	145	49.7
40.5	200	225	950	4.2	0.5	145	38.5
28.9	150	168	667	4	0.45	38	12.5
28.9	150	212	667	3.1	0.71	32	17.5
28.9	150	263	667	2.5	0.86	32	25
37.3	160	346	952	2.8	0.72	42	54.5
37.3	160	346	952	2.8	0.72	42	63.7
43.2	160	346	1149	3.3	1.1	42	42.7
43.2	160	346	1149	3.3	1.1	42	45.5
34.1	160	325	1151	3.5	1.54	42	48.7
34.1	160	325	1151	3.5	1.54	42	44.9
37.3	130	310	949	3.1	0.72	120	49.2

In1	In2	In3	In4	In5	In6	In7	output
fc (MPa)	bw (mm)	d (mm)	a (mm)	a/d	ρf (%)	Ef (GPa)	Vexp (KN)
37.3	130	310	949	3.1	0.72	120	45.8
43.2	130	310	1150	3.7	1.1	120	47.6
43.2	130	310	1150	3.7	1.1	120	52.7
34.1	130	310	1150	3.7	1.54	120	55.9
34.1	130	310	1150	3.7	1.54	120	58.3
39.7	457	360	1219	3.4	0.96	40.5	108.1
39.9	457	360	1219	3.4	0.96	37.6	94.7
40.3	457	360	1219	3.4	0.96	47.1	114.8
42.3	457	360	1219	3.4	1.92	40.5	137
42.5	457	360	1219	3.4	1.92	37.6	152.6
42.6	457	360	1219	3.4	1.92	47.1	177
24.1	178	279	750	2.7	2.3	40	53.4
24.1	178	287	750	2.6	0.77	40	36.1
24.1	178	287	750	2.6	1.34	40	40.1
34.7	200	260	700	2.7	1.3	130	62.2
34.3	150	250	750	3	1.51	105	45
39.8	250	305	763	2.5	0.86	46.3	61
39.8	250	305	1068	3.5	0.86	46.3	43.7
34.5	250	310	465	1.5	0.42	144	87.3
34.5	250	310	775	2.5	0.42	144	64.6
34.5	250	310	1085	3.5	0.42	144	58.9
44.7	250	440	1100	2.5	0.9	46.3	77.2
37.4	250	584	1460	2.5	0.91	46.3	103.7
37.4	300	734	1762	2.4	0.91	46.3	129.4
42.4	300	460	1150	2.5	0.45	144	74.1
37	250	594	1485	2.5	0.43	144	112.9
42.4	300	744	1786	2.4	0.4	144	137.3
37.4	300	310	775	2.5	0.33	46.3	72.7
39.8	250	296	740	2.5	1.43	46.3	65.5
42.4	250	296	740	2.5	1.43	46.3	70.9
37.4	250	455	1138	2.5	0.35	46.3	68
37.4	250	434	1085	2.5	1.47	46.3	92.2
42.4	250	310	775	2.5	0.18	144	58.7
34.5	250	310	775	2.5	0.67	144	72.5
42.4	250	460	1150	2.5	0.22	144	70.3
42.4	250	439	1098	2.5	0.65	144	82.5
74.2	300	449	1123	2.5	0.69	144	100.4
74.2	250	594	1485	2.5	0.65	144	146.1
74.2	300	442	1105	2.5	1.27	46.3	116.1
74.2	250	578	1445	2.5	1.38	46.3	155.2
65.3	250	310	775	2.5	0.42	144	71.6
88.3	250	310	775	2.5	0.42	144	77.9
65.3	250	291	728	2.5	0.89	46.3	75.6
88.3	250	291	728	2.5	0.89	46.3	80.2
29.6	457	889	2756	3.1	0.6	4.1	159
42.8	150	223	491	2.2	1.28	45	44.7
42.8	150	223	245	1.1	1.28	46	81
38.1	150	210	767	3.7	1.31	45	26.5
35	450	438	1524	3.5	0.55	37	86

In1	In2	In3	In4	In5	In6	In7	output
fc (MPa)	bw (mm)	d (mm)	a (mm)	a/d	ρf (%)	Ef (GPa)	Vexp (KN)
35	450	194	762	3.9	0.66	37	54.5
36	450	857	3051	3.6	2.23	37	232
35	450	405	1527	3.8	2.36	37	138
35	450	188	761	4.1	2.54	37	74
29.5	457	883	2746	3.1	0.59	40.7	154.1
38.8	457	883	2746	3.1	0.59	40.7	158.9
32.1	114	294	914	3.1	0.59	40.8	19.3
32.1	114	294	914	3.1	0.59	40.8	18.1
32.1	229	147	457	3.1	0.59	40.8	36.8
29.5	457	880	2737	3.1	1.18	40.7	220.7
30.7	457	880	2737	3.1	1.18	41.4	216.2
63	250	326	1000	3.1	1.71	135	130
63	250	326	1000	3.1	1.71	42	87
63	250	326	1000	3.1	2.2	42	115.5
61.8	159	141	910	6.5	0.58	139	19.8
61.8	159	141	910	6.5	0.58	139	17
81.4	89	143	910	6.4	0.47	139	8.8
81.4	89	143	910	6.4	0.47	139	11.7
81.4	89	143	910	6.4	0.47	139	8.9
81.4	121	141	910	6.5	0.76	139	14.3
81.4	121	141	910	6.5	0.76	139	15.3
81.4	121	141	910	6.5	0.76	139	16.6

2.2. ANFIS methodology

ANFIS network has five layers as it shown in Figure 1. The main core of the ANFIS network is fuzzy inference system. Layer 1 receives the inputs and convert them in the fuzzy value by membership functions. In this study bell shaped membership function is used since the function has the highest capability for the regression of the nonlinear data.

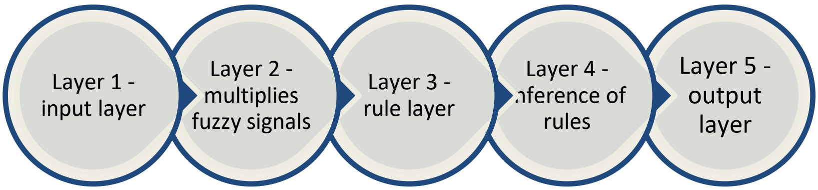

Fig. 1 ANFIS layers

Bell-shaped membership functios is defined as follows:

$$\mu(x) = bell(x; a_i, b_i, c_i)h_{ci} = \frac{1}{1 + \left[\left(\frac{x - c_i,}{a_i,} \right)^2 \right]^{b_i}} \tag{1}$$

where $\{a_i, b_i, c_i\}$ is the parameters set and x is input.

Second layer multiplies the fuzzy signals from the first layer and provides the firing strength of as rule. The third layer is the rule layers where all signals from the second layer are normalized. The fourth layer provides the inference of rules and all signals are converted in crisp values. The final layers summarized the all signals and provied the output crisp value.

3. RESULTS

ANFIS methodology was used for selection of the optimal predictors for shear strength of FRP-RC beams. The selection is important as preprocessing of the input parameters to remove the inputs with small relevance. The data set is obtained from the data file in Table 1. The dataset is then partitioned into a training set (odd-indexed samples) and a checking set (even-indexed samples) by following command in MATLAB Software:

```
>>[data] = shear;
>>trn_data = data(1:2:end,:);
>>chk_data = data(2:2:end,:);
```

The function “exhsrch” performs an exhaustive search within the available inputs to select the set of inputs that most influence the shear strength of FRP-RC beams. The first parameter to the function specifies the number if input combinations to be tried during the selection procedure. Essentially, “exhsrch” builds an ANFIS model for each combination and trains it for one epoch and reports the performance achieved. The following command line is used for determine the one most influential attribute in predicting the output:

```
>> exhsrch(1,trn_data,chk_data);
```

The following results are obtained (Figure 2):

```
ANFIS model 1: in1 --> trn=47.6685, chk=50.4654
ANFIS model 2: in2 --> trn=28.7684, chk=29.9848
ANFIS model 3: in3 --> trn=38.5202, chk=39.6556
ANFIS model 4: in4 --> trn=35.9930, chk=39.0937
ANFIS model 5: in5 --> trn=46.9295, chk=51.8274
ANFIS model 6: in6 --> trn=47.4247, chk=50.3212
ANFIS model 7: in7 --> trn=47.7124, chk=53.5527
```

Fig 2 Predictors' influence on the shear strength of FRP-RC beams

The lest-most input variable (in2) in Figure 2 has the least error or in other words the most relevance with respect to the output. The plot and results from the function clearly indicate that the input attribute "beam width" is the most influential. The training and checking errors are comparable, which implies that there is no overfitting. This means we can push a little further and explore if we can select more than one input attribute to build the ANFIS model.

Intuitively, one can simply select "beam width" and "beam shear span" directly since they have the least errors as shown in the Figure 2. However, this will not necessarily be the optimal combination of two inputs that results in the minimal training error. To verify this, one can use:

```
>> exhsrch(2,trn_data,chk_data);
```

The following results are obtained (Figure 3):

```
ANFIS model 1: in1 in2 --> trn=22.9756, chk=36.3469
ANFIS model 2: in1 in3 --> trn=32.8510, chk=41.5568
ANFIS model 3: in1 in4 --> trn=31.7283, chk=51.7965
ANFIS model 4: in1 in5 --> trn=34.4541, chk=45.8268
ANFIS model 5: in1 in6 --> trn=44.0512, chk=49.8283
ANFIS model 6: in1 in7 --> trn=44.0962, chk=50.6159
ANFIS model 7: in2 in3 --> trn=15.4313, chk=23.3665
ANFIS model 8: in2 in4 --> trn=18.1118, chk=24.2689
ANFIS model 9: in2 in5 --> trn=21.6377, chk=26.7704
ANFIS model 10: in2 in6 --> trn=26.4107, chk=30.2595
ANFIS model 11: in2 in7 --> trn=24.9798, chk=35.7504
ANFIS model 12: in3 in4 --> trn=24.0954, chk=209.7226
ANFIS model 13: in3 in5 --> trn=19.6570, chk=92.5814
ANFIS model 14: in3 in6 --> trn=34.8755, chk=75.9777
ANFIS model 15: in3 in7 --> trn=30.2766, chk=172.0246
ANFIS model 16: in4 in5 --> trn=18.9079, chk=177.1485
ANFIS model 17: in4 in6 --> trn=33.8664, chk=58.3976
ANFIS model 18: in4 in7 --> trn=34.5913, chk=104.2876
ANFIS model 19: in5 in6 --> trn=38.4331, chk=46.0639
ANFIS model 20: in5 in7 --> trn=33.4146, chk=54.6191
ANFIS model 21: in6 in7 --> trn=44.5389, chk=65.6771
```

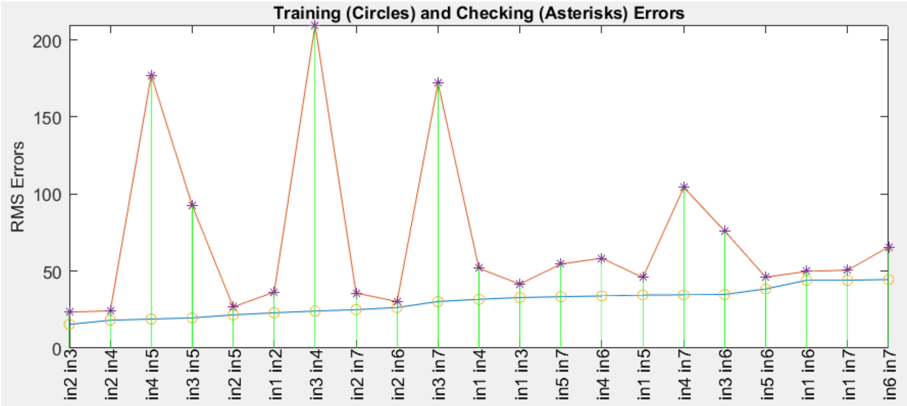

Fig 3 All two predictors combinations influence on the shear strength of FRP-RC beams

The results from "exhsrch" indicate that "beam width" and "effective depth" form the optimal combination of two input attributes or two predictors. The training and checking errors are getting distinguished which indicates the outset of overfitting. It may be not preferable to use more than two input for building the ANFIS model. However, one can confirm the premise to verify its validity by following command line:

```
>> exhsrch(3,trn_data,chk_data);
```

The following results are obtained (Figure 4):

```
ANFIS model 1: in1 in2 in3 --> trn=11.2498, chk=162.8687
ANFIS model 2: in1 in2 in4 --> trn=12.6280, chk=101.0679
ANFIS model 3: in1 in2 in5 --> trn=15.6878, chk=559.0779
ANFIS model 4: in1 in2 in6 --> trn=14.1832, chk=50.9990
ANFIS model 5: in1 in2 in7 --> trn=15.2771, chk=110.3073
ANFIS model 6: in1 in3 in4 --> trn=14.7596, chk=522.1914
ANFIS model 7: in1 in3 in5 --> trn=13.9229, chk=92.3709
ANFIS model 8: in1 in3 in6 --> trn=22.0726, chk=250.5787
ANFIS model 9: in1 in3 in7 --> trn=18.3099, chk=459.7988
ANFIS model 10: in1 in4 in5 --> trn=14.1184, chk=134.6110
ANFIS model 11: in1 in4 in6 --> trn=21.6134, chk=1194.7738
ANFIS model 12: in1 in4 in7 --> trn=22.0705, chk=473.0779
ANFIS model 13: in1 in5 in6 --> trn=28.0365, chk=64.7652
ANFIS model 14: in1 in5 in7 --> trn=27.0283, chk=108.5869
ANFIS model 15: in1 in6 in7 --> trn=32.7692, chk=211.8272
ANFIS model 16: in2 in3 in4 --> trn=10.2168, chk=799.1103
ANFIS model 17: in2 in3 in5 --> trn=10.4146, chk=237.0670
ANFIS model 18: in2 in3 in6 --> trn=8.4013, chk=211.8117
ANFIS model 19: in2 in3 in7 --> trn=8.8978, chk=851.6215
ANFIS model 20: in2 in4 in5 --> trn=11.1824, chk=370.7922
ANFIS model 21: in2 in4 in6 --> trn=13.4324, chk=459.2600
ANFIS model 22: in2 in4 in7 --> trn=11.2578, chk=1617.5548
ANFIS model 23: in2 in5 in6 --> trn=15.4825, chk=180.2330
```

ANFIS model 24: in2 in5 in7 --> trn=17.6976, chk=151.3632
ANFIS model 25: in2 in6 in7 --> trn=19.9275, chk=95.7980
ANFIS model 26: in3 in4 in5 --> trn=13.4424, chk=6156.9596
ANFIS model 27: in3 in4 in6 --> trn=17.0637, chk=805.7227
ANFIS model 28: in3 in4 in7 --> trn=13.4865, chk=19362.0331
ANFIS model 29: in3 in5 in6 --> trn=11.5879, chk=81.4807
ANFIS model 30: in3 in5 in7 --> trn=12.9908, chk=281.5371
ANFIS model 31: in3 in6 in7 --> trn=17.6058, chk=194.4082
ANFIS model 32: in4 in5 in6 --> trn=10.8919, chk=138.6010
ANFIS model 33: in4 in5 in7 --> trn=13.5533, chk=291.5226
ANFIS model 34: in4 in6 in7 --> trn=24.1216, chk=332.4736
ANFIS model 35: in5 in6 in7 --> trn=27.3702, chk=89.2608

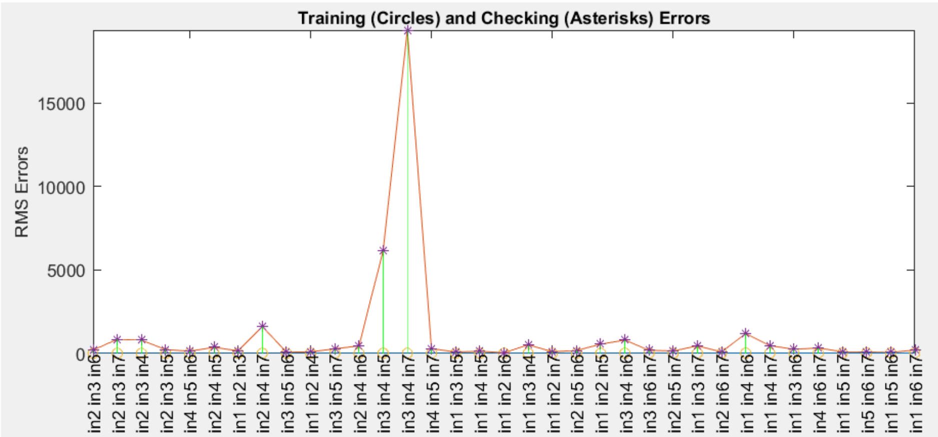

Fig 4 All three predictors combinations influence on the shear strength of FRP-RC beams

The Figure 4 shows the results of selecting three predictors, in which “weight”, “effective depth” and “reinforcement ratio of longitudinal FRP bars” are selected as the best combination of three predictors. However, the minimal training and checking error do not reduce significantly from that of the best two predictors model, which indicates that the newly added predictor “reinforcement ratio of longitudinal FRP bars” does not improve the prediction much. For better generalization it is preferable to pick a model with simple structure. For further analysis model with two predictors will be extracted.

The function “exhsrch” only trains each of the ANFIS model for a single epoch to be able to quickly select the optimal input attributes. In the next step, after extraction of the two optimal predictors, 100 epochs are used for training the new ANFIS model. Figure 5 shows error curve for 100 epochs of the ANFIS training for two predictors. The green curve presents the training errors and the red curve presents the checking errors. The minimal checking error occurs at epoch 100, which is indicated by a circle. Notice that the checking error curve is almost constant after epoch 70, indicating that further training over fitch the data and produces worse generalization.

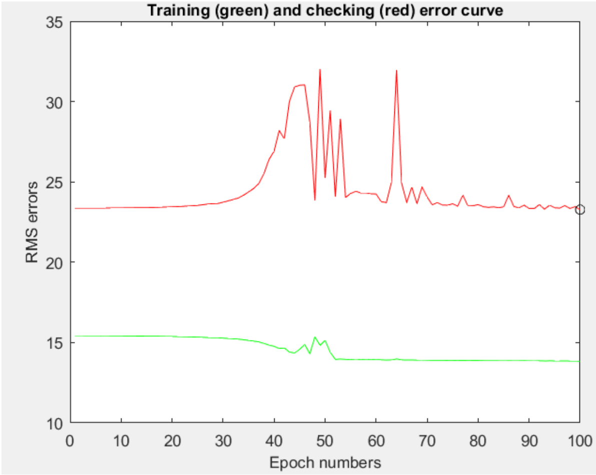

Fig 5 Training and checking errors for two optimal predictors

The ANFIS model could be compared against a linear regression model by comparing their respective RMSE values against checking data. ANFIS RMSE value against checking data is 29.978, while linear regression RMSE value against checking data is 35.656.

Figure 6 shows input/output surface of the ANFIS model at the minimal checking error during the training process. The surface shown in the figure 6 is a nonlinear and monotonic surface and illustrates how the ANFIS model will respond to varying values of beam width and effective depth.

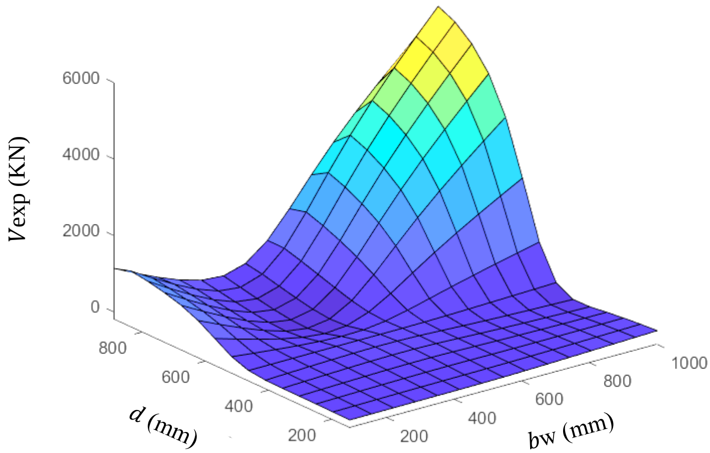

Fig 6 Input/output surface for trained ANFIS model

4. CONCLUSION

A computational intelligence model for the shear strength estimation of fibre reinforced polymers (FRP) used as internal reinforcement for reinforced concrete (RC) beams has been proposed in this paper. A set of experimental data from the published literature has been collected and divided into input and output parameters.

Adaptive neuro fuzzy inference system or ANFIS was used for optimization of the predictors for the shear strength of the FRP-RC beams. Based on the input/output data pairs ANFIS models were created. The results from the searching procedure indicated that "beam width" and "effective depth" form the optimal combination of two input attributes or two predictors for the shear strength prediction of the FRP-RC beams. This selected combination of two predictors could be used effectively to estimate the strength of confined ultimate concrete.

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SMICANJE OJAČANIH VLAKNASTIH POLIMERA U PRIMENI KOD UNUTRAŠNJIH BETONSKIH STUBOVA

Osnovni cilj istraživanja prikazanog u radu je analiza procedure selekcije, kako bi se pronašli optimalne prediktore za smicanje ojačanih vlaknastih polimera, u primeni kod unutrašnjih ojačanih betonskih stubova. Procedura selekcije je urađena primenom adaptivne neuro fazi logike, ANFIS, i svi dostupni parametri su bili uključeni. ANFIS model bi mogao da se koristi kao primer ne suviše komplikovane analize smicanja unutrašnjih betonskih stubova. MATLAB softver je korišćen za ANFIS aplikaciju. Rezultati su pokazali da širina stuba i efektivna dubina stuba čini optimalnu kombinaciju od dva ulazna parametra za predikciju smicanja stubova.

Ključne reči: *FRP; prediktori; smicanje; ojačani beton; ANFIS.*

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Original Scientific Paper

CONTRIBUTION TO THE STUDY OF PUBLIC BUILDINGS OF OTTOMAN ARCHITECTURE IN SOUTHERN AND EASTERN SERBIA

UDC 72.033.3:725(497.11)

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Abstract. *The paper presents buildings from the period of Ottoman domination in southern and eastern Serbia. The paper first presents the architectural analysis of the buildings in question. The historical context of their construction, their original function and the social role they had when they were created are also considered. A special emphasis was placed on the analysis of the current state of preservation of these buildings, their new functions and the role they play in society today.*

Key words: *Islamic architecture, mosque, hammam, conservation, preservation, heritage*

1. INTRODUCTION

With the arrival of the Ottoman Empire in the Balkans, numerous changes began to take place. Apart from the inevitable and very pronounced socio-political and economic changes, changes in the architectural and urban design of cities were unavoidable. Cities that were primarily predominantly inhabited by the Slavic population began to take on an oriental appearance with greater or lesser intensity. Intensive construction of facilities such as mosques, madrasas, hammams, caravanserais began.

Later, after the liberation from the Turkish rule, the population tried to restore the Serbian spirit to the cities. These buildings, the legacies of Ottoman architecture, which were created during the period when these areas were under the Turkish rule, were exposed to the rage of destruction of the newly liberated people (Fig. 1). The demolition of mosques and other Turkish buildings began immediately. Some of the buildings were completely destroyed, some were maintained to a minimum. Hence, there is only one preserved mosque in Belgrade [1], two mosques in Niš with partial remains of the third

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one [2]. Buildings of Islamic architecture, due to abandonment and war destruction, and also due to lack of interest in them, have completely fallen into oblivion.

This paper gives an overview of the current state of the buildings of Islamic architecture from the period of the Ottoman rule.

In the territorial sense, the area of southern and eastern Serbia was considered, which in terms of jurisdiction over cultural monuments is covered by the Institute for the Protection of Cultural Monuments Niš [3]. Religious buildings, fortifications and military buildings, as well as public buildings were analyzed. Residential architecture was not the subject of this paper.

2. Historical Conditions

The Ottoman rule in the Balkans lasted from the 14th to the 20^{th} century. Some parts of the Balkans were under the Ottoman rule continuously, while for other parts this was not the case. After the defeat in the Battle of Maritsa in 1371, and later in the Battle of Kosovo in 1389, Serbia fell under the Turkish rule. The year 1459 and the fall of Smederevo is considered the final conquest of the entire Serbian territory by the Ottomans.

Serbia gained liberation and complete independence from the Ottoman Empire in 1878, as well as a new territorial expansion to the area of today's southeastern Serbia [4], and after the Balkan Wars of 1912 and 1913, and a new territorial expansion of Serbia, the Turkish administration ceased. This ends the period of the Turkish rule in the history of Serbia.

During this very long period of rule on the territory of Serbia, a large number of monuments of Islamic architecture was built, both religious and profane [2]. The towns got a completely oriental look. In the works of the travel writers of that time, one can find descriptions of towns dominated by mosques, madrasas and so on.

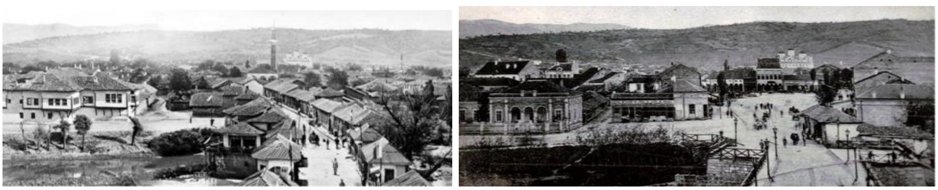

Fig. 1 Niš 1878 (left) and 1900 (right) [5]

3. Architectural Objects

When the Ottoman Turks came to these parts, they already had a centuries-old tradition of building fortifications and urban settlements. The Ottomans brought with them the ready-made principles of building small and large settlements – provincial towns (kasaba) and regional towns (sehir). The basic principle of forming the settlement was its division into a craft and trade part – business district (carsi) and housing units - mahallah. The entire economic activity took place in the business district, almost all public buildings (hans, caravanserais, bezistans, hammams, madrasas, clock towers, imarets), as well as sacral buildings (mosques, mescits, turbes, cemeteries) were located there. Upon their arrival in this area, the Ottomans created conditions for the development of existing squares and towns, and for the establishment of new settlements, smaller towns and larger sehirs. The existing settlements changed rapidly, taking on the character of oriental settlements divided into a carsi and mahalas [6]. The architectural program was unique in various areas of the Islamic State. The following buildings were built: religious buildings (mosque, masjid), hammams, caravanserais, hans, bazaars, bezistans, tekyehs, turbes.

In construction, mainly two types of materials were used - hewn stone for public buildings and brick for private buildings. Buildings made of hewn stone are better preserved. Their massive dimensions were directly related to their purpose, and as public buildings, the construction of which was financed by the state, they were the basis of urban development of every environment [7 according to 8]. There was also the use of wood, mostly in residential architecture.

In the area of southeastern Serbia, there are several buildings dating from this period which are under protection [3 and 9]. In addition, some of these buildings have been registered as an immovable cultural heritage, but have not been declared yet (Table 1). The buildings of Pasha's konaks in Vranje, Radul Beg's konak in Zaječar, the building of the Turkish Embassy in Niš, and the Skull Tower are also protected.

Among the remains of buildings of this period that can be found on the territory of the Niš Institute for the Protection of Cultural Monuments are the tekyeh in Medveđa, the mosque in Biljača, the Turkish customs building in Davidovac, the remains of the hammam in Prokuplje, the Turkish tower in Klisura, the remains of the mosque in Šumatovačka Street in Niš, the remains of the Gurgusovac tower in Knjaževac, then the old powder magazine and underground passage in Knjaževac, as well as the remains of the Turkish tekyeh in Zagrađe in Kuršumlija.

Table 1 Confirmed immovable cultural property

no	Name of the immovable cultural property	Place	Decision on proclamation for immovable cultural property	Category	Decision for category	Note
1.	The Fortress of Niš	Niš, Crveni Krst municipality	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 671, May 6, 1948	of big importance	Official Gazette of the Republic of Serbia no. 14/79	Hammam, arsenal, Bali Bey’s mosque, mezulana
2.	The Fetislam fortress	Kladovo municipality	Decision of the Institute for the Protection of Cultural Monuments Serbia no. 1767/1, October 27, 1964	of big importance	Official Gazette of the Republic of Serbia no. 14/79	/
3.	Pirot fortress	Pirot	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 115/53, February 16, 1953	of big importance	Official Gazette of the Socialistic Republic of Serbia no. 14/79	the Pirot fortress is a Serbian medieval fortress, but parts of the rampart of a lower town were built in the Turkish period
4.	Islam aga mosque	Niš	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 913/54, November 9, 1954	/	/	/

no	Name of the immovable cultural property	Place	Decision on proclamation for immovable cultural property	Category	Decision for category	Note
5.	Ibrahim bey’s mosque	Preševo municipality	Decision of the Republic of Serbia no 633-9866/2013 November 22, 2013	/	/	/
6.	Hammam	Vranje municipality	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 1057, June 29, 1948	of big importance	Official Gazette of the Socialistic Republic of Serbia no. 14/79	/
7.	Old spa bath	Sokobanja	Decision of Sokobanja municipality no. 011-62/83-01, December 14, 1983	/	/	/
8.	Old bath in Niška banja	Niška banja	Decision of the Government of the Republic of Serbia no. 633-6872/2001-17, July 17, 2001	/	/	has leyers from Roman, Turkish and new period
9.	Hammam in Brestovačka banja	Brestovačka banja	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 1301/49, July 22, 1949	/	/	/
10.	Old prison	Boljevac	Decision of Boljevac municipality no. 633-492/80-07, May 15, 1980	/	/	/
11.	Turkish tower, old municipality building	Vlasotince municipality	June 14, 2005	/	/	/
12.	White bridge	Vranje municipality	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 1085, June 29, 1948	/	/	/
13.	Beg’s bridge near Staničenje	Pirot municipality	Decision of Pirot municipality 02 no. 020/41-92, April 13, 1992	/	/	/
14.	Osman beg’s fountain in Podgorac	Boljevac municipality	Decision of Boljevac municipality no. 633-488/80-07, May 15, 1980	/	/	/
15.	Đerenka fountain	Vranje municipality	Decision of the Institute for the Protection and Scientific Study of Cultural Monuments Serbia no. 184, February 2, 1949	/	/	/
16.	Complex of old fountains in Vidrovac	Negotin municipality	Decision of Negotin municipality no. 633-10/80-III, June 18, 1980	/	/	/

3.1. Mosques

Architecture and religion have always been very closely connected. Buildings of sacral architecture have a special value for religious people, they represent a place of prayer and a sacred place [10]. The beginnings of Islamic art are largely associated with mosques. A mosque is a basic expression of Islamic culture. The unity of the sacral and profane phenomenon has been achieved in a mosque, because the space of the mosque is simultaneously used for performing prayers and for social gatherings of believers [6] .

In the documents from the period of the Turkish rule, it can be concluded about a large number of mosques in the cities in Serbia, the southeast part of the country as well. There were about twenty mosques in Niš during the Turkish rule; there were ten of them in the Fortress, one mosque in Beograd mala, the Arabaji mosque from 1725, and eight of them on the left bank of the Nišava river [11]. Today there are two mosques in Niš, and the remains of the third one are visible.

After the liberation from the Turks, there were eight mosques in Leskovac, some of which were demolished immediately after the liberation in 1877. The mosques which survived the liberation are the Carsi mosque, the Clock mosque and the mosque of Sultan Bayezid II, the one that was demolished due to dilapidation in 1942 [12]. There were two such buildings in Pirot, none of which has been preserved to this day.

There are several mosques in Preševo, of more recent date, given the large number of inhabitants of the Muslim religion. There is only one such building in this city from the period of Ottoman rule.

The mosques that have remained to this day as witnesses of some past times speak in favour of the fact that the architect gave priority to functionality and spatial planning, while the decoration was put in the background.

3.1.1. Bali Bey's mosque in the Niš fortress

The mosque is located in the central part of the Niš fortress. As a part of the entire Fortress, it was declared a cultural property in 1948. It was built between 1521-1523 and it was the endowment of Bali Bey. There is information that along the north wall of the mosque, at the entrance porch, there used to be a library [11]. The minaret was added in the 17th century. It has a square base with a mihrab facing Mecca. It is vaulted with a semi-calotte. At the entrance, a two-domed porch with four arches and three pillars has been renovated. To the right of the entrance there was a minaret, which was demolished over time, and today there are only its remains[13]. It was built of stone and brick. The bricks appear in horizontal and vertical rows, framing the hewn walls. The walls were reinforced with wooden trusses, which had the role of ring beams. Broken brick arches are above the window openings. The roof covering is roof tiles.

The Institute for the Protection of Cultural Monuments Niš, performed conservation works on the mosque during 1972, as well as between 1976 and 1978. The works were carried out on the renovation of the central domed area, with a complete reconstruction of the collapsed northwest porch, and partially the minaret.

The building is in good condition now. The main current problem with the physical structure of the building is moisture, due to which damage to bricks, stone and mortar is visible. Also, there is a certain degree of biodegradation in the form of mold that occurs inside the building. In addition, on the roof, due to difficult accessibility and irregular cleaning, there is a large layer of biological material from which wild plants grow. [2]

Now this building has the purpose of an exhibition gallery, the so-called "Salon 77". It is safe and accessible to visitors.

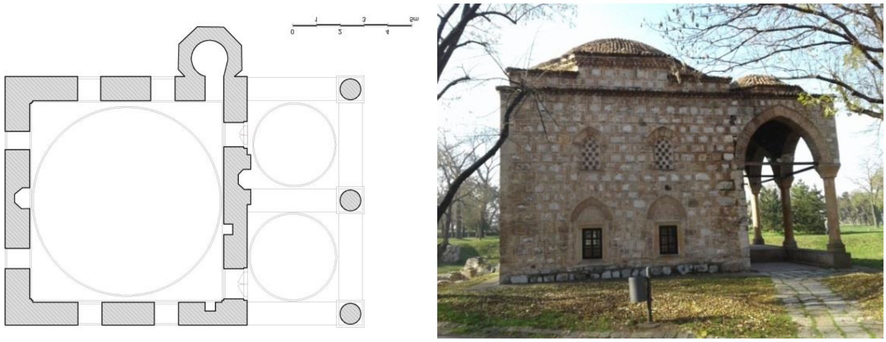

Fig. 2 Floor plan (left) and photo (right) of Bali Bey's mosque in the Niš fortress. Drawing A.M.Petronijević according [5], Photo A.M. Petronijević

3.1.2. Islam Aga Mosque in Milojka Lešjanina Street in Niš

It was built in the very center of the city. It is the only fully preserved mosque in Niš. It was restored in 1870 on the remains of the old one, built around 1720. The masjid of Hajji Musli-hudin was first built on this place, and it was transformed into a mosque by adding a minaret around 1720. In the middle of the 18th century, he renovated it, and added a school next to it - the mekteb of Yahya Pasha. Between 1782 and 1804, it was extended by the Niš defterdar Abdurahman. The current mosque is the endowment of Islam Aga Hadrević [11].

This mosque is the last public Turkish architectural structure built in Niš. It is a rectangular building, with a flat wooden ceiling and a gallery on pillars. From this gallery you can reach the circular stairway of the minaret. It has a hip roof covered with roof tiles. The main entrance used to be from the street. It does not have significant architectural values. Its walls are made of untreated stone, so they are plastered. It is a typical example of the buildings from the period of the sudden Turkish economic and military decline.

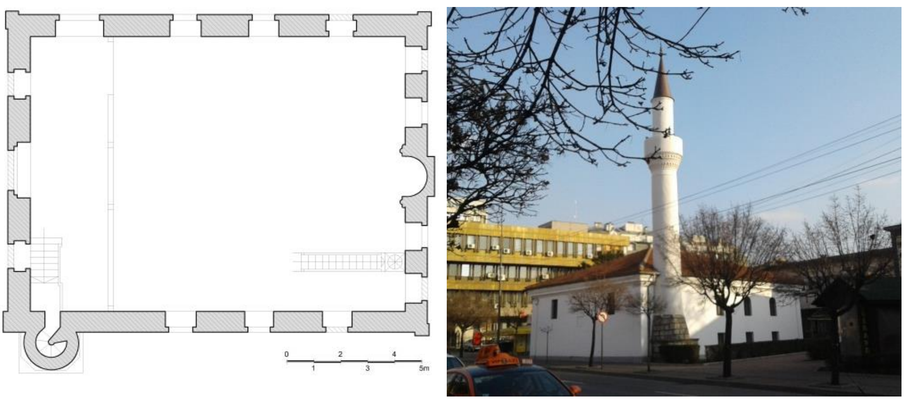

Fig. 3 Floor plan (left) and photo (right) of Islam Aga Mosque. Drawing A.M.Petronijević according [5], Photo A.M. Petronijević

In March 2004, in response to riots in Kosovo, the mosque was set on fire and suffered significant damage. It was then completely restored. As the only Islamic place of worship that has retained its purpose, it is often the target of nationalist and religiously intolerant graffiti[2]. Today it is used by the Islamic community of Niš.

3.1.3. Ibrahim Pasha's mosque in Preševo

It is located in the center of Preševo. According to the inscription on the marble slab above the entrance to the mosque, the mosque was built in 1805 by Ibrahim Pasha Ginoli, originally from Shkoder. It is a two-storey building. The base is rectangular, measuring 18.5/11 meters. It was built of stone, then plastered and painted white. The mihrab and minbar are along the south wall, facing Mecca. Internal, wooden stairs lead to the first floor with a gallery. Along the west facade is a slender spear-shaped stone minaret. Along the south facade, towards the street, a stone fountain was built in 1878, with an arched niche and a carved text - tarih. Within the complex of Ibrahim Pasha's mosque, there is a tekyeh and a cemetery in the same yard. The mosque has been renovated several times. The entrance was added after the Second World War [5]. The building has been renovated and is in good condition.

3.2. Hammams

Hammams are baths that originated in the east. In the Islamic religion, bathing had, in addition to its hygienic role, also a ritual significance. Hammams were very important as places for socialization. The hammams could be double, which means that there were a completely separate program of rooms for men and women. In the case of only one program of rooms, men and women bathed on different days.

In addition to bathing, hammams have other hygiene facilities. They also include rooms for relaxation, dining rooms, meeting rooms, and in that way they were places where people spent time, ran a business, had fun. The basic rooms that make up the hammam are: *shadirvan, halvati, kapaluk, hazna and culhan. Shadirvan* was the largest room where people waited their turn for bathing. People talked there, came into contact with each other, which was a tradition since the ancient Roman baths. *Halvati* were rooms where people bathed. In these rooms were tubs and stone benches for lying and steaming. There were *meydans* with sofas, stone beds for sweating and *kurnas* from which water for pouring was taken [14]. *Kapaluk* were rooms for rest after bathing, necessary as a person after bathing, still warm, should not go out immediately, especially in winter. These rooms were also used for massage. Behind it, there were technical facilities for water heating and they consisted of a *hazna*, a water tank, a *culhan* - firebox for water heating and a terrace for raising water in order to direct it with a natural fall. The heating in the hammams was that of Roman hypocausts, with warm air circulating between double walls and under the floors [15]. Hammams were most often built in a combination of stone and brick. Most hammams have a dome over the central part or the entire building is covered by a system of domes and vaults. Lighting often came through round (in some cases star-shaped) openings in the dome

3.2.1. Hamam in Vranje

The hammam in Vranje was built at the end of the 17^{th} century. It basically consists of three parts: a large dressing room, a cross-shaped bathing area and a narrow room with water tanks. The dressing rooms are covered with a hip roof and roof tiles. The *halvat* is covered with five domes with glass oculi that light the interior. The central dome is slightly larger, while those in the corners of the cross are somewhat smaller. It is built of hewn stone and brick. The first renovation of the hammam was done in 1954-1955 by the Institute for the Protection of Cultural Monuments of SR Serbia. Renovation and conservation-restoration works were carried out in 1983, 2002 and 2009, and today it is in good condition but not available to visitors. Indoor installation and furniture no longer exist [16, 17].

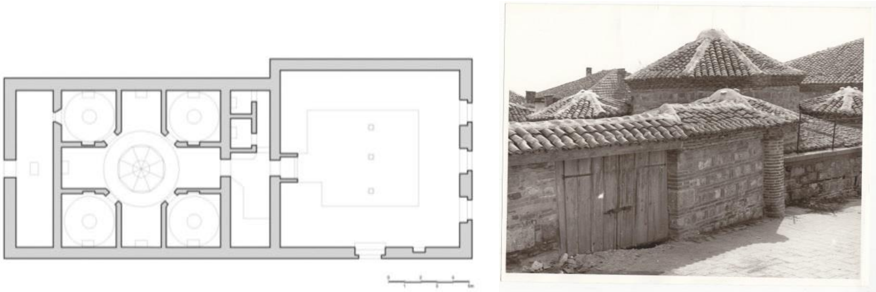

Fig. 4 Floor plan (left) and photo (right) of Hammam in Vranje. Drawing A.M.Petronijević according to [1], photo [9]

3.2.2. Hammam in the Fortress of Niš

There used to be four hammams in Niš [18]. Today only one of them is preserved. It is located at the entrance plateau of the Niš Fortress, next to the Stambol Gate. It was built in the 15th century and it was the endowment of Mehmed bey [19].

The shadirvan, from which one entered the dressing room, has not been preserved. Then there is the meydan, which was connected with the *halvat* - a part for bathing divided into two parts. At the end of this series of rooms are the hazna and the culhan. Over the massive transverse walls and pendentives, there is the under-dome area. The hammam was supplied with water from Nišava, which was purified in a reservoir [11]. Unclean water was returned to Nišava through a special canal. One part of the purified water was heated, and the other cold was used for bathing. The hammam was built with brick and stone. Restoration and conservation works were carried out on the hammam from 1973 to 1975 [20]. For many years, it functioned as a restaurant. Today it operates as the Nishville Jazz Museum. It has had this purpose since 2017, when it was officially opened at the time of the traditional 35th Nishville Jazz Festival ("Nišvil 2018").

Fig. 5 Floor plan (left) and photo (right) of Hamam in Niš. Drawing A.M.Petronijević according to [20], photo A. M. Petronijević

3.2.3. Hammam in Sokobanja

It is located in the center of the park in Sokobanja. It dates from the 15th century. It is based in the oldest part of the spa bath from the Roman period. During the 17th and 18th centuries, it passed into the hands of the Austrians twice. The Austrian General Schmetaus said that the spa was very popular among the Turks from all parts of the empire while it was under the Turkish rule [9].

The old part consists of two spacious functional units, with rooms for women and men. The area of the women's pool is vaulted centrically with a hemispherical vault. The area of the men's pool is vaulted with a hemispherical, domed construction above the square base, with lighting openings that also occur in the women's pool.

It was renovated for the first time in 1834 during the reign of Prince Miloš Obrenović. In 1880 it was expanded. Rehabilitation and conservation - restoration works have been performed on several occasions. The most extensive works were performed during 2004 and 2005. The last rehabilitation works were performed in 2011. Today, the hammam functions as a "Wellness Center" [16].

3.2.3. Hamam in Brestovačka Banja

It is believed that it originates from the Turkish period, and that Prince Miloš also used it during his stays in the spa. This hammam is small in size, 5.5/5.9 meters. It is semicircularly arched and has niches in the corners, and nine openings in the dome through which light enters. The main light comes through a window on the north side. Inside it has a round swimming pool which is 1.10 m deep, 2.60 m in diameter [21]. The hammam was repaired, but not completely. It is expected that the building will operate as an exhibition gallery.

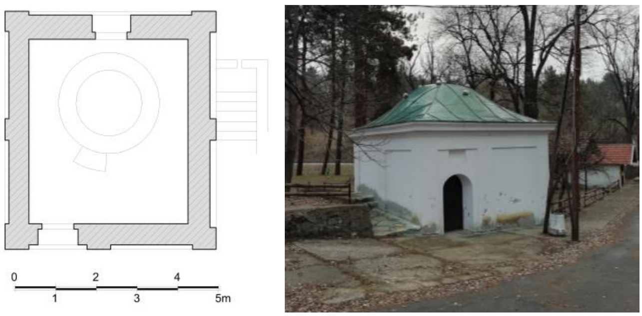

Fig. 6 Floor plan (left) and photo (right) of Hammam in Brestovačka Banja drawing A.M.Petronijević according to [22], photo [9]

3.2.4. Niška Banja bathroom

It is located in the central area of the spa, in the park, on a slight elevation above the New Bath and at the foot of the hill. The building was renovated in 1934 on the remains of a Turkish male and female bath, erected above the Roman catchment of the main spring. It is a ground floor building, with an elongated rectangular base, the dimensions of which follow the configuration of the terrain cascading. The octagonal pool number 3 and the rectangular pool number 4 have a central place, next to which there are changing rooms, surgeries, ancillary rooms and a sanitary block, while the inhalation hall is located in the northeastern part of the building. It is composed in an eclectic style [9].

3.3. Military facilities

3.3.1. The old prison in Boljevac

The old prison in Boljevac was erected as a prison building, so it does not have significant architectural values. It was built after 1860. During the Timok rebellion, in 1883, it served to imprison the rebels from the Boljevac area.

It is a rectangular building with a hip roof. It is made of brick. The building was reconstructed and serves as a museum. As such, it was opened in 1983, on the centenary of the Timok rebellion. The museum has a permanent exhibition that follows the events and people of the 1880s and 1890s, the period immediately before, during and after the Rebellion [9].

3.3.2. Cebhane - gunpowder magazine in the Niš fortress

Inside the walls of the Fortress are gunpowder magazines, Turkish buildings that were used to store gunpowder, ammunition and weapons. There are four of them in total, all of approximately the same size. They are located along the northern rampart, and lean against it with one side. The gunpowder magazines were built between 1720 and 1723, at the time of the construction of the Fortress. These are ground floor, rectangular buildings. They have hip roofs with tiles. In a constructive sense, all four gunpowder magazines were built on the same principle. The double walls are about 1 m thick, and form a protective corridor around the central room, where ammunition and gunpowder were stored. The central room, semi-arched, was entered through narrow corridors, also semi-arched. The purpose of the corridors was to protect soldiers, as a defensive area in case of an attack. Narrow openings on the walls - loopholes, were places for soldiers from which in case of an attack, they could shoot and defend the building. The massive exterior and interior walls of the gunpowder magazine were built in lime mortar from easily accessible material - crushed stone of various size, river pebbles, crushed limestone and hewn sandstone blocks of poor quality. The space between the two faces of the wall was filled with rubble. The corners of the gunpowder magazine as well as the doorjambs were built of larger hewn blocks - sandstones. The roof cornice is made of brick and plastered, the gunpowder magazine has a hip roof, the roof is covered with tiles, and the space between the vault and the roof covering is filled with rubble [23, 24].

"Gunpowder magazine no. 4" is by its external dimensions the largest one. The net area of the central room is about 50 m^2, and the hallway that surrounds it is 48 m^2. During 2012 and 2013, conservation and restoration works were performed on it [25]. Its new purpose is an exhibition gallery and a "Museum of Gunpowder and Medieval Weapons".

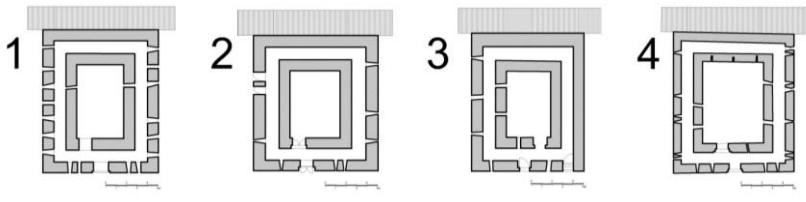

Fig. 7 Gunpowder magazine no 1, 2, 3, 4 drawing A.M.Petronijević according to [5], Photo A.M.Petronijević.

Fig. 8 Gunpowder magazine no 2 (left) and no 4 (right), Photo A.M.Petronijević.

3.3.3. Mezulana / a smithy in the Niš Fortress

The smithy building is in one of five gunpowder magazines. It is located in the eastern part of the Fortress, next to one of the current main communications. It was built between 1720 and 1723. The building contains two almost identical rooms, which do not have mutual connection, but each one has a separate entrance from the outside, the eastern side. They were probably built in two phases. The walls are massive, made of crushed stone. The corners, doorjambs and lintels are made of sandstone and brick. It has a simple loft cornice. The hip roof is covered with tiles. The interior is vaulted with a semi-circular vault.

In the 1970s it was used as a smithy of the construction department of the Institute for the Protection of Cultural Monuments Niš, hence its name [11].

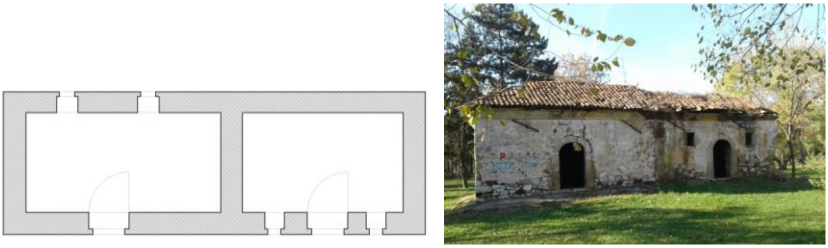

Fig. 9 Floor plan (left) and photo (right) of Mezulana. Drawing A.M.Petronijević according [5], Photo A.M. Petronijević

3.3.4. Arsenal in the Niš Fortress

To the right of the Stambol Gate is the building of the arsenal (depot, warehouse of cannons and war material). It housed cannons, gunpowder, cannon balls and other military material. It is a ground floor building with a large arched entrance, with a massive double door. To the left and right of the entrance are niches, three on each side, the same height and dimensions as the entrance area, each with an area of about 10 m^2. At the back of the arsenal, to the east, there are two small entrances with arched doors and exit staircases. The arsenal occupies an area of about 300 m^2, with eight wooden pillars inside. There are narrow openings in the walls - loopholes, high above the ground. Along the walls inside the arsenal, there were guard posts, at the height of the loopholes, used in the event of an attack [11]. The walls are massive, built of stone. The vaults and cornices are made of bricks. The hip roof is covered with tiles.

The arsenal was built, according to the inscription on the plaque at the front door, in 1857, on the site of the former old tophane - a house for cannons. Conservation work was carried out in 1972, when it was renovated, and since then it has been used as a gallery for exhibiting paintings. A souvenir shop is located in the niche near the entrance.

Fig. 10 Floor plan (left) and photo (right) of Arsenal. Drawing A.M.Petronijević according [5], Photo A.M. Petronijević

3.3.5. Turkish prison in the Fortress of Niš

The building of the Turkish prison has also been preserved in the fortress. It is located in the eastern part of the Fortress, next to administrative and military buildings, between Pasha gate and Vidin gate.

The first information about it was recorded by Felix Kanitz in 1864. He stated that a new prison was built in the fortress at that time, at the request of the then commander of Niš, Midhat Pasha. Based on that, it can be concluded that the current building was erected between 1861 and 1864. A Turkish source from 1873 also mentions this prison. It is stated that it was built of brick and stone, with seven rooms on the ground floor and ten on the first floor. Of the ground-floor rooms, five were intended for prisoners and two for prison guards, while on the first floor eight rooms were for prisoners and two for patients. After the liberation of Niš from the Turks, the prison was surrounded by a high wall and renovated, becoming the first Niš penitentiary within Serbia [11]. During the First World War, the prison was taken over by the Bulgarian occupiers. After the First World War, it was used as a military prison. It is in very bad condition now

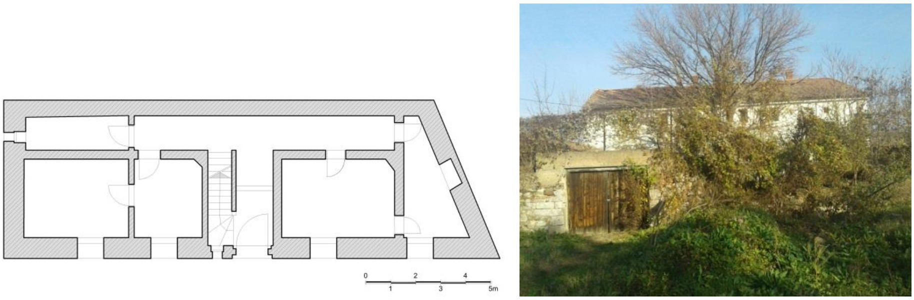

Fig. 11 Floor plan (left) and photo (right) of Turkish prison. Drawing A.M.Petronijević according [5], Photo A.M. Petronijević

3.3.6. Turkish tower in Vlasotince

It is located in the center of Vlasotince. It was built in the second half of the 18th century for the needs of the Turkish municipality of "Ućutmata". It was an administrative building, and as a security for local trade routes. It has a symmetrical base with a staircase in the middle and side polygonal towers with loopholes. The walls are massive, made of crushed stone, while the partition walls are in a wooden skeleton with infill. The walls are plastered and painted on the outside and inside. The hip roof is covered with tiles. [26]. A mudir, a scribe and seven seymens lived in it. Today it is the building of the Museum.

Apart from the described buildings, several fountains from the period of Turkish domination have been preserved (Osman Bey's fountain in Podgorac, Boljevac municipality, the Stone fountain "Đerenka" in Vranje), and several stone bridges (White Bridge in Vranje, Beg's Bridge near Staničenje, Pirot municipality).

4. Reflections

The Turks ruled for centuries in the Balkans, and thus in Serbia as well. Bringing their culture, religion, customs, they also brought elements of their architecture. During their rule in this area, the Turks built numerous buildings characteristic of their culture and religion. At the heyday of Ottoman rule, Serbian cities were full of these facilities.

With the weakening of the power of the Ottoman Empire, the appearance of the cities began to change. After the end of the Ottoman rule, the cities underwent an architectural transformation. There was no more room for mosques on the new face of the city. Enthusiastic people tried to give back the old look to their cities as soon as possible, demolishing buildings that reminded them of the period of slavery, and building new ones for which they sought inspiration in European cities. The demolition was carried out both in the desire to modernize the cities, and to catch up the previously liberated parts of the country [1]. The number of buildings of Islamic architecture dropped drastically in the 19th and the beginning of the 20th century. The systematic demolition of mosques was pronounced, but so was the disregard for the remaining buildings. The number of mosques in major Balkan cities had fallen by 95% since the peak of the Ottoman Empire [10].

When we look at the number and condition of buildings of Islamic architecture on the territory of southern and eastern Serbia, which is described above, it can be concluded that a very small number of buildings have been preserved in this area as well.

Out of three preserved mosques in the researched area, one is being used as an exhibition space, while the two remaining, mosque in Preševo and in the Milojka Lešjanina street in Niš, retain their original use. Most of the buildings from the period of Turkish domination have been preserved in Niš, on the territory of its Fortress. The arsenal, gunpowder magazines, the smithy and the hammam are located within the walls of the fortress, and they witness the old historical period. Today they are a gallery, a museum, and an exhibition space.

Even 5 hammams survived in the investigated area - out of 13 preserved in the entire territory of Serbia [16]. The hammam of Niš has worked as a restaurant for years, and in the last few years as a jazz museum. Regardless of the fact that it is the only building of this type in Niš, the fact that it is positioned in a very attractive place in the city, at the very entrance to the Fortress, there were no possibilities for its exploitation with the original function. The hammam in Brestovačka Banja will work as an exhibition gallery when the rehabilitation works are completed. Hamam in Soko Banja has retained its original function to some extent. The proximity of thermal springs, as well as the spa environment opened to health tourism have created the principle of sustainability of the bathing function of this facility. It is also commendable that the bathroom in Soko Banja, in addition to its function, also retained its architectural form. Although in good condition, the hammam in Vranje is unfortunately inaccessible to the public.

Military facilities have also undergone a certain level of changes, and today they are mainly buildings in the service of cultural institutions. Niš Arsenal is a gallery, with souvenir shops in its niches. One of the gunpowder magazines is intended for a museum of gunpowder and medieval weapons. Today, the Turkish Tower in Vlasotince is a museum building.

After the period of systematic demolition of buildings has passed, and after the passions have calmed down a bit, there comes a period in which this heritage is protected. Although there are few of these facilities, most of them have been preserved or revitalized and still have a certain function today. Only a few buildings from this period retained their primary function. Most of the preserved ones have the purpose of cultural institutions. There are also those who are left to decay.

Cultural monuments are valued differently, depending on the governing structures. With the change of policy, the attitude towards certain monuments also changes. Representation and equal treatment of cultural monuments of all periods is necessary for the society. The period of Turkish occupation is part of the history and culture of the Serbian people. Whether they are a symbol of victory or defeat of our people, they are part of our past and they should have the same treatment as other cultural heritage, regardless of the period they testify.

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U radu su predstavljeni objekti iz perioda osmanske dominacije na prostoru južne i istočne Srbije. U radu je data najpre arhitektonska analiza predmetnih objekata. Razmatran je istorijski kontekst njihove izgradnje, njihova izvorna funkcija i društvena uloga koju su imali u vremenu u kome su nastali. Poseban akcenat je stavljen na analizu trenutnog stanja očuvanosti ovih objekata, njihove nove funkcije i uloge koju danas imaju u društvu.

Ključne reči: *islamska arhitektura, džamija, hamam, konzervacija, očuvanje, nasleđe*

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