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Editor-in-Chief: **Dragoslav Stojić**, e-mail: *dragoslav.stojic@gmail.com*
University of Niš, Serbia, Faculty of Civil Engineering and Architecture
18000 Niš, Aleksandra Medvedeva 14, 18000 Niš, Republic of Serbia
Phone: +381 18 588 181, Fax: +381 18 588 181

Technical Assistance: **Vladan Nikolić**, **Vojislav Nikolić**, e-mail: *fuacets@junis.ni.ac.rs*
University of Niš, Serbia, Faculty of Civil Engineering and Architecture

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Original scientific paper

ANALYTICAL PREDICTION OF MECHANICAL PROPERTIES IN HORIZONTAL DIRECTION OF LEAD-RUBBER BEARINGS

UDC 624.042.7:550.34.01/.016

Andrija Zorić, Marina Trajković-Milenković, Dragan Zlatkov, Žarko Petrović, Todor Vacev

Faculty of Civil Engineering and Architecture, University of Niš, Serbia

Abstract. *Application of seismic isolation devices is an efficient way for designing seismically resistant structures. For that purpose, various types of seismic isolation devices are developed. The main differences between them are in the materials used for their production and in the way they provide horizontal flexibility. Dynamic analysis of a base isolated structure requires an adequate mathematical model of the seismic isolation devices which can describe their mechanical properties in horizontal and vertical directions. The paper is considering analytical models used for the prediction of mechanical properties in the horizontal direction of lead-rubber bearings, which are proposed in the contemporary literature. Results obtained using these analytical formulas are compared with the results obtained by the finite element analysis model developed in this paper, as well as with available test results provided by the manufacturer. Improvements of the existing analytical models are suggested in order to enable a better prediction of mechanical characteristics in the horizontal direction of lead-rubber bearings.*

Key words: *lead-rubber bearing, elastic stiffness, post-elastic stiffness, yield force, equivalent viscose damping ratio, finite element analysis*

1. INTRODUCTION

In seismically active areas, the effect of an earthquake on a structure is dominant in structural design. During an earthquake, damage of the structural and non-structural elements can occur, and that could also lead to the total collapse of the structure. That is the reason why the seismic protection of buildings is a very important field of research nowadays.

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Corresponding author: Andrija Zorić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: andrija.zoric@gaf.ni.ac.rs

The concept of the design of the seismically resistant structures dates back to the end of the 19th and the beginning of the 20th century, with the registration of the first patents [1, 2]. The modern base isolation concept is based on the application of the special devices mounted in the seismic dilatation. The seismic dilatation divides a structure into the isolated structure (or superstructure) and the substructure. The seismic isolation devices possess small stiffness in horizontal directions which provides an increase of the natural period of vibration and a decrease of the intensity of seismic forces in the structure compared to the rigidly founded structure. On the other hand, seismic isolation devices are stiff enough in the vertical direction to transfer the gravity load.

From the aspect of the used materials and mechanism of functioning, seismic isolators can be divided into elastomeric, sliding and combined bearings [3]. Elastomeric bearings provide the seismic isolation of structures through the flexibility of the rubber material used for their manufacture. Regarding the damping level there are low damping rubber bearings, lead-rubber bearings and high damping rubber bearings [4-7].

The lead-rubber bearings (LRB) are developed with the aim to increase the damping of the elastomeric bearings. By increasing the damping of the seismic isolation devices, the displacements of the isolated structure are reduced [8]. LRB consists of steel mounting plates, rubber, steel shims and a lead core (Fig. 1). The lead core is dominantly deformed by the shear, characterized by relatively small yield strength, and consequently by the low value of yield shear strength. Seismic energy is absorbed due to the plastic deformations of the lead core.

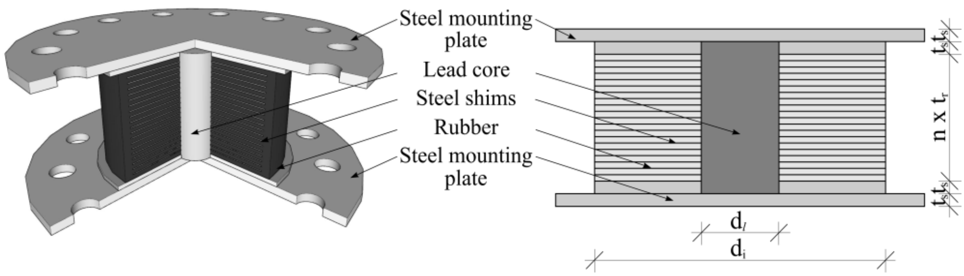

Fig. 1 The lead-rubber bearing

Mechanical characteristics of LRB are determined experimentally, and it is confirmed that the lead core provides an adequate level of seismic energy dissipation. The force-displacement relationship of LRB in the horizontal direction can be idealized by a bilinear diagram [4, 8-15]. The numerical analysis of performances of LRB is also the subject of research [16-19]. It is confirmed that the application of LRB brings benefits, as in the response of buildings [20-23], as well as in the response of bridges [24, 25], during an earthquake.

The paper analyses the nowadays widely used analytical models for prediction of the mechanical properties in the horizontal direction of LRB. Results obtained using existing analytical models are compared to the results obtained by the finite element analysis model developed in this paper and to available test results provided by the manufacturer. The analysis includes the influence of the lead core diameter on the mechanical properties in the horizontal direction of LRB, as well as the influence of the number and thickness of the rubber layers and the number of the steel shims. Based on the comparative study of the analytical and numerical results, the calibration of the existing analytical models is performed. As a result, an improved analytical model is proposed, which exhibited a better prediction of mechanical characteristics in the horizontal direction of LRB, used for the dynamic analysis of the base isolated structures.

2. Analytical Model

An idealized bilinear force-displacement relationship in the horizontal direction of LRB can be defined by the elastic stiffness (K_e), post-elastic stiffness (K_y) and yield force (Q_y) (Fig. 2). The analytical relations presented in the following text are proposed in literature in order to determine the post-elastic stiffness and the yield force of LRB.

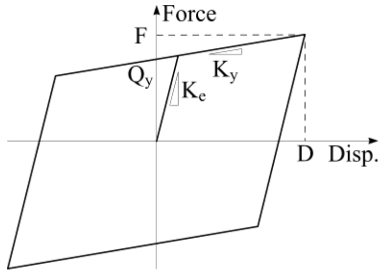

Fig. 2 Idealized bilinear force-displacement relationship in horizontal direction of LRB

The post-elastic stiffness (K_y) is defined as a superposition of stiffnesses of the elastomeric part and the lead core of LRB [6, 26]:

$$K_y = C_{Ky}\left(\frac{G_r A_r}{H} + \frac{G_l A_l}{H}\right), \tag{1}$$

where: C_{ky} – modification modulus,
G_r, G_l – shear modulus of rubber/lead,
A_r, A_l – cross-section area of laminated rubber/lead core,
H – total rubber thickness and height of lead core.

The post-elastic stiffness of LRB is dependent on the shear strain (γ) and the latter is introduced by a modification modulus C_{Ky} [6, 26]:

$$C_{Ky} = \begin{cases} 0.779\gamma^{-0.43} & (\gamma < 0.25) \\ \gamma^{-0.25} & (0.25 \le \gamma < 1.00) \\ \gamma^{-0.12} & (1.00 \le \gamma < 2.50) \end{cases}. \tag{2}$$

The other recommendation for the prediction of the post-elastic stiffness is given in [27] in the following form:

$$K_y = \left(1 + 12\frac{A_l}{A_r}\right)\frac{G_r A_r}{H} \,. \tag{3}$$

In the latest research it is noticed that the contribution of the stiffness of the lead core to the overall post-elastic stiffness of LRB is small. Therefore, a new analytical model is proposed [28]. According to this recommendation, the post-elastic stiffness of LRB is proportional to the stiffness of the elastomeric part, whereas the influence of the lead core is encompassed by the factor f, and the overall post-elastic stiffness of LRB can be calculated by the following formula:

$$K_y = f \cdot \frac{G_r A_r}{H} = 1.1 \cdot \frac{G_r A_r}{H} \,. \tag{4}$$

The yield force (Q_y) of LRB is proportional to the cross-sectional area of the lead core and the yield shear stress of lead (f_{yl}), while the influence of the shear strain is encompassed by a modification modulus C_{Qy} [6, 26]:

$$Q_y = C_{Qy} f_{yl} A_l \,, \tag{5}$$

$$C_{Qy} = \begin{cases} 2.036\gamma^{0.41} & (\gamma < 0.10) \\ 1.106\gamma^{0.145} & (0.10 \le \gamma < 0.50) \\ 1 & (\gamma > 0.50) \end{cases} \,. \tag{6}$$

An analytical formula for the prediction of the elastic stiffness of LRB has not been proposed yet. However, the adoption of the elastic stiffness which equals to the product of the factor β and the post-elastic stiffness (K_y) is recommended by the manufacturer of these isolation devices [29] and the other researchers [5, 27, 28], with different suggestions for the value of the factor β (6.5 or 10).

An equivalent viscose damping ratio (ξ_{eq}) is a parameter important for the estimation and modelling of the damping. The equivalent viscose damping ratio is a ratio of the total dissipated energy per cycle, which is equal to the area of the hysteretic loop (E_D), and the elastic strain energy (E_s). As a function of the maximum displacement (D) and the corresponding force (F) it can be calculated as:

$$\xi_{eq} = \frac{E_D}{4\pi E_S} = \frac{E_D}{2\pi F D} \,. \tag{7}$$

The equivalent viscose damping ratio of LRB can be calculated based on the mechanical properties in the horizontal direction as [6, 26]:

$$\xi_{eq} = \frac{2}{\pi} \frac{Q_y \left[\gamma H - \frac{Q_y}{(\beta - 1)K_y}\right]}{\left(\frac{Q_y}{\gamma H} + K_y\right)(\gamma H)^2} \,. \tag{8}$$

3. Numerical Analysis

For the purpose of calibration of the existing analytical models, a numerical analysis of the mechanical characteristics in the horizontal direction of LRB has been conducted by the finite element analysis using the software package Ansys Workbench. For the numerical analysis, LRB with the isolator diameter d_i = 650 mm (Fig. 1), produced by the manufacturer Dynamic Isolation Systems [29], is chosen. The influence of the lead core diameter (d_l) on the mechanical properties of LRB is analysed for the cases of d_l = 50, 100, 150 and 200 mm. In order to obtain the impact of the number of rubber layers on the mechanical properties of LRB, two types of isolators are examined in the numerical analysis. The first type of isolators is composed of n = 20 layers of t_r = 12 mm thick rubber whereas the second is composed of n = 10 layers of t_r = 24 mm thick rubber. Steel shims 3 mm thick are between the rubber layers. On the top and bottom of the isolator are two steel plates with thickness t_s = 32 mm. All these variants provided eight different models for analysis, systematized in Table 1.

Table 1 Analysed models

Name	Lead core diameter d_l [mm]	Number of rubber layers n	Rubber layer thickness t_r
D50N20	50	20	12
D100N20	100		
D150N20	150		
D200N20	200		
D50N10	50	10	24
D100N10	100		
D150N10	150		
D200N10	200		

3.1. Geometry, material models and finite element mesh

The geometry of the models is developed in accordance to the adopted geometry of the analysed models. The geometry and loads are symmetric in regard to the middle vertical plane, therefore only one half of the isolator is modelled with the aim to decrease the number of finite elements and to rationalize the numerical calculation. Steel mounting plates are not modelled because their influence on the mechanical properties of LRB is negligible. The geometry of the models D150N20 and D150N10 is shown in Fig. 3. The geometry of the other models is similar except for the different lead core diameter.

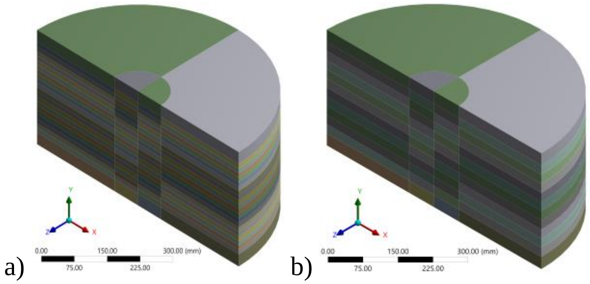

Fig. 3 Geometry of the numerical models: a) D150N20, b) D150N10

Nonlinear characteristics of the steel parts are modelled with the bilinear kinematic material model. The modulus of elasticity of steel is E = 200 GPa and Poisson's ratio is ν = 0.30. Linear elastic behaviour of steel is up to the yield stress f_y = 250 MPa, after which the plastic deformations occur (Fig. 4a). In the plastic regime, the stress is proportional to the strain by the tangent modulus E_t = 1450 MPa. Nonlinear characteristics of the lead are modelled with the bilinear isotropic material model, where the modulus of elasticity is E = 17500 MPa, Poisson's ratio ν = 0.44, and the yield stress is f_y = 10 MPa. In the plastic regime there is no hardening, i.e., the tangent modulus is equal to zero (Fig. 4b). The rubber is a hyperelastic material, modelled by the Neo-Hookean material model with the initial shear modulus μ_0 = 0.40 MPa and an incompressibility parameter d = 0.001 MPa^{-1} defined for the typically assumed bulk modulus of rubber 2000 MPa [30].

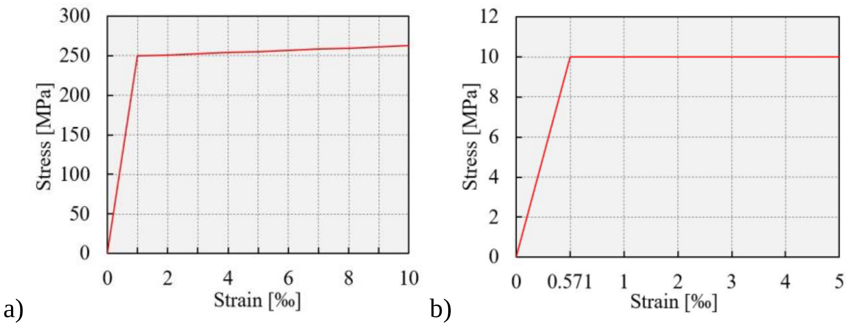

Fig. 4 Stress-strain diagram: a) steel, b) lead

The solid finite element with 20 nodes and three translational degrees of freedom (DOF) per node (SOLID186) is adopted for steel plates, lead core and rubber. This finite element is suitable for modelling the elastoplastic and hyperelastic behaviour of material, as well as for modelling the geometric nonlinearity [31]. For the steel shims the shell finite element with 8 nodes and three translational and three rotational DOF per node (SHELL281) is adopted. This finite element is suitable for modelling steel shims including their material and geometric nonlinear behaviour [31]. The finite element mesh is rotationally symmetric, which corresponds to the symmetry of the geometry. The nodes of the rubber, steel shims and lead core in the zone of contact are merged. Therefore, the interaction of these parts is modelled as discrete, without sliding, friction and separation, which is an idealisation of the problem with the aim of simplifying the numerical models. The finite element mesh density in all analysed models is similar. However, there are differences in the number of finite elements and nodes due to the differences in the geometry. The number of finite elements is in the range of 5664 to 6464 in the models with 20 layers of 12 mm thick rubber, and the number of nodes is in the range of 15314 to 18235. In the models with 10 layers of 24 mm thick rubber the number of finite elements is in the range of 2936 to 3504, and the number of nodes is in the range of 9597 to 10865. The finite element mesh of the models D150N20 and D150N10 is shown in Fig. 5. The finite element mesh of the other models is similar except for the different lead core diameter.

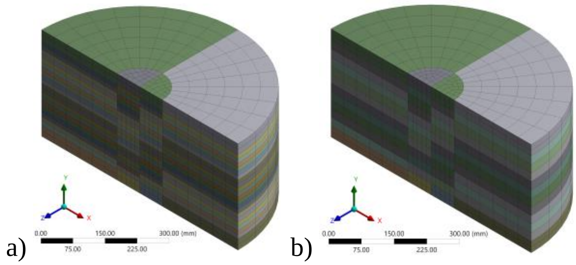

Fig. 5 Finite element mesh: a) D150N20, b) D150N10

3.2. Boundary conditions and loads

The seismic isolation device is placed on a substructure, so all translations of the bottom surface of the isolator are constrained (Fig. 6a). The upper surface of the isolator is connected to the isolated superstructure, so the translation of the surface is allowed, but the rotations are constrained, which is modelled by applying the appropriate boundary conditions (Fig. 6b). Due to the symmetry of the geometry only one half of the isolator was modelled and the influence of the other half is included by defining a symmetry boundary condition on the vertical symmetry plane (Fig. 6c).

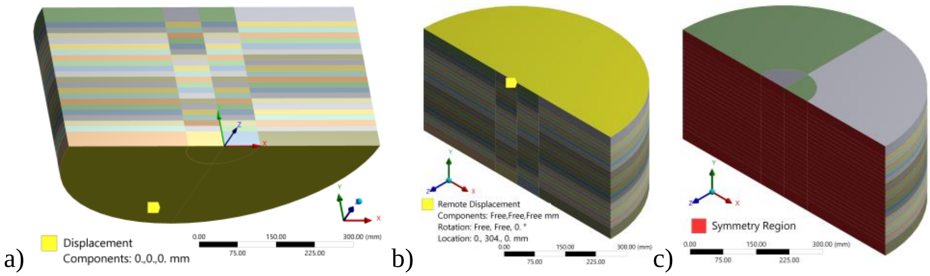

Fig. 6 Boundary conditions: a) support at the lower surface of LRB, b) fixed rotation around z axis at the top surface of LRB, c) symmetry boundary condition

The seismic isolation device is loaded by the gravity load of the isolated superstructure. In the numerical analysis the vertical load was applied as 4 mm displacement of the upper surface of the isolator in the vertical direction (Fig. 7a). The vertical displacement is defined in the first step of the analysis and kept constant in all further steps in which the horizontal load is acting. For the analysed LRB the maximum declared displacement in the horizontal direction is 410 mm [29]. In the numerical analysis of the force-displacement relationship the horizontal displacement is defined in the x direction (Fig. 7b). In the first step of the analysis, when only the vertical displacement is applied, the horizontal displacement is equal to zero, while during the last three steps the full cycle of horizontal displacement with magnitude ±400 mm is applied (Fig. 7c).

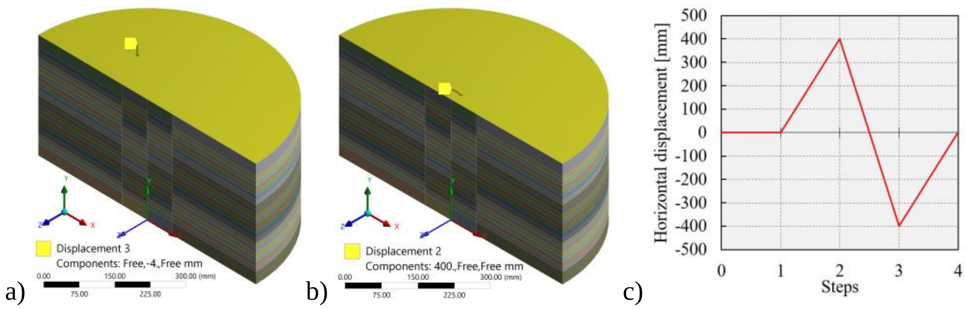

Fig. 7 Loads: a) vertical displacement, b) horizontal displacement, c) rate of horizontal displacement

3.3. Analysis parameters

The numerical analysis includes material and geometric nonlinearity. In order to obtain convergence of the calculation it is necessary to apply load in small increments. Consequently, each analysis step is initially divided into 1600 substeps, while the minimum and maximum number of substeps are 400 and 16000, respectively. Force, displacement and moment convergence criteria are set by the software package. As output results, force-displacement relationship and a von-Mises stress for evaluation of plastification of the lead core are chosen.

3.4. Numerical results

The force-displacement relationship in the horizontal direction, for all analysed models, is shown in Fig. 8. The results are presented as a comparative analysis of the

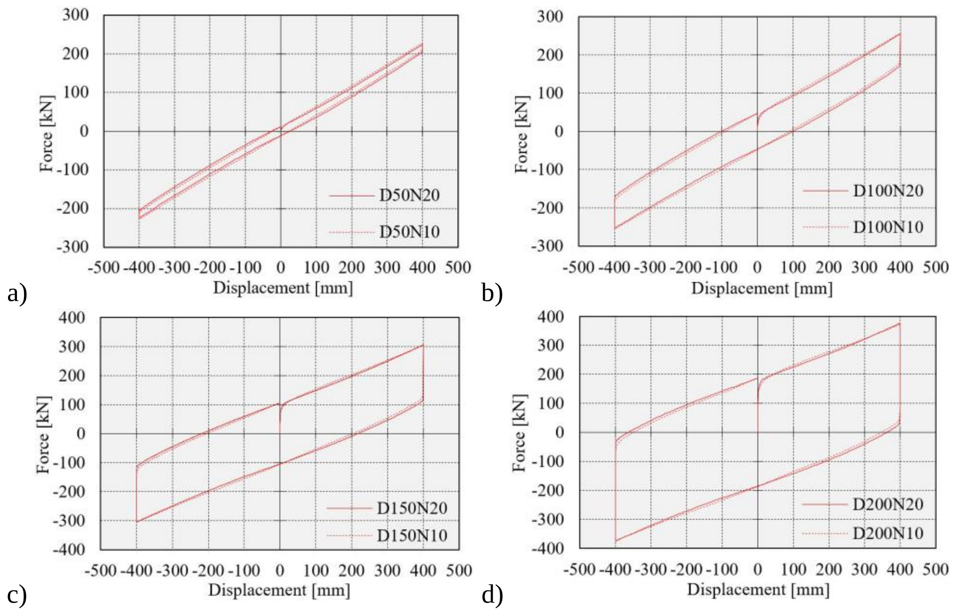

Fig. 8 Force-displacement relationship in horizontal direction: a) D50N20 and D50N10, b) D100N20 and D100N10, c) D150N20 and D150N10, d) D200N20 and D200N10

influence of the number and thickness of rubber layers. It can be concluded that the difference between hysteretic loops, in cases of different number and thickness of rubber layers, is negligible. This result confirms analytical formulas presented in Section 2 from the aspect that the number and thickness of rubber layers and number of steel shims do not influence the mechanical properties in the horizontal direction of LRB.

The area of hysteretic loops as a measure of the dissipated energy is proportional to the diameter of the lead core. Due to the low yield stress of lead, the plastic deformation of the lead core occurs at small horizontal displacement of the isolator, so the lead core is fully plastified under considered cyclic horizontal displacements (Fig. 9).

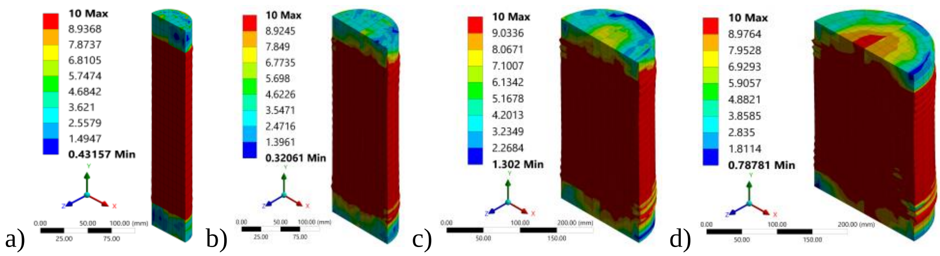

Fig. 9 Von-Mises stress of lead core: a) D50N20, b) D100N20, c) D150N20, d) D200N20

The post-elastic stiffness, the yield force and the equivalent viscose damping ratio are calculated based on the numerical results. The comparative analysis of the numerical and analytical results and the calibration of the analytical models are performed in the next section.

4. Calibration of the Analytical Models

4.1. Post-elastic stiffness

Based on the Eqs. (1), (3) and (4), the post-elastic stiffness is calculated for different cases of the diameter of the lead core of LRB. Results are systematized and compared with the numerical results (see Table 2).

Table 2 The post-elastic stiffness according to the numerical analysis and the existing analytical models

Lead core diameter d_l [mm]	Post-elastic stiffness [kN/m]			
	Numerical analysis	Analytical model, equation (1)	Analytical model, equation (3)	Analytical model, equation (4)
50	550.37	47273.63	589.05	604.76
100	541.46	187534.01	697.04	593.96
150	524.52	421301.32	877.03	575.96
200	505.37	748575.55	1129.01	550.76

From the Table 2, it can be concluded that the existing analytical model based on Eq. (1) overestimates the post-elastic stiffness. Better results are obtained by the analytical model based on Eq. (3), but in the case of a large diameter of the lead core, the post-elastic stiffness starts to increase significantly over the experimentally obtained range [29]. This is a consequence of taking into account the stiffness of the lead core in the existing analytical models. The analytical model based on Eq. (4) gives a better prediction of the post-elastic stiffness than the other two models, since the difference between the analytical and numerical results is around 10 %.

In this paper, a new analytical model is proposed. Namely, as it is stated in Section 3.4, the total plastification of the lead core occurs at relatively small displacements. Therefore, as a result of the analysis, it can be recommended that only the stiffness of the elastomeric part should be accounted for in the post-elastic stiffness of LRB. The stiffness of the lead core should be neglected, since, it does not contribute to the post-elastic stiffness of LRB after the total plastification. This means that the post-elastic stiffness of LRB should be calculated using the following relation:

$$K_y = C_{Ky} \frac{G_r A_r}{H}. \tag{9}$$

The post-elastic stiffness, calculated by the newly proposed Eq. (9), is compared with the obtained numerical results (see Fig. 10). It can be concluded that the proposed analytical model correctly predicts the post-elastic stiffness of LRB for all cases of the lead core diameter since the differences between the analytical and numerical results are less than 7 %. Also, the post-elastic stiffnesses calculated by the proposed Eq. (9) is in a very good correlation to the experimental results given by the manufacturer [29].

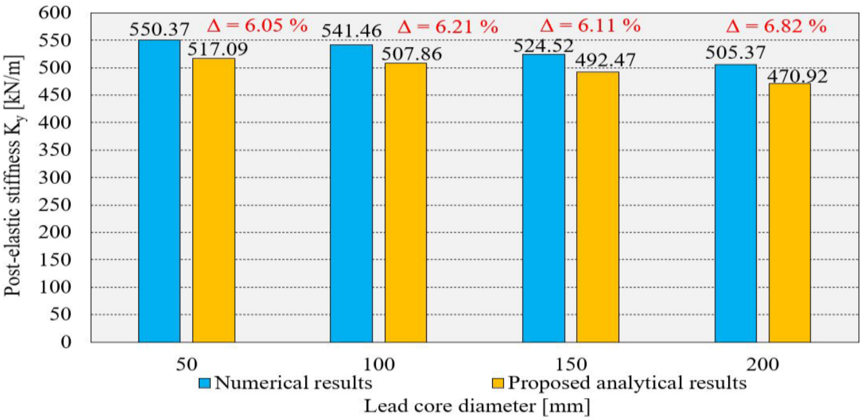

Fig. 10 Comparison of the numerical and proposed analytical results of the post-elastic stiffness

4.2. Yield force

Determining the yield force using Eq. (5) requires defining of the yield shear stress of lead (f_{yl}). This quantity usually cannot be easily defined, so one can use the more available quantity, the yield stress (f_y), which is equal to 10 MPa in the analysed models. In order to determine the yield shear stress, the von Mises or Tresca yield criterion can be applied. According to the von Mises criterion, the yield shear stress is 57.74 % of the yield stress, while according to the Tresca criterion it is 50 % [32]. With such defined values of the yield shear stress, the yield force was calculated for different cases of the diameter of the lead core of LRB. The results are summarized and compared to the numerical results (see Fig. 11). It can be concluded that the von Mises criterion for the definition of the yield shear stress gives the yield force of LRB which is in a good correlation to the numerical results, taking into account that differences between analytical and numerical results are less than 3 %, while using the Tresca criterion these differences are around 15 %.

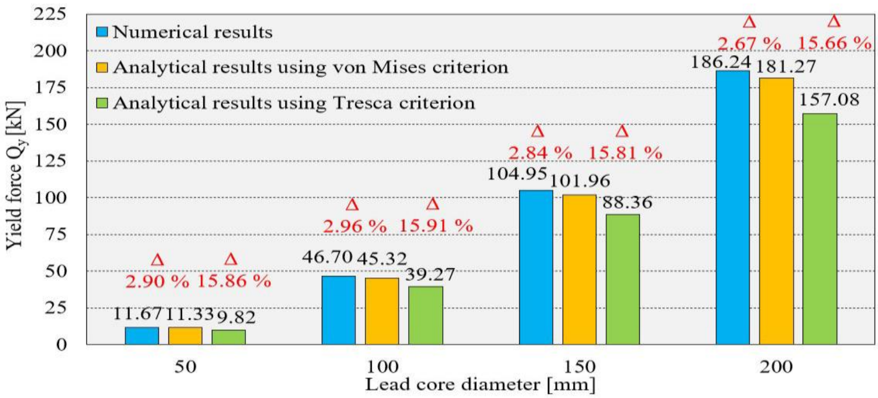

Fig. 11 Comparison of the numerical and proposed analytical results of yield force

4.3. Elastic stiffness

The elastic stiffness of LRB for the dynamic analysis of the isolated structure is defined as the post-elastic stiffness multiplied by the factor β. The equivalent viscose damping ratio of the analysed models with different lead core diameters was calculated based on the numerical results and Eq. (7) (Table 3).

Table 3 Equivalent viscose damping ratio based on the numerical analysis

Lead core diameter d_l [mm]	Equivalent viscose damping ratio ξ_{eq} [%]
50	3.23
100	11.37
150	21.36
200	30.78

From the Eq. (8), it can be concluded that the equivalent viscose damping ratio of LRB depends on the factor β. Calibration of the recommended value of the factor β is conducted based on the numerical results of the equivalent viscose damping ratio. Analytical formula Eq. (8) is used to calculate values of the equivalent viscose damping ratio of LRB for the factor β = 10, 20, 30, 40, 50, 100, ∞, and the results are shown in Fig. 12. It can be concluded that the proposed value of the factor β = 10 gives satisfying values of the equivalent viscose damping ratio for isolators with the lead core diameter up to 100 mm (difference between the numerical and analytical results is less than 2 %). In the cases of the isolators with the lead core diameter 150 mm, the authors suggest to use the value of the factor β = 30, and in the case of the isolators with the lead core diameter 200 mm the value of the factor β = 100, in order to obtain the satisfying results for the equivalent viscose damping ratio. This conclusion comes from the comparative analysis of the analytical and numerical results.

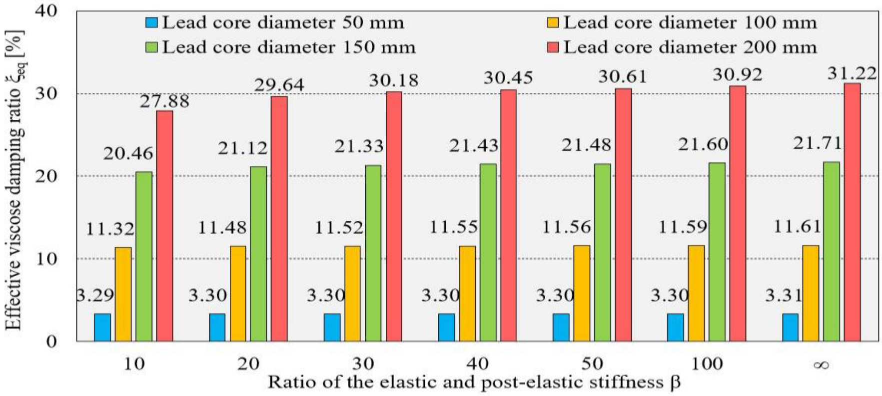

Fig. 12 The equivalent viscose damping ratio for different values of factor β

5. CONCLUSIONS

The existing analytical models for the prediction of mechanical properties in the horizontal direction of the lead-rubber bearings are presented in the paper. Based on the conducted finite element analysis of the adopted LRB isolator, with variation of the lead core diameter, number and thickness of rubber layer and number of steel shims, the calibration of the existing analytical model is performed and corrected analytical model and recommendations are given. With the newly proposed model and recommendations one can obtain a better prediction of the mechanical properties in the horizontal direction of the lead-rubber bearing. Taking into account everything presented in this paper, it can be concluded:

- The number and thickness of the rubber layers, as well as the number of steel shims, have negligible effects on the mechanical properties in the horizontal direction of the lead-rubber bearing, therefore their influence should not be included in the analytical model,
- The existing analytical models overestimate the post-elastic stiffness regarding the numerical results and experimental results given by the manufacturer,
- The post-elastic stiffness should be determined including only the stiffness of the elastomeric part of the isolator in order to obtain satisfying results,
- The value of the yield shear stress of lead is necessary in the calculation of the yield force. According to that, the application of the von Mises criterion is recommended for defining the yield shear stress based on the yield stress of lead rather than the Tresca criterion.
- The elastic stiffness is defined as the product of the post-elastic stiffness and the factor β and it is recommended to use value of 10 for the factor β for lead-rubber bearings with the lead core diameter up to 100 mm, whereas in the cases of the lead core diameter 150 mm and 200 mm, the value of 30 and 100 should be used, respectively.

The aim of this paper is to give a contribution to the more precise determination of mechanical properties in the horizontal direction of lead-rubber bearings. A better prediction of mechanical properties of lead-rubber bearings leads to a more accurate dynamic models for the analysis of response of an isolated structure during earthquakes, which is very important for the contemporary engineering practice.

Further research should be focused on development of a more accurate analytical model for prediction of the lead-rubber bearings elastic stiffness. Furthermore, the development of the numerical models of the lead-rubber bearings with different isolator diameter and comparison of the results with the new proposed analytical model would be useful for the additional validation.

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ANALITIČKA PREDIKCIJA MEHANIČKIH KARAKTERISTIKA U HORIZONTALNOM PRAVCU GUMENOG LEŽIŠTA SA OLOVNIM JEZGROM

Primena uređaja za seizmičku izolaciju je efikasan način za projektovanje seizmički otpornih konstrukcija. Razvijene su različite vrste uređaja za seizmičku izolaciju. Glavne razlike između njih se ogledaju u primenjenim materijalima i načinu na koji obezbeđuju horizontalnu fleksibilnost. Dinamička analiza bazno izolovanih konstrukcija zahteva adekvatan matematički model za opisivanje mehaničkih karakteristika u horizontalnom i vertikalnom pravcu uređaja za seizmičku izolaciju. U radu su analizirani analitički izrazi za predviđanje mehaničkih karakteristika u horizontalnom pravcu gumenog ležišta sa olovnim jezgrom. Rezultati dobijeni analitičkim izrazima su upoređeni sa rezultatima dobijenim na osnovu numeričkog modela metodom konačnih elemenata razvijenog u ovom radu i dostupnim rezultatima ispitivanja proizvođača. Postojeći analitički izrazi su unapređeni kako bi se adekvatnije definisale mehaničke karakteristike u horizontalnom pravcu gumenih ležajeva sa olovnim jezgrom.

Ključne reči: *gumeno ležište sa olovnim jezgrom, elastična krutost, postelastična krutost, karakteristična čvrstoća, ekvivalentno viskozno prigušenje, metod konačnih elemenata*

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Original scientific paper

OPTIMIZATION OF 1ST ORDER OF THE TRAVERSE NETWORK OF BELA PALANKA

UDC 528.06(497.11)

Nenad Ćirić

University of Niš, Faculty of Civil Engineering and Architecture, Niš, Serbia

Abstract. *1st order design optimization results of the geodetic network, developed for the purpose of surveying details in municipality of Bela Palanka are presented in the paper.A preliminary analysis of the accuracy and reliability of the 2D network of Bela Palanka-Varos was performed, and then observations were made on the quality of the network with regard to the results obtained by the optimization procedure.The data were processed in NetExpert 2.0. software.*

Key words: *1st order design, optimization, surveying, 2D network, accuracy,reliability*

1. INTRODUCTION

Cadastre Municipality of Bela Palanka - Varoš is located in the Pirot District, in the municipality of Bela Palanka. Reconnaissance, stabilization and determination of coordinates of a traverse network for the purpose of surveying details was realized.

Based on the measuring performed for the purpose of calculating the coordinates of the points of traverse network a 1st order optimization was carried out.

The idea was to optimize the network, and based on the results determine the quality of the network regarding the position of the network point, i.e. regarding the plan of observations in the network. A similar problem is described in [1].

2. OPTIMIZATION IN DESIGNING OF GEODETIC NETWORKS

Optimization is a science whose goal is to determine the "best" solutions to certain mathematically defined problems, which are often physical reality. "Optimum" = "best", which can mean "maximum" or "minimum" depending on the specific case, and both of

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Corresponding author: Nenad Ćirić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: geosone84bp@yahoo.com

these meanings are mathematically defined [2]. The application of optimization methods is widespread and reaches in almost all areas in which ways of obtaining numerical information have been developed (Science, Engineering, Mathematics, Economics, etc.).

2.1. Classification of the optimization method

Optimization of geodetic network design is classified within different orders (Table 1). The division into orders was performed with respect to the constant and free parameters of the functional and stochastic model, indirect equalization by the method of least squares.

The 0th order design - represents the selection of the optimal coordinate system for the parameters of geodetic networks. When the design matrix and the accuracy of the measured quantities *P* are known, a coffactor matrix of unknown parameters $Q_{\hat{x}}$ or vector of unknown parameters $\hat{x}$ is determined.

The 1st order design - lead to the solution of the optimum design of a geodetic network. For the known accuracy of the planned measuring defined in the form of a difficulty matrix and for the defined accuracy of the unknown parameters $Q_{\hat{x}}$, it is necessary to determine the optimal design, i.e. the optimal measurement plan in the geodetic network *A* (Table 1).

The 2nd order design - leads to the solution of optimal difficulty or accuracy of planned measuring in the network. These data are of great importance for the selection of optimal measurement methods and measuring instruments, because observation of different physical quantities can occur in the network.

The 3rd order design - enables optimal improvement of existing networks in terms of design and accuracy. This most often refers to making the network denser by additional observations or points in parts of the network where the accuracy or reliability is poor.

Table 1 Classification of the optimization method of geodetic networks [3]

Design	Constant parameters	Unknown parameters	Problem solution
0. order	$A\ A$	$\hat{x}$, $Q_{\hat{x}}\hat{x}, Q_{\hat{x}}$	Datum
1. order	P, $Q_{\hat{x}}P, Q_{\hat{x}}$	AA	Design
2. order	A, $Q_{\hat{x}}A, Q_{\hat{x}}$	PP	Accuracy
3. order	$Q_{\hat{x}}Q_{\hat{x}}$	$A, P\ A, P$	Quality improvement

Optimization methods are applied in the design of geodetic networks in order to obtain optimal, i.e. the best solutions for design implementation. The optimal geodetic network has high precision and reliability and is designed in accordance with economic conditions [4].

3. Quality of Geodetic Network

In the design process when optimization methods are applied, it is necessary to define the quality criteria of the geodetic network. The quality of a geodetic network usually means accuracy, reliability, sensitivity, economy or some special quality parameters depending on the purpose of the network. The criteria of accuracy of geodetic networks usually refer to the accuracy of points and functions. Global or local accuracy criteria can be defined. Reliability criteria of geodetic networks usually refer to internal and external reliability. Global or local reliability criteria can be defined. Sensitivity criteria of geodetic networks most often refer to the magnitudes of deformations that can be identified for a particular design of the deformation network and the planned accuracy of measuring [5].

3.1. Apriori analysis of accuracy of geodetic networks

In the process of designing geodetic networks, in order to obtain numerical values for the purpose of determining the apriori accuracy of the network, it is necessary to determine the design of the network and plan measuring in it. After the analysis of accuracy, it is necessary to compare the obtained accuracy with the defined accuracy in the design specification task. If the accuracy obtained from the apriori analysis is identical or better than the accuracy defined by the design specification, then it can be expected that even after the realization of the entire project, the network will be of adequate quality. Otherwise, if the accuracy requirements from the design specification are not met, changes in the network design, planned measurements or their accuracy are necessary.

If the designed network is of homogeneous positional accuracy, but the accuracy obtained from the apriori analysis is lower than the accuracy defined by the design specifications, then it is necessary to increase the accuracy of the planned measurements. The accuracy of planned measurements is increased by a larger number of measurements or better quality instruments and accessories are planned for measurements that are expected to meet the requirements of defined accuracy. If the designed network does not have a homogeneous positional accuracy, then changes in the measurement plan are necessary, usually by adding new measurements or changing the position of a certain number of points.

After the changes have been made in the design phase, it is necessary to repeat the apriori accuracy analysis and the procedure is repeated until the requirements from the design specifications are met. The procedure of the apriori accuracy analysis is described in [6].

3.2. Apriori analysis of geodetic networks reliability

As reliability indicates the possibility of observing gross errors or determining their impact on the estimates of unknown parameters, if no gross errors are observed, then it is very important to determine its reliability in the network design phase.

If poor reliability is obtained after the apriori analysis, then in order to achieve good reliability in the network, it is necessary to add new planned measurements of quantities and thus increase the number of redundant measured quantities. The best effect is achieved by closing the geometric figures in the geodetic network: triangle, quadrilateral or polygon.

After the change in the measurement plan, it is necessary to do the apriori analysis of accuracy and reliability again. The procedure is repeated until the criteria of accuracy and reliability are met. With adequate software, these calculations take only a few seconds of time. The procedure of the apriori analysis of reliability is described in .

4. OPTIMIZATION OF 2D NETWORK OF BELA PALANKA

4.1. Basic characteristics and position of the network of Bela Palanka - Varoš

The traverse network is located in the area of the cadastre Municipality of Bela Palanka - Varoš. In the geometric sense, the network is designed as a system of 10 closed polygons, interconnected into one whole (Fig. 1).

The traverse network is reconnoitered and stabilized according to the following rules:

- Lengths of individual traverses do not exceed 2 km,
- Traverses are such that the angles between the adjacent traverse sides are approximately 180˚,
- Lengths of traverse sides do not exceed 200 m.

Measurements in the traverse network were performed by total stations, which were previously tested and rectified if necessary. Angular measurement in traverse network were performed in both faces twice, independent of the linear measurement. The lengths of all traverse sides were measured with total stations from the both sides, in both faces, with millimeter accuracy.

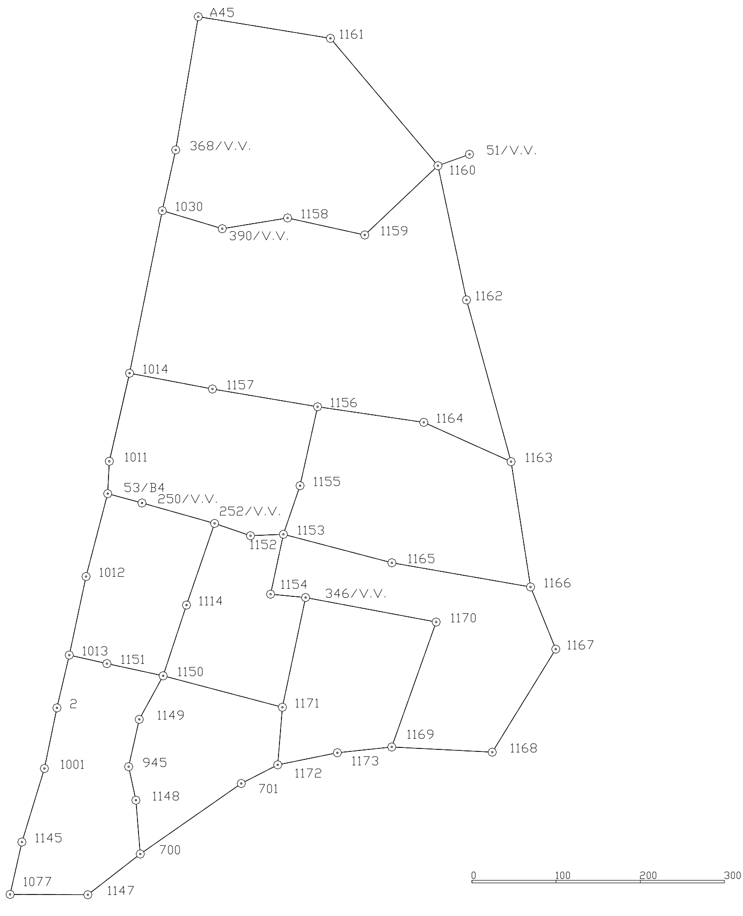

Fig. 1 Sketch of the traverse network of Bela Palanka - Varoš

Coordinates of traverse points were calculated based on the results of measuring horizontal angles (derived from the values of measured directions), the length of traverse sides in the National Coordinate System (obtained on the basis of mean values of measuring lengths back and forth and reduced to projection) and approximate coordinates of points.

4.2. 1st Order Optimization of 2D network of Bela Palanka - Varoš

As already mentioned, within the 1st order design optimization a prior analysis of accuracy and reliability of geodetic network is implemented [8]. It is necessary to determine the optimum design, i.e. optimum measurement plan in the geodetic network , for the known accuracy of the planned measuring defined in the form of the difficulty matrix and for the defined accuracy of unknown parameters $Q_{\hat{x}}$.

After determining the temporary values of coordinates, defining the plan of measured parameters and as well as the accuracy of measuring them in the network, a design matrix and covariant matrix of measured parameters K_l were determined.

Based on the matrix $K_{\hat{x}}$ elements, a complete prior analysis of accuracy of point and functions in a geodetic network was performed.

For the purpose of a prior analysis of a geodetic network, 2D equalization was performed. The data were processed in NetExpert 2.0. software. The network was equalized as free, whereby the total number of points is 48, the number of assigned points 0. In total, there was 171 measured parameters, 58 sides and 113 directions.

The solution was analyzed according to the following criteria:

- The ratio of the major and minor semi-axis of the error ellipse should be in the range of values:

$$1 \leq A/B \leq 2 \tag{1}$$

- Standard deviations of equalized measurements should be within the following range:

$$\sigma_d \leq 5'' \tag{2}$$

$$\sigma_l \leq 5mm + 5ppm \tag{3}$$

- Coefficients of internal and external reliability should be within tabular values, which, for the traverse network, are:

$$0.1 \leq r_{ii} \leq 0.1 \tag{4}$$

- Positional accuracy of traverse points, from the apriori analysis must be consistent with the accuracy defined as the given criterion:

$$\sigma_{pos} \leq 15mm \tag{5}$$

- The accuracy of measured values, unknown parameters, position accuracy of the points and parameters of error ellipses are explained in [6] and [7].

4.3. Optimization results of the network of Bela Palanka - Varoš

Apriori analysis of the accuracy and reliability of point and functions in geodetic network has been carried. Table 2 gives data on the quality of the network of Bela Palanka - Varoš: the estimation of the accuracy of the coordinates of the geodetic network, ratio of semi-axes of the standard error ellipses, the estimation of the accuracy of measured values. The obtained coefficients of internal and external reliability are in the range with the values obtained empirically and which are recommended in designing of geodetic networks.

Table2 Data on the quality of the traverse network Bela Palanka - Varoš

	min	max	average
s(direction)	4,19	5	4,59
s(linear)	3,7	5,7	4,7
s_Y	3,2	7,6	4,8
s_X	3,4	8,1	5,2
s_{pos}	4,8	11,1	7,2
A/B	1,03	1,88	1,29

Figure 2 shows the ellipses of standard errors of the traverse network Bela Palanka -Varoš.

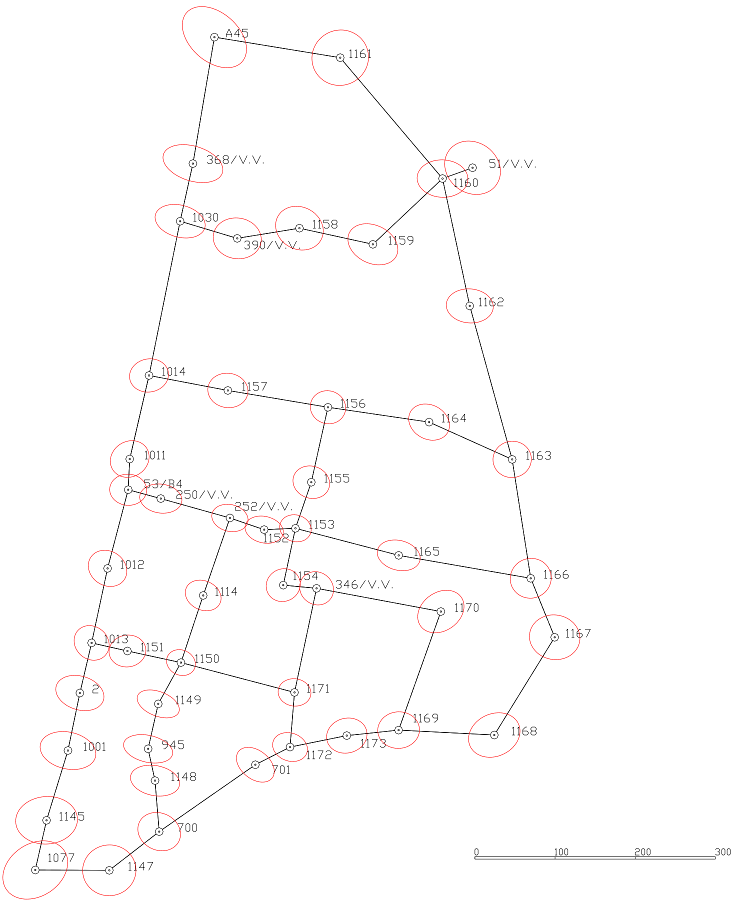

Fig. 2 Standard error ellipses of the network of Bela Palanka - Varoš

4. CONCLUSION

The quality of the existing geodetic network on the territory of the cadastral municipality of Bela Palanka - Varoš was analyzed. Based on the results obtained by the preceding analysis of accuracy and reliability, the following was concluded:

- The network is homogeneous. The ratio of the major and minor semi-axis of the error ellipse is in the defined range of values ($1 \leq A/B \leq 2$).
- The obtained positional accuracy from the preceding analysis of the traverse points agrees with the accuracy which was defined by the design specifications ($\sigma_{pos} \leq 15mm$).
- Standard deviations of measured values are in the defined range ($\sigma_d \leq 5''$ and $\sigma_l \leq 5mm + 5ppm$).
- The obtained coefficients of internal and external reliability are in the range with the values obtained empirically and which are recommended in designing of geodetic networks.

Therefore, by 1st order optimization of the traverse network of Bela Palanka - Varoš, it can be concluded that the network serves its function in terms of the position of points of the geodetic network and measurement plan in it, i.e. that the network has an optimal design.

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OPTIMIZACIJA 1. REDA POLIGONSKE MREŽE BELA PALANKA

U radu su predstavljeni rezultati optimizacije dizajna prvog reda, geodetske mreže razvijene za potrebe snimanja detalja na području opštine Bela Palanka. Urađena je prethodna analiza tačnosti i pouzdanosti 2D mreže Bela Palanka - Varoš a zatim su data zapažanja o kvalitetu mreže s obzirom na rezultate dobijene optimizacionim postupkom.Podaci su obrađeni u programu NetExpert 2.0.

Ključne reči: *dizajn prvog reda, optimizacija, snimanje, 2D mreža, tačnost, pouzdanost*

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Original scientific paper

MODELLING OF PEDESTRIAN-INDUCED LOAD IN SERVICEABILITY LIMIT STATE ANALYSIS OF FOOTBRIDGES

UDC 624.21.042

Marija Spasojević Šurdilović, Srđan Živković, Dragana Turnić, Marko Milošević

Faculty of Civil Engineering and Architecture, University of Niš, Serbia

Abstract. *The last few decades new trends in the design of pedestrian bridges have resulted in lighter and more slender structures. This leads to a reduction in natural frequencies and increased flexibility, and thus a greater possibility for structures to become more exposed to excessive vibrations caused by pedestrians. The lager amplitudes of vibrations occur if the pace frequency of excitation load approaches one of natural frequency of footbridge. The vibration of high proportions may cause pedestrians to feel uncomfortable, sick or unsafe while crossing the bridge. In modern pedestrian bridge design, human-induced vibrations have become an important issue. Footbridge vibrations occur in vertical, lateral and longitudinal direction, and torsion of the bridge deck is also possible. The main types of pedestrian action on the bridge are walking and running, while jumping, bouncing, swaying are considered to be intentional, or sometimes even vandal excitation. Pedestrian-induced loads are difficult to model since pedestrians may have different weight, various number in the groups randomly distributed over the bridge deck. Also, the walking velocity may vary from a pedestrian to a pedestrian. The load models appropriately set up are of great importance for understanding the response of the bridge. Principles of modeling of the human-induced load and some characteristic models of pedestrian loads, described in proposals and codes, are presented in this paper. Some results of Serviceability Limit State analysis, in terms of human-induced vibration, of the pedestrian bridge over the Nišava River in Niš, are also presented.*

Key words: *pedestrian-induced load, footbridge, dynamic load model, serviceability limit state*

Received March 1, 2022 / Accepted September 19, 2022
Corresponding author: Nenad Ćirić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: marija.spasojevic.surdilovic@gaf.ni.ac.rs

1. Introduction

The last few decades technical and technological developments, as well as the new trends in the design of pedestrian bridges resulted in more slender and flexible structures. This leads to a reduction in natural frequencies, and as a consequence, footbridges tend to be more sensitive to pedestrian-induced dynamic loads. The lager amplitudes of vibrations occur if the pace frequency of excitation load approaches one of the structural natural frequencies. The vibration of high proportions may cause pedestrians to feel uncomfortable, sometimes sick, or even unsafe while crossing the bridge, that is highly compromising the vibration serviceability limit state. Therefore, more detailed dynamic analyses have become inevitable in the design of footbridges. For good understanding of the bridge response, the load models have to be appropriately set up. Although pedestrian-induced loads are difficult to model, some of the current Codes and guides for practice are offering guidelines for their selection. Principles of modelling of pedestrian load and some characteristic models from existing literature are presented in addition.

2. Pedestrian-Induced Forces

Pedestrian-induced loads are results of human activities such as walking, running, jumping, bouncing, swaying in horizontal direction, jumping on the spot. Some of these actions are often characterized as intentional or vandal excitations.

Pedestrian-induced loading due to walking is a periodic excitation that depends on the pace frequency and body weight. The frequency range for loading due to walking is roughly between 1.5 and 2.5Hz, and for running above 2.5Hz. The force has three components: vertical, lateral and longitudinal. The vertical one is about 40% of body weight. While walking, the body weight changes position by shifting from one foot to the other. Load curves for each foot overlap (Figure 1).

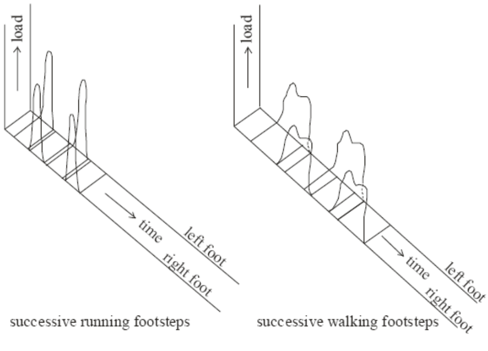


Fig. 1 Changes of the force due to a) running; b) walking [1]

2.1. Vertical component

Normal walking induces a vertical force of a double hump shape. The curve has two force maximums, where the first one comes from the heel impact, and the second one is due to push off. The ground reaction is shown on (Figure 2).

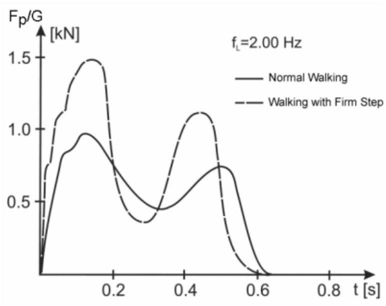


Fig. 2 Vertical ground reaction forces: normal walking and walking with firm step [2]

2.2. Transverse and longitudinal components

The frequency of the transverse component of the force induced by walking is half the vertical component and is about 1 Hz. This force is caused by the lateral body oscillation. The longitudinal component has the same magnitude as the lateral one. The main characteristic of the longitudinal force is the retarding and pushing walking period. Their pattern is shown on Figure 3.

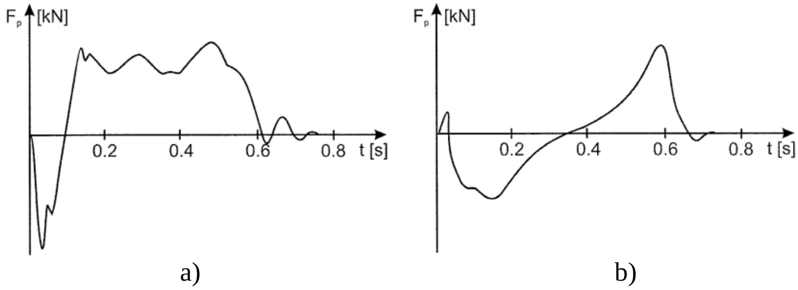


Fig. 3 Ground reaction forces from walking: a) lateral; b) longitudinal [3]

3. PEDESTRIAN-INDUCED FORCES

It is difficult to mathematically represent the dynamic force induced by a single pedestrian since it is essentially a narrow-band phenomenon that is poorly understood [4]. Modelling of the walking load is more complex than modelling of the running one. Yet, walking is a more common activity on footbridges, and only the basis of modelling of time domain load induced by walking will be given below.

3.1. Vertical load model

Due to periodic nature of the pedestrian-induced force, this load can be divided into a set of sinusoidal oscillations by using the Fourier transformation:

$$F(t) = F_0 + \sum_{i=1}^{n} F_i \cdot \sin(2\pi \cdot i \cdot f_s \cdot t - \varphi_i) \qquad (1)$$

where:

F_0 is mean or static load

F_i is load component for frequency $i \cdot f_s$

f_s is step frequency

φ_i is phase angle of load component F_i

The number of harmonics that have to be considered depends on their amplitude and their dynamic influence. Usually, the first three harmonics are taken into account. The ratio of the force amplitude to the person's weight that is the static load, is defined as the dynamic load factor. The loading coefficients according to different authors are given in Table 1.

Table 1 Recommended dynamic load factors (DLF) for vertical loads

DLF	$F_{1,v} / F_0$	$F_{2,v} / F_0$	$F_{3,v} / F_0$
Bachmann [2]	0,4 for f_s = 2 Hz 0,5 for f_s = 2,4 Hz	0.1	0.1
Kerr [5]	Freq. dependent	0.07	0.06
Young [6]	$0.37(f_s-0.95)\leq 0.5$	$0.054+0.0044\,f_s$	$0.026+0.0050\,f_s$

Taking into account the first three harmonics, Bachmann [2] described the vertical load as:

$$F_v = F_0 + F_{1,v} \cdot \sin(2\pi \cdot f_s \cdot t) + F_{2,v} \cdot \sin(4\pi \cdot f_s \cdot t - \varphi_2) + F_{3,v} \cdot \sin(6\pi \cdot f_s \cdot t - \varphi_3) \qquad (2)$$

where:

F_0 is dead load of the pedestrian (800 N)

F_i is participation of the i-th harmonic to the resulting load

f_s is step frequency

φ_i is phase angle of the i-th harmonic ($\varphi_2 = \varphi_3 = \pi/2$)

3.2. Horizontal load model

Horizontal load can also be represented by the Fourier transformation. The frequency of the lateral load is half of the vertical load. Considering the first 3 harmonics of the Fourier coefficients the lateral force is:

$$F_h = F_{1,h} \cdot \sin\left(2\pi \cdot \frac{f_s}{2} \cdot t\right) + F_{2,h} \cdot \sin\left(4\pi \cdot \frac{f_s}{2} \cdot t - \varphi_2\right) + F_{3,h} \cdot \sin\left(6\pi \cdot \frac{f_s}{2} \cdot t - \varphi_3\right) \qquad (3)$$

where:

$F_{i,h}$ is participation of the i-th harmonic to the resulting load

f_s is step frequency

φ_i is phase angle of the i-th harmonic ($\varphi_2 = \varphi_3 = \pi/2$)

Table 2 Recommended dynamic load factors (DLF) for lateral loads

DLF	$F_{1,h} / F_0$	$F_{2,h} / F_0$	$F_{3,h} / F_0$
Sétra [7]	0.05	0.01	0.05
Bachmann et al. [8]	0.1 for f_s=2 Hz	/	0.1

Running or walking, load induced by pedestrians has been extensively studied and is expressed as a point force exerted to the support, as a function of time and pedestrian position. The load of a pedestrian moving at constant speed v can be described as the product of a time component $F(t)$ by a space component $\delta(x - vt)$, δ being the Dirac operator and x being the pedestrian position in relation to the footbridge centerline [7], that is:

$$P(x,t) = F(t)\delta\,(x - vt) \tag{4}$$

4. Load Models in Codes and Guides for Practice

Even after twenty years of intensive study in the area of human-induced vibration, there are still no sufficiently reliable load and response models to evaluate the vibration serviceability of footbridges under the human-induced excitation, particularly in view of crowded conditions [9]. The dynamic phenomenon of footbridge behavior under the human-induced load is yet not well understood. That is why many codes and standards differ in their approach to this topic. Some proposal and recommendations for dynamic load models are given in ISO 10137:2007 [10], Australian Standard AS 5100.2-2004 [11], British Standard BS 5400 [12], Ontario Highway Bridge Design Code OHBDC ONT 83 [13], UK National Annex to EN 1991-2:2003 [14], Guidelines for the design of footbridges FIB [15], Design of Lightweight Footbridges for Human-Induced Vibration-JRC Scientific and Technical Reports [16], Footbridges-Assessment of vibrational behavior of footbridges under pedestrian loading SETRA [7] etc.

4.1. Eurocode

Eurocode is a set of building codes developed by the European Committee for Standardization. There are three parts of Eurocode dealing with human-induced loads and structural requirements. Comfort criteria, defined in terms of maximum acceptable acceleration, are given in EN 1990:2002 "Basis of structural design" [17] while EN 1991-2:2003 "Action on structures" [18], instead of giving dynamic loads which should be applied, proposes that complementary load models, with associated combination rules, may have to be defined for the individual project. According to Eurocode, National Annexes are supposed to propose appropriate load models for dynamic analysis of footbridges. Performance criteria are contained in EN 1993-2:2006 "Design of steel structures" [19].

4.2. ISO 10137:2007

According to ISO 10137:2007 [10] dynamic pedestrian action on footbridges can be described as:

- *Single pedestrian dynamic action*

The dynamic force $F(t)$ induced by a person of weight, Q, doing repeated, coordinated activities can be expressed as a function of time t by a series of pulses:

$$F_v(t) = Q\left(1 + \sum_{n=1}^{k} \alpha_{n,v} \sin\left(2\pi n f t + \phi_{n,v}\right)\right) \text{ in vertical direction} \tag{5}$$

and

$$F_h(t) = Q\left(1 + \sum_{n=1}^{k} \alpha_{n,h} \sin(2\pi nft + \phi_{n,h})\right) \text{ in horozontal direction} \tag{6}$$

where: $\alpha_{n,\mathrm{v}}$ and $\alpha_{n,\mathrm{v}}$ are numerical coefficients corresponding to the n_{th} harmonic for vertical and horizontal direction, respectively; Q is the static load of the participating person; f is the frequency component of repetitive loading and f is half the activity rate in the case of walking or running for determining transverse horizontal vibrations; $\phi_{n,\mathrm{v}}$ and $\phi_{n,\mathrm{h}}$ are the phase angles of the n_{th} harmonic, for vertical and horizontal direction, respectively; n is the integer designating harmonics of the fundamental; k is the number of harmonics that characterize the forcing function in the frequency range of interest. The number of harmonics k required to effectively model the time history of the load will vary depending on how complex it is.

- *Dynamic action of groups of participants*

The main factors that determine the dynamic action induced by groups of participants are the weight of the participants, the maximum number of people per unit floor area that can be accommodated for the pedestrian activity, and the level of participant coordination. Considering that there is some variation in the frequency f, the phase angle ϕ_n, and the numerical coefficient α_n in a group of people representing general population, the dynamic response of the structure will be less than it would be in a group with perfect coordination. This reduced response of the structure can be approximately described by applying a coordination factor $C(N)$ to the forcing function:

$$F(t)_N = F(t) \cdot C(N) \tag{7}$$

where N is the number of participants.

4.3. Guidelines for the design of footbridges FIB

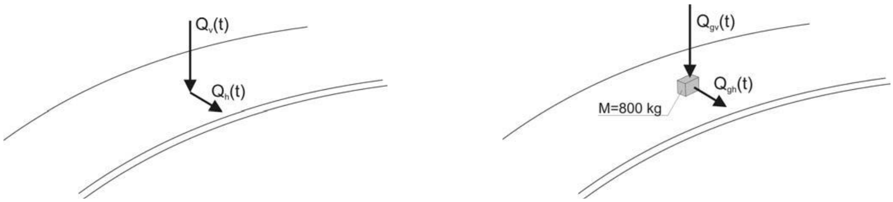
Even it has not ever been officially approved, Proposal Annex C to EN 1991-2:2003 "Action on structures" [20,21] proposed three dynamic load models that were subsequently recommended by guidance for footbridge design of Féderation internationalle du béton (FIB) [15]. Those models are:

- *Single pedestrian dynamic load model*

The dynamic load model of a single pedestrian (Fig.4a), also contained in British Standard BS 5400, Part 2 [12] is limited to the first harmonic of the force F(t). It consists of a pulsating stationary force with two components. That considers the effect of pedestrian weighing 700 N and moving with speed equal [m/s] to 0.9 times the walking frequency f_s, considering the first harmonic of the reaction force and dynamic factor for vertical direction according to Blanchard [22].

vertical component: $Q_{pv} = 180 \cdot \sin(2\pi \cdot f_v \cdot t)$ [N] (8)

lateral component: $Q_{ph} = 70 \cdot \sin(2\pi \cdot f_h \cdot t)$ [N] (9) where f_v is the natural vertical frequency of the bridge that is the closest to 2 Hz, and f_h is the natural horizontal frequency of the bridge that is the closest to 1 Hz.



a) b)

Fig. 4 Dynamic load model: a) single pedestrian; b) group of pedestrians [15]

- *Group of pedestrians dynamic load model*

The dynamic load model of a group of pedestrians (Fig. 4b) has a stochastic approach and describes the effect of a group (8-15 persons) of unsorted walking persons. The synchronisation of a frequencies and phases is taken into account by the coefficient k_v and k_h. This pulsating stationary force has two parts:

$$\text{vertical component: } Q_{gv} = 180 \cdot k_v(f_v) \cdot \sin(2\pi \cdot f_v \cdot t) \text{ [N]} \tag{10}$$

$$\text{lateral component: } Q_{gh} = 70 \cdot k_h(f_h) \cdot \sin(2\pi \cdot f_h \cdot t) \text{ [N]} \tag{11}$$

where f_v is the natural vertical frequency of the bridge that is the closest to 2 Hz, f_h is the natural horizontal frequency of the bridge that is the closest to 1.5 Hz, and k_v i k_h are synchronisation factors.

- *Dynamic load model of continuous stream of pedestrians*

The dynamic load model for a continuous stream of pedestrians considers the excitation forces due to a continuous stream of pedestrians with a density of 0.6 pers/m^2 and has to be used separately from the dynamic load model of a pedestrian group. This load is applied as a uniformly distributing two component pulsating area load. The total number of pedestrians is N=0.6BL, where B is the effective bridge width and L is the bridge length.

$$\text{vertical component: } q_{s,v} = 12{,}6 \cdot k_v(f_v) \cdot \sin(2\pi \cdot f_v \cdot t) \text{ [N/m}^2\text{]} \tag{12}$$

$$\text{lateral component: } q_{s,h} = 3{,}2 \cdot k_h(f_h) \cdot \sin(2\pi \cdot f_h \cdot t) \text{ [N/m}^2\text{]} \tag{13}$$

where f_v is the natural vertical frequency of the bridge that is the closest to 2 Hz, f_h is the natural horizontal frequency of the bridge that is the closest to 1.5 Hz and k_v and k_h are synchronization factors.

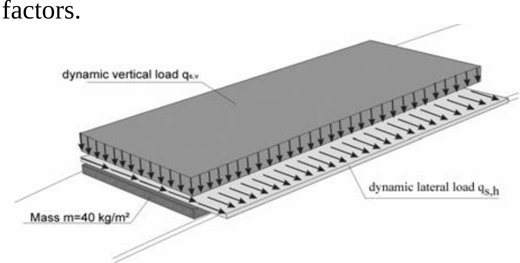


Fig. 5 Dynamic load model of a continuous stream of pedestrians [15]

5. APPLICATION EXAMPLE -VIBRATION ANALYSIS OF THE PEDESTRIAN BRIDGE OVER THE NIŠAVA RIVER IN NIŠ

5.1. Structural information

The pedestrian bridge over the Nišava River in Niš (Fig.6, 7) is a cable-stayed bridge that has been opened in 2003. The total footbridge lenght is 78 meters. The bridge has two spans 14.00 + 56.00 = 70.00 meters. The bridge consists of a composite deck (steel-concrete), steel pylon 20.443 meters high, and stay cables SPB SUPER. The bridge is supported on three different places: at each end and at the pylon (see [23], [24] for more structural information).

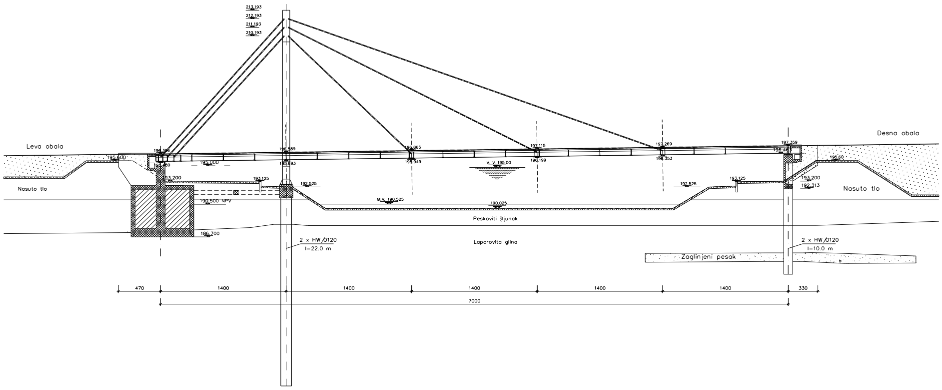
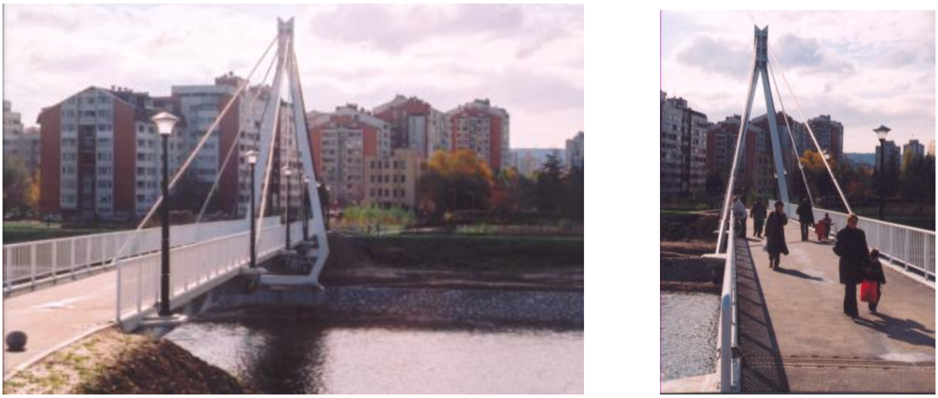


Fig. 6 Layout of the bridge

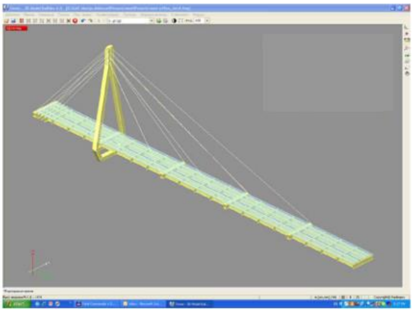


a) bridge view from the right river bank b) traffic on the bridge

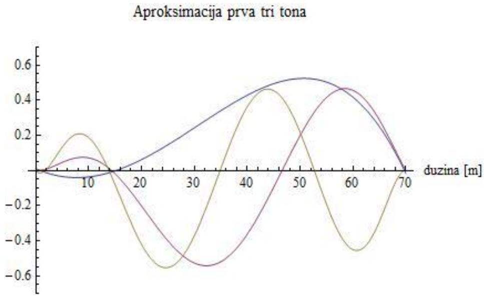
Fig. 7 Pedestrian bridge over the Nišava River in Niš

5.1. Vibration analysis

Vibration analysis is performed according to the solutions, algorithms and Wolfram Mathematica® programmes, developed within research in thesis [24]. In addition, some results of footbridge resonant vertical vibration due to single pedestrian excitation are presented.



a)



b)

Fig. 8 a) FE Model of the bridge superstructure; b) approximation of first three vertical modes shapes

Eurocode 1990:2002 proposes to check vertical vibrations in the case that at least one of the Natural Frequencies lies below 5 Hz. The frequency that is the most nearby to 2 Hz should be considered for the analysis.

Table 3 Natural Frequencies of the bridge superstructure

Natural Frequency	Mode shape 1	2	3	4	5	Direction
f_y [Hz]	1.396	3.32	5.77	9.15	11.68	vertical
f_z [Hz]	3.40	7.06	10.93	19.23	26.04	transversal
f_x [Hz]	10.92	13.77	32.05	33.11	37.31	longitudinal

The damping ratio ζ is an important input parameter for the bridges and this value can only be estimated. For composite bridges, Eurocode proposes using a logarithmic decrement (δ) of 0.04 for steel and concrete composite structures, which represents a damping ratio ($\zeta=\delta/(2\pi)$) of 0.006. The dynamic single walking pedestrian force is modelled as the moving harmonic concentrated load [24].

Figure 9 shows a three-dimensional simulation of bridge response (acceleration along the span of the bridge), in the case of vertical damped vibrations, induced by the force $P(t)= 0.18\sin(2\pi f_0 t)$, representing a moving pedestrian. Analyzing the output for resonant vibrations, when the pace frequency f_p is equal to the vertical natural frequency of the bridge f_0=1.396 Hz (Table 3), and the pedestrian velocity is $c = 0.9f_p = 1.2564$ m/s, it was concluded that the maximum acceleration occurs at the section $x = 52$ m, and at the time $t = 50$ s, when the force position is $x = c \cdot t = 62.82$ m. The maximum acceleration is 0.121 m/s^2.

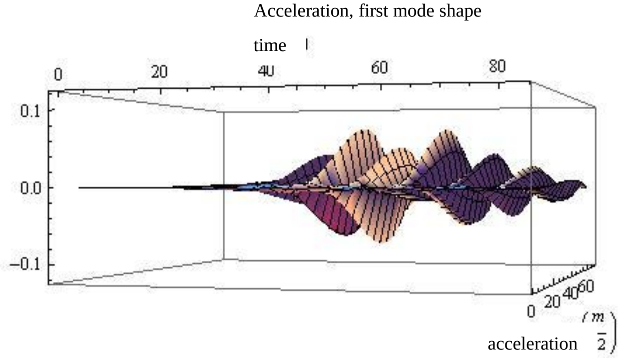
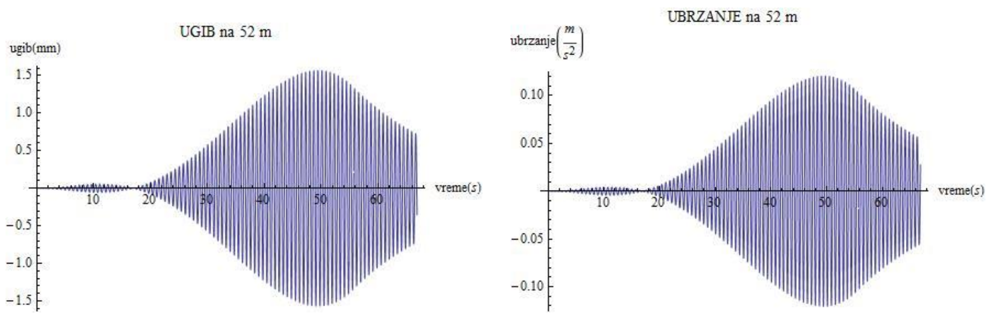


Fig. 9 Mathematical simulation of the bridge response due to a single pedestrian moving excitation force P(t)=0.18sin(2πf$_0$t)

Figures 10 a) and 10 b) show the time-histories of deflection and acceleration in the critical section x=52 m, for the case of vertical vibrations due to the same action as in the previous case. The maximum deflection is 1.58 mm and the acceleration is 0.121 m/s^2.



a) deflection b) acceleration

Fig. 10 Time-history due to a single pedestrian moving excitation force $P(t) = 0.18\sin(2\pi f_0 t)$: a) deflection; b) acceleration.

Comparing the obtained results of dynamic analysis, it was concluded that the response of the bridge for single pedestrian load in terms of acceleration stays within the limits recommended in relevant Code of practice as EN 1990:2002 ($a_{\lim} < 0.7$ m/s^2) [14].

6. CONCLUSION

New trends in footbridge design, mainly arising from demanding aesthetic criteria and possibility of using modern construction materials, have led to more slender and flexible structures. As a consequence, lightweight pedestrian bridges are more prone to vibrate with amplitudes of high proportions, and that way cause pedestrians to feel uncomfortable.

Therefore, the dynamic analysis of footbridges has become inevitable, and load model determination is necessary for its implementation. The basis of modelling of time domain pedestrian loads using the Fourier transformation and their use in Codes are presented. It should be emphasized that the extensive research on this topic is still ongoing in order to improve the existing dynamic load models and to propose more reliable and accurate ones. Some of presented results of the dynamic analysis in terms of serviceability of the pedestrian bridge over the Nišava River in Niš, have shown that the bridge response stayed within limits recommended by EN 1990:2002.

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MODELIRANJE PEŠAČKOG OPTEREĆENJA U ANALIZI GRANIČNOG STANJA UPOTREBLJIVOSTI PEŠAČKIH MOSTOVA

Novi trendovi u projektovanju pešačkih mostova, koji uglavnom proizilaze iz zahtevnih estetskih kriterijuma i mogućnosti korišćenja savremenih građevinskih materijala, doveli su do vitkih i fleksibilnijih konstrukcija. Kao posledica toga, lagani pešački mostovi su skloniji da vibriranju sa amplitudama velikih proporcija i na taj način izazivaju nelagodnost kod pešaka. S toga je dinamička analiza pešačkih mostova postala neizbežna, a određivanje modela opterećenja je neophodno za njeno sprovođenje. U radu su date osnove modeliranja vremenski zavisnog opterećenja pešaka korišćenjem Furijeove transformacije i prikazana je njihova upotreba u važećoj regulativi. Treba naglasiti da je opsežno istraživanje na ovu temu još uvek u toku, kako bi se poboljšali postojeći i predložili pouzdaniji modeli dinamičkog opterećenja. Prikazan je i deo analize graničnog stanja upotrebljivosti pešačkog mosta preko Nišave u Nišu. Pokazano je da je odziv konstrukcije za opterećenje izazvano kretanjem pešaka u granicama preporučenim važećom regulativom.

Ključne reči: *opterećenje indukovano pešacima, pešački most, dinamički model opterećenja, granično stanje upotrebljivosti*

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Original scientific paper

TENSILE MEMBRANE STRUCTURES AT WORLD FAIRS

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Nemanja Ranđelović

Faculty of Civil Engineering and Architecture, University of Niš, Serbia

Abstract. *World Fairs provide the opportunity for all nations to show their achievements to the rest of the world. In addition to state of the art developments in science, technology and culture, Expos also became the showcase for architecture. The history of application of tensile membrane structures at Expos started in 1958 in Brussels and continues until today. This paper researches the progress of tensile membranes through the structures built for World Fairs.*

Key words: *tensile membrane structures, world fair, expo, lightweight structures, tension structures*

1. WORLD FAIRS

The history of World Fairs started in 1851. Although not intended as an architectural showcase, the Expos became one of the most important architectural events in the world. Some of the most significant architectural landmarks such as the Eiffel's Tower, Atomium, and Habitat 67 were built for the World Fairs.

First world exhibition happened under the big influence of industrial revolution. However, after the second world war, the idea of the technological revolution has totally changed, first of all because of using technological achievements in a destructive way without the social and political responsibility. World exhibitions are becoming events that promote progress of human kind and multi-cultural dialogue as well as current topics of that time. Some of them are “Progress and Mankind” 1958, in Brussels, “Man in the Space Age” in Seattle 1962, “Man and His World” Montreal 1967. From the beginning of the 21st century Expo started promoting the sustainable development and its importance for the mankind. Despite the promotion of current topics, Expo has always provided architects with the opportunity to showcase their new ideas and use this big event as a creative laboratory for testing their innovations in design and technology of building.

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Corresponding author: Nemanja Ranđelović
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: nemanjarandjelovic@gmail.com

Fig. 1 The famous object made of membrane structure at World Fairs

The research that was conducted and partially presented in this paper revealed that tensile membrane structures had an important role at World Fairs. Their being one of the newest structural types, makes it possible to follow their progress and improvements through the structures built for Expos. As membranes evolved some of their properties became superior to other structural types and they became one of the leading structures at Expos. This is especially notable in the past decade, where some of the dominant structures at World Fairs were built as tensile membranes. This paper shows only a few selected membrane structures built at World Fairs and discusses their progress over the years (Fig. 1).

2. Tensile Membrane Structures

Tensile membrane structures emerged as the successor of traditional tents. Characterized by their light weight and tension they became popular mostly due to the attractive double curved form they attain. Membrane material is extremely thin, about 1 mm, and has a decisive role in defining the structural behavior [10,11]. Fast erection and inexpensive transport reduce the total construction price, while complex production and unique design process impede a more frequent use of membrane structures.

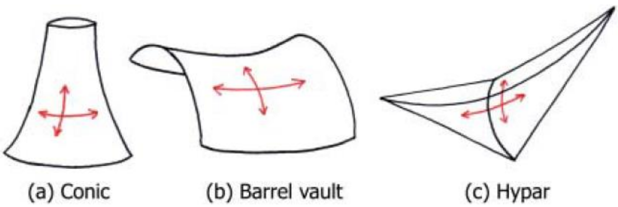

Fig. 2 Shapes for double curvature[10]

The regulations on designing tensile membranes in Europe are still not complete. Currently, there is a Design Guide [8] and a Prospect for European Guidance [9], while the Eurocode for Designing Tensile Membrane Structures is expected to be published in the next few years. Wind and snow loads combined with the membrane prestress are dominant actions on membrane structures, although recent researches also showed the importance of point load actions [13,14]. Up to date, thermal properties remain the critical issue of the membrane structures [15,16] which are therefore best used for covering of open spaces. In cases where space needs to be enclosed, multi-layer membrane of air-cushion structures are preferably used. Some of the membrane properties will be highlighted in the following analyzed examples.

3. Connection between Tensile Membranes and World Exhibitions

The relation between the tensile membranes and Expos starts in 1958 when a minor and relatively insignificant membrane was used to cover a stage. Only a few years later in Lausanne membranes got a much more prominent role. In 1967 at Montreal Expo, one of the most famous membrane structures was erected. At Osaka Expo several attractive membranes were designed and erected. For the recent Expos in Shanghai, Milan and Dubai some extraordinarily big tensile membrane structures were built.

3.1. Bruxelles

First world exhibition after world war was held in Brussels 1958. In addition to the great importance for global community and reuniting the world, Expo 58 has its big importance because of membrane constructions. Even though in the first plan of this exhibition we have imposing constructions such as Atomium, US Pavilion, USSR Pavilion, Philips's Pavilion, one small podium covered by membrane construction represents the beginning of a new era in history of pavilion architecture.

This podium was projected by architect Oger Schomblood and engineer André Paduart. Although several important cable net structures were erected at the World Fair in Brussels, the bandstand appears to be the only double-curvature cable-and-textile structure built for the event. The bandstand (Fig. 3) had a rounded wedge plan form (13.91 m long, 15.04 m wide) and consisted of an anticlastic cable net tensioned between an inclined mast at the

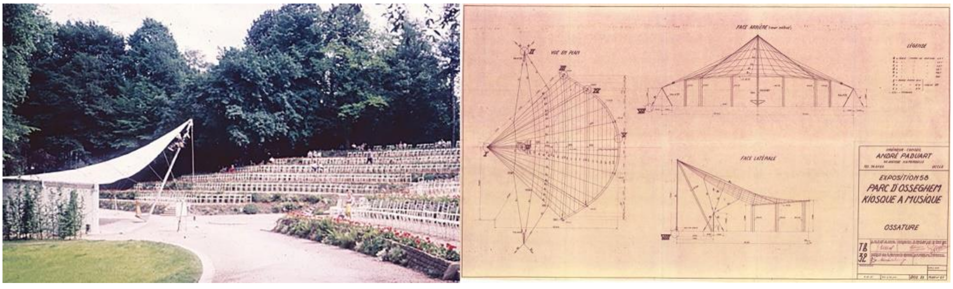

Fig. 3 The bandstand at Expo 58 and plan of the steel members for the bandstand by Paduart, Dec 1958 [1]

front, 7.50 m high, and a curved wall with varying height (2.82–3.22 m) at the back [1]. Although this was the first membrane covered structure, because of its small dimensions it was not as attractive at the exhibition as its successor. In this example, the membrane has a secondary role where it accepts the external loads and transmits them to the primary load bearing cable net.

3.2. Lausanne 1964

World exhibition 1964. (Expo 64) was held in Lausanne, precisely in Vidi on the coast of Geneve lake. For the duration of Expo 64 the visitors could see a big number of technological achievements, some of them are the “Spiral” tower, the Mésoscaphe Auguste Pisccard, symphony of exchanges.

In architecture, this exhibition we remember because of the idea of Marc Saugev, Swiss architect. He used large multi-coloured tents to imitate Alps, their snow and rock. After creating the basic shape of the structure and initial plans, Frei Otto has joined the project and his task was to define the definitive geometry and solve structural problems.

In proximity of a small harbor 24 pavilions were set up with their sides touching and overlapping. A huge number of pavilions were basically simple saddle-shape with four points of support, but with a large diagonal span of 36 m between the lowest and highest point. The biggest challenge but also an attraction was the pavilion intended for a restaurant in the north eastern part of the port. This pavilion was formed by multiplying three large saddle tents supported in 4 points, each of which had 2 smaller saddle-shaped tents with supports in 3 points. In perfect harmony with angled slim lattice masts, the elegant architectural look has been achieved (Fig. 4).

Fig. 4 Exhibition Pavilions in Lausanne 1964.[2]

Structurally the pavilions are not at all usual membrane structures but prestressed equally meshed steel cable net structures, covered with cotton fabric as a weather skin. The cables of the net are disguised in lipped PVC-pouches which continuously are sewn on the fabric. All main stresses are taken by the cable net whose deformation under load is much smaller than for the fabric [3]. Once again, like in Brussells, this is not a typical membrane structure, but rather a combination with the cable net. Nevertheless, some advances are still present. Most notably, the span of the structure was doubled. This allowed for the creation of more impressive structures. In addition to this the multiplication of structures with some variations of each one led to showing what architecture can achieve with light, playful membrane construction even though pavilion looks are repeating themselves.

3.3. Montreal 1967

World exhibition in Montreal 1967 has been considered as one of the most successful exhibitions in XX century. Big number of countries participants had its very own pavilion designs. Among these pavilions are the Montreal Biosphere designed by Buckminster Fuller, the modular Habitat 67 housing complex designed by Moshe Safdi and the pavilion of the Federal Republic of Germany designed by Frei Otto (Fig. 5).

In collaboration with architect Rolf Gutbrod, Frei Otto designed the exhibition pavilion of the Federal Republic of Germany, a tent structure representing his experiments, in the field of lightweight membrane construction, to an international audience at the time.

The pavilion was located in the eastern part of the island of Ile de Notre-Dame and covered almost 8000 m^2. The entire area was covered by a single membrane of irregular plan and varying heights. Its contours were determined by the high points of the masts and low points where the membrane was drawn, funnel-like, down to the ground. Eye loops filled with clear plastic material accentuated these points and the saddle surface they created. The prestressed membrane consisted of a translucent skin hung from a steel wire net, which, by eye, ridge, and edge ropes, was connected with the mast heads and anchor blocks. Membrane construction was relying on 8 masts, height from 14 to 38 meters, while the maximum span was from 105 to 130.

Fig. 5 German Pavilion in Montreal 1967. [www.archdaily.com,www.arch.mcgill.ca]

Compared to the previous two examples, this membrane is even bigger in size. However, more importantly the membrane is here separated and distanced from the cable net. This was a very important step towards implementing exclusively membranes as both supporting and covering element. The German Pavilion is a technologically sophisticated, conceptually simple solution that, with its elegant irregular shape, arouses the admiration of observers who were in post-war modernism. As well as the first building of this size in the architecture of light constructions.

3.4. Osaka 1970

There are various aspects of Expo ’70 in Osaka that should be highlighted in terms of the historical development of membrane structures whose stability is based on pneumatic principles. In the first place, emphasis should be placed on the individual value of certain pavilions, both due to the structural-typological innovation they reflect and the large spans they achieved. Two pavilions stand out in this sense; the U.S. Pavilion and the Fuji Group Pavilion.

The U.S. Pavilion was made up of a low-pressure pneumatic vault reinforced with cables covering a space with a super-elliptical shape of exponent 2.5 measuring 83.5 x 142 m (Fig. 6). The low-profile vault was only raised 6.5 m above the ground and was encircled by a reinforced concrete compression ring, while the exhibition space remained half-buried. The super-elliptical shape was chosen for aesthetic reasons.

Fig. 6 U.S. Pavilion in Osaka 1970. [www.davisbrodybond.com]

When dealing with the pneumatic pavilions in Expo ’70 in Osaka that had acquired an individual value both in terms of structural innovation and size, reference has to be made to the Fuji Group Pavilion. Created by the engineer Mamoru Kawaguchi and the architect Yutaka Murata, it was the largest high-pressure pneumatic structure ever built, as well as displaying a brilliant design of organic inspiration (Fig. 7). The structure was made up of 16 tubes 72 m long and with a diameter of 4 m filled with pressurised air. The tubes arched and were inter-connected by 50-cm-wide strips placed every 4 metres. The plan of the tube bases formed a circumference with an outer diameter of 50 metres. Each tube was connected at its base to a metal ring anchored to circular pile caps. All the tubes were the same length, while the central ones were semi-circular and the others were progressively raised the closer their bases were situated [17].

Fig. 7 Fuji Group Pavilion in Osaka 1970. [17]

3.5. Shanghai 2010

After the Beijing Olympics, the World Exhibition in Shanghai was the largest international event in China. The theme of "Better City Better Life" has put the life in 21st century cities at the center of this world exhibition. 246 countries and international organizations exhibited on 5.28 km^2. Expo 2010 is the most expensive and largest world exhibition in history.

Fig. 8 Expo Boulevard in Shanghai 2010. [www.archdaily.com]

In addition to all the pavilions, the Expo Boulevard stood out (Fig. 8), a structure that was 100 m wide and 1 km long and was the largest and most important building in the exhibition. Positioned to form the central part of the entrance and provides over 350000m^2 for all necessary facilities. The size and short construction period led the designers to use the membrane construction as a roof covering.

The Expo Boulevard is covered by a membrane roof with a total surface of 65,000 m^2, the currently largest of its kind world-wide. With a free span of almost 100 m, it sounds the limits of technical feasibility. The roof is carried by 19 interior and 31 exterior masts and by six funnel shaped framework shells consisting of steel and glass. It has a height of 45 m and a free projection of 80 m. The applied PTFE-glass membrane is of the sturdiest type V and has a tensile strength of 8,000 N/5cm, which is equivalent to 16 t relating to a strip of 1 m width [4].

This megastructure has once again proven the potential of membrane material, not only when it comes to large ranges and low cost, but also when it is necessary to create a sophisticated, elegant solution that goes beyond the stereotypical cubic form.

Two more pavilions have appeared in Shanghai, whose roof construction is made of membrane material. One of them is the Norwegian pavilion, which is made of wooden constructions and membrane material as a cover, while the other Japanese pavilion was made of a combination of steel and membrane.

Norwegian architects Helen & Hard, guided by the idea of “The Nature of Norway”, designed a pavilion of 15 separate trees that multiply to form a single space, but can also exist separately (Fig. 9). All 15 trees are basically rectangular in shape, covered by a simple saddle-shaped tent construction with a diagonal span of 16 m and a vertical difference of 3 m between the lowest and highest point of support. A translucent PTFE membrane by the name of Gore™ Tenara® 4T20HF Architectural Fabric was chosen. This fabric is highly flexible, non-flammable and non-dripping. The complex membrane structure is prestressed on site and connected to the timber arm ends. This introduces considerable forces to the timber structure [5]. Norwegian pavilion has shown very interesting combination of wooden and membrane constructions and it really showcased spirit of Norwegian landscapes.

Fig. 9 Norway Pavilion in Shanghai 2010. [www.archdaily.com]

Japan also presented a large number of its technological achievements at this world exhibition, and one of them represents their pavilion. The pavilion is officially named "zi cao dao" ("purple silkworm island"), which best describes its shape and color of the pavilion (Fig. 10).

Fig. 10 Japanese Pavilion in Shanghai 2010. [www.designboom.com]

Structurally very simply constructed from steel lattice girders whose facade is a two-layer membrane material filled with air, the facade itself is a series of innovative technological systems. The semi-circular 'breathing organism' makes an efficient use of natural resources, incorporating solar energy collection batteries and a double-layer membrane that filters sunshine coinciding with its interpretation of how technology can better our lives. Energy-saving technologies are displayed and performances are also being staged, highlighting the role of ecological technology in helping humans achieve a more comfortable life and confidence in the future [6]. This pavilion has proven that membrane material is not only used for large ranges, but it is also possible to form energy efficient facade systems.

3.6. Milan 2015

EXPO 2015 in Milan showcases the theme “Feeding the Planet, Energy for Life”, offering answers to the major future challenges of human nutrition. In the context of a conceptual master plan, this world exhibition introduces a clear paradigm shift by dispensing with prestigious monumental buildings, and by presenting itself rather as a "sustainable AgroFood Park" [7].

After Shanghai, which reminded the world public of the importance of membrane constructions, in Milan we had the opportunity to see membrane material in a slightly larger number of pavilions than before. Starting from Cardo and Decumano streets, main streets on Expo, and the German pavilion where the membrane is also used as sun protection, the pavilions of Kuwait and Mexico where it has the function of an aesthetic element on the facade and the pavilions of China, Malaysia and COPAGRI using membrane material as a roof structure (Fig. 11).

Fig. 11 Exhibition Pavilions in Milan 2015 [www.archdaily.com]

Of all these pavilions with a membrane construction, the largest, but also the most important, was Cardo and Decumano. Cardo and Decumano occupied a central position among the other pavilions and formed a covered connection between them. These two streets which together are around 1,700m long with a covered surface of 65,000 m2. This structure represents one of the largest membrane structure roofs in Europe (Fig. 12). In addition to the membrane material that acts as a roof covering, this megastructure is composed of more than

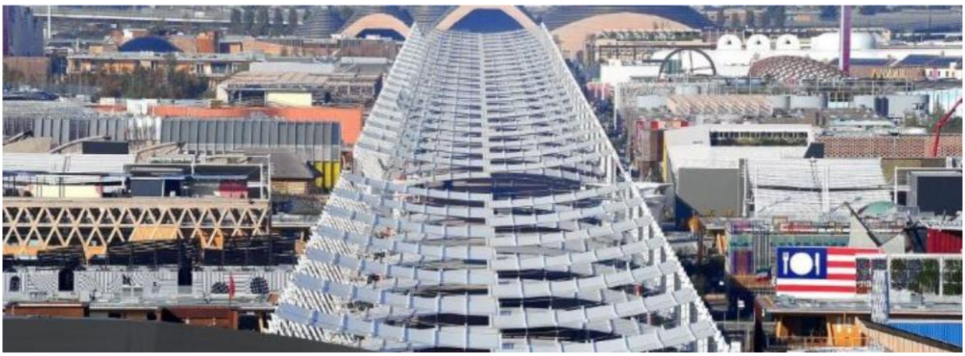

Fig. 12 Top view of Decumano [18]

400 steel columns of 17m height; supporting and stabilizing cables are connected to the columns and more than 2000 steel beams were installed between the cables in order to support the membrane [18].

Cardo and Decumano best show how membrane megastructures progressively occupy a central position at world exhibitions, primarily because of their constructive features, but also because of the visual effect of elegance achieved by their application.

3.6. Dubai 2020

The first Expo to be held in the Middle East, Africa and South Asia with many reasons to be counted as one of the most important in exposition history. The main site of Expo 2020 Dubai was a 438-hectare area located between the cities of Dubai and Abu Dhabi, near Dubai's southern border with Abu Dhabi [19].

Considering the size of the space it occupies as well as the climatic conditions of the location itself, membrane structures appeared at this world exhibition in the form of structures that protect visitors from the sun along communications between pavilions, but also as a facade cladding of individual pavilions (Fig. 13). Within this paper, several pavilions with membrane construction will be presented.

Fig. 13 Membrane structure at Expo 2020 [23]

The Spanish Pavilion at Expo 2020 Dubai is composed of a series of interlaced membrane structures, which create a series of sub-spaces with diverse experiences. When people are strolling through the designs of various countries, the Spanish Pavilion will provide resting seats and shade for the weary viewers. This design expresses welcome and friendliness to visitors. Therefore, this building does not want to be a shopping mall or a commercial center, but to create a space that is within reach, friendly, and full of a warm atmosphere like home [20]. This ambience was achieved by multiplying and varying the dimensions and colors of the fringed cups that make up the Spanish pavilion. The main construction of the grooved cups is represented by steel profiles of circular cross-section, while the membrane construction serves as a sheath and has no bearing role in this joint (Fig. 14).

Fig. 14 The Spanish Pavilion at Expo 2020 [20]

The Opportunity Pavilion was designed by AGi architects for Expo 2020 Dubai. The pavilion also includes a membrane structure that floats 32 meters above the ground, symbolizing the dream that people desire to realize (Fig. 15). The structure is formed by covering the metal frame with fabric, like clouds, shielding the square from direct sunlight. The membrane structure is very clever in the use of transparency, light and color, and they will constantly change with the time of day, sunlight and people's movement [21]. The membrane construction of this pavilion is not in the function of the main supporting structure, but only has the function of a roof covering.

Fig. 15 The Spanish Pavilion at Expo 2020 [21]

The Brazil Pavilion at Expo 2020 Dubai provides visitors with a rich sensory experience about Brazil's biome and cultural heritage. The structure was envisioned in steel, both in the roof of the pavilion and in the space beneath. The pavilion presents a tensile structure with large trusses on its four facades, from whose upper edges are stretched the fabric of the roof, tensioned so as to take the form of a concave impluvium of four faces that converge in a circular water spout positioned slightly off-center. The fabric is reinforced with steel cables that form the ridges of the impluvium and which, passing through a traction ring are taken down and tied at a single point to the ground, inside the water mirror. The resulting geometry, as in any tensile structure consisting of elastic elements, is not entirely flat, with the ridges curving upwards from their center (along with the steel cables) with a curve of the order of 5 percent along their length, while the fabric tensioned between the cables curves almost imperceptibly downwards (Fig.16). In the horizontal plane along the top of the trusses of the facade is envisioned a compression ring, formed by the beams of the facade and by two more beams inserted in the former, rotated and crossed over each other so as to form struts between the nodes of the facade trusses [22].

Fig. 16 The Brazil Pavilion at Expo 2020. [22]

The fabric is a Precontrant fabric by Serge Ferrari, which features a flexible structure of high tenacity PET micro-cables coated with several layers of polymers and finished with a dirt-resistant surface treatment, offering low solar factor translucence and avoiding excessive heat gains. The internal volume has trusses in both of its longitudinal facades, each supported by two pillars, resolving in a rational manner the large proposed cantilevers [23].

4. CONCLUSIONS

The information given in the paper shows that membrane structures have often been used at World Fairs. At the couple of last Expos membrane structures had absolutely dominant place at the exhibition site, which shows the importance of these structure for today's architecture. By comparing first membrane structures to the newest ones we can also monitor their progress through time. From being dependant on cable nets they became one of the structures with highest spans. Pneumatic structures were also developed from tensile membranes.

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MEMBRANSKE KONSTRUKCIJE NA SVETSKIM SAJMOVIMA

Svetske izložbe pružaju prilikumu nacijama da prikažu ostatku sveta svoja dostignuća. Pored najnovijih dostignuća u nauci, tehnologiji i kulturi, Expo je takođe postao i podijum za arhitekturu. Istorija pimene membranskih konstrukcija počela je na Expo-u 1958. godine u Briselu i traje i dan danas. Ovaj rad istražuje konstantni napredak membranskih konstrukcija kroz paviljone izgrađene za Svetske izložbe

Ključne reči: *membranske konstrukcije, Svetksa izložba, Expo, lake konstrukcije, zatezne konstrukcije*

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Original scientific paper

TEACHING ARCHITECTURAL STRUCTURES WITH THE AID OF VIRTUAL TOURS

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Vuk Milošević, Veliborka Bogdanović, Dragan Kostić, Miomir Vasov

Faculty of Civil Engineering and Architecture,
Chair for Designing Architectural Structures, University of Niš, Serbia

Abstract. *Architectural structures are one of the main components of architecture. This is the reason why they are taught at every architectural study programme. The Faculty of Civil Engineering and Architecture of the University of Niš is no exception to this. With its strong background in civil engineering, this faculty gives even more attention to the architectural structures than most, and this has proven in practice to be a great advantage for its students. With the rise and development of new technologies, architectural structures are also being innovated and upgraded. However, new methods for teaching architectural structures are still being explored and there has not yet been an established direction for innovations in teaching architectural structures. This paper aims to analyze possible techniques and tools that could be used in enhancing teaching methodologies of architectural structures with respect to modern technologies.*
The paper will first present the need for innovation in teaching of architectural structures in the context of digitalization. Then, virtual tours as one of the means of digitalization will be analyzed and discussed. Next, architectural structures as a topic will concisely be introduced and systematized. In addition to this, teaching of architectural structures at the Faculty of Civil Engineering and Architecture in Niš will be briefly displayed. Finally, the possibilities for using virtual tours in teaching architectural structures will be investigated. Special attention will be paid to analyzing benefits, as well as limitations and possible problems of such an approach. Based on this, conclusions about the use of virtual tours in teaching architectural structures will be drawn and presented.

Key words: *virtual tours, architectural structures, education, architecture, digitalization, teaching method*

Received April 28, 2022 / Accepted August 18, 2022
Corresponding author: Vuk Milošević
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: vukamer@yahoo.com

1. INTRODUCTION

We live in the times of unprecedented technological development. This development is so fast and powerful that it is affecting all areas of our lives. Everyday life has changed significantly even compared to what it was a couple of decades ago. Two areas that are the focus of this research have, however, not changed as dramatically as some others. These are construction and education. It seems obvious that the developments in these fields will continue to happen, which is necessary in order to keep up with the speed the world is evolving. The research field of this paper is the one of education about architectural structures, with the specific interest in application of new technologies to this subject.

"Everything that can be digitalized will be digitalized" is an idea that has been gaining momentum in the past decade. Today it seems much more realistic and plausible than a few years ago. For example, the government of the Republic of Serbia has recently made digitalization one of its top priorities[1] and sees it as the most important catalyst of innovation. Recent events in the world, more specifically the pandemic of COVID-19, have worked in favor of the digitalization. There are numerous ways in which digitalization can happen and is happening. Today, it is quite common to have digital meetings, work and collaborate digitally, to have fun or learn digitally. While it is still too soon to evaluate the effects and results of these changes to education, it is certain that some positive aspects have been recognized and that it would be beneficial to continue to use them even if, or when, the classes are restored to classrooms.

Virtual reality is one of the important means of digitalization. It is one of the ways of representing space. Spaces represented in virtual reality can exist in reality or can be virtually created. Physically existent spaces can be presented in virtual reality in real time, in a period from the past or in one frozen moment in time. Usually, devices for creation or recording and devices for viewing virtual reality are necessary. For recording or creating virtual reality special expertize is needed, while no knowledge is needed for viewing it. Application of virtual reality can range between many different areas. In tourism, nothing can replace the physical presence at the site, but virtual reality is the next best alternative. In entertainment, virtual reality is widely spread, and video games are one of the most used forms of virtual reality. In culture, the form of art tourism was especially popular during the lock-downs caused by the pandemic. In retail, this form of digitalization is gaining significance and market share. In education, virtual reality has a great potential, especially in particular fields, such as for training surgeons or pilots. One of the means of virtual reality are virtual tours and they will be discussed in the next chapter in more detail.

This paper explores the possible connection between the virtual tours and the teaching of architectural structures. Architectural structure is an integral part of any building. Thus, they are thought at all architectural study programmes. The main purpose of architectural structures is to provide stability for the buildings and resist loads. This is the area in which architects and structural engineers cooperate, since the structures need to be analyzed and their dimensions must be calculated, whilst their appearance, position and form can be very important for the overall quality of the building. Technological advancements have significantly helped in analysis and design of architectural structures. The design and analysis of complex architectural structures built in the world today would have been impossible without the use of computers and specially created software. To some extent,

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[1] Programme of the Government of the Republic of Serbia, 2020, https://rsjp.gov.rs/wp-content/uploads/Ekspoze-2020.pdf *(visited 17 April 2022)*

the construction of architectural structures has also been modernized, especially through automation, and work is being done in the field of printing structures and research on new structural materials. However, not much progress has been done in innovating the teaching methods in this area. This finding motivated the research on updating the approach to teaching architectural structures, as part of architecture very different in nature from architectural design. This paper will provide information on virtual tours as one of the means of digitalization, and on architectural structures. It will then explore the connection between teaching architectural structures and virtual tours. Based on this, conclusions will be drawn and presented about possibilities and limitations on using virtual tours as an aid in teaching architectural structures.

2. Virtual Tours

Virtual tours are a type of virtual reality that is most commonly dedicated to showcasing places that exist in reality[2]. These places can be both interiors and outside spaces, including exteriors of buildings. These spaces are recorded at one moment in time, and can be viewed an infinite number of times at any given location. Devices for recording virtual tours can have different properties. Today, virtual tours can even be recorded with relatively simple smart phones. The next level recording devices, that also provide better quality of the tour, are omnidirectional cameras. These cameras have 360° field of view, and can be of different capabilities. The highest level of recording devices are cameras that also measure distance to objects. In this category, there are cameras that use infrared technology for determining distance, and the ones that have laser technology that provides higher precision. The devices for viewing virtual tours can also be divided into three categories: small screens, large screens and VR glasses. The first two categories are widely available and are mainly already in use for other purposes. “Small screens” used for viewing virtual tours are smart phones and tablets. Their biggest downside is the size of their screen, but on the other hand they are very easily transportable. Large screens provide better sense of immersion into the virtual reality, but are relatively fixed in position. Virtual reality glasses provide total immersion, but are not yet widely available and for small number of people they can cause discomfort while using them. Therefore, it is important to find the appropriate equipment for both recording and viewing virtual tours.

Recording and viewing are the first and the last step in creating virtual tours. There is an important segment in-between in which the virtual reality is actually made, for which software for creating virtual reality is needed. There are many available software packages for this purpose today. Some of the most popular are Cupix[3], Pano2VR[4], 3DVista[5], Kuula[6], Matterport[7] and Orbix 360[8]. Capabilities of these software packages are very different. While some of them only provide basic features, others are much more sophisticated. The elementary level of the capability is to connect the recordings of the space and allow for moving of the viewpoint from one point in space to another. The next

[2] Virtual tour of the Housing Exhibition in Niš, https://bit.ly/3r0Kvw1*(visited 17 April 2022)*
[3] https://www.cupix.com/ *(visited 10 April 2022)*
[4] https://ggnome.com/pano2vr/ *(visited 10 April 2022)*
[5] https://www.3dvista.com/en/ *(visited 10 April 2022)*
[6] https://kuula.co/ *(visited 10 April 2022)*
[7] https://matterport.com/ *(visited 10 April 2022)*
[8] https://orbix360.com/ *(visited 10 April 2022)*

level is to analyze the recorded data and create the floor plan of the recorded space. An even higher level is the ability to use the recoded data to create a 3D model of the recorded space. When using the top quality cameras with distance meters, this possibility seems natural, but in some software it is even possible to get 3D models from the data recorded with simple smart phones. This feature is enabled by using advanced artificial intelligence, and despite its lower accuracy compared to state-of-the-art cameras, it is truly remarkable. The possibility of creating 3D models of spaces generates completely new perspectives for development. This opens a space for data analytics, also a critical element in the field of digitalization. For example, the spaces do not have to be measured in reality, since they can be measured digitally in virtual reality. Additionally, spaces can be analyzed according to the objects they contain, their size, position or interrelations. On top of this, there is a possibility to digitally modify spaces in virtual reality. This is potentially the largest segment for using virtual reality in architecture. Starting from simple adding of objects or their deletion, this can be a quick way of producing new architectural designs. Other features are alteration of colors, materialization and textures. This can be perfectly connected with existing architectural tools for digital design of spaces. Such potentials are still not in use, but it is expected that they will be available in very near future.

3. Architectural Structures

It is considered today that there are three main components of architecture, and these are function, structure and form. This points to the importance of structure for architecture. The most traditional view of the relation between these components is that the function is most important. The structure serves the building by not interfering with the function and providing stability, while the form follows the function thus also making the form of secondary priority. However, it is now most commonly believed that the relation between these three components is not fixed and can vary for each analyzed building. Based on the type of the building and the architect's vision, one of the components can have the dominant role. This is usually easily noticeable. The structure is frequently the primary component in buildings with larger sizes and relatively simple function. Perfect examples of this are sport stadia. In such cases the form follows structure, or if the primary role is given to the form, than the structure will follow form. However, in order for the building to be completely successful, the function, the structure and the form need to be perfectly harmonized.

There are different ways to systematize structures in architecture. One of the recently popular criteria is the self-weight of the structure. In general, it is beneficial if the self-weight is lower, provided the load bearing capacity is not impaired [10]. According to this criterion, the properties of structures differ extremely. One of the heaviest types are flat concrete slabs that can have self-weight of about 5 kN/m^2. At the other end of the spectrum, modern tensile structures have self-weight in the range of 0.01 kN/m^2 [17,18]. This enormous difference results in completely different structural requirements, behavior of the structures and dominant forces [8]. Another criterion for differentiating between structures is that of the types of used structural elements. Simple structural elements are linear and planar, and can be further developed either by combining or bending in space. Hence, the structural systems made out of these elements can be divided to linear and space-surface systems. One more possible criterion is the construction technique. In this sense, structures can be divided into those made on site, partially prefabricated and prefabricated. With the increase of automation, more and more structures are now being prefabricated at least to some degree and fully prefabricated where this is possible and economical.

The role of architectural structures has developed significantly and needs to be elaborated here. The main functions of architectural structures are listed and discussed in the following paragraphs:

- Load bearing. This is the primary role of architectural structures and their first reason of being. Architectural structures provide stability of buildings under different external loads [2]. Most common loads are wind, snow seismic and dead loads. Expected loads are analyzed and based on the analysis appropriate structures are chosen. The loads are transferred through different structural elements to the ground [5].
- Partitioning. In addition to resisting external loads, architectural structures also provide partitioning. Partitioning can be horizontal, where vertical structural elements, usually walls, divide space, and vertical where horizontal elements such as slabs or roof divide space. Another type of partitioning is done according to position, so there is external partitioning where structure provides a limit to the interior space, and internal partitioning where interior is divided into smaller spaces.
- Protecting. Architectural structures provide protection from the sun, rain, temperature, moisture and sound. Although it is usually believed that exterior skin of the building provides all the protection, this is not always the case. For example, the interior partitioning structure should provide acoustical protection. In addition, some parts of the building could have different designed temperatures from the others and rely on interior structure to provide thermal resistance. This segment is very important in the context of energy efficiency and much work has been done in this area. Some of the measures for reduction of energy consumption include implementing Trombe wall [15], double skin [7] or improvement of building envelope characteristics [12] and can result in reduction of CO_2 emission [13].
- Esthetical. This role of the structure is the least utilized among the listed functions. There are cases when the structure is so well fitted into the building that it perfectly completes its three previously mentioned roles, but is not visually attractive. Opposed to visually neglecting the architectural structures is the example of using them as works of art. For such structures the first three mentioned roles are of no importance and they exist only for their attractiveness. Between these two extremes there are many examples where architectural structures, in addition to fulfilling their other roles, also add important esthetical value to the buildings [3,4].

While all architects have understanding and knowledge about architectural structures, what remains unresolved is how detailed this knowledge should be. One thing is certain, the better the architect’s knowledge in architectural structure is, the easier his collaboration with the structural engineers will be [11] and more value will be extracted from architectural structures as a necessary component of any building.

4. Teaching Architectural Structures at the Faculty of Civil Engineering and Architecture

The Faculty of Civil Engineering and Architecture has a relatively long history of more than 60 years of teaching architectural structures. Up to date, more than 5000 engineers earned their degrees in Architecture and Civil Engineering in Niš. Many architecturally important buildings projects included students from this faculty in their project teams, confirming that students received high quality level of conventional education in architectural structures. Some courses at the faculty already applied advanced teaching methods in their classes [14]. So far, novel educational methodologies including virtual tours are not implemented for teaching architectural structures at the Faculty of Civil Engineering and Architecture in Niš.

4.1. Faculty of Civil Engineering and Architecture, University of Niš

What is now the Faculty of Civil Engineering and Architecture in Niš was first founded in 1960 as the Faculty of Technical Sciences, even before the University of Niš was established in 1965. The Faculty changed its name in 1970, into the Faculty of Civil Engineering. In 1998 it got the name it still has today – Faculty of Civil Engineering and Architecture at the University of Niš. From its very beginning the faculty had a study programme in Architectural Structures. Unfortunately, this study programme was ended in 1968 and eventually replaced with the new, similar programme, Structural Engineering. This study programme was superseded with Architecture programme in 1995 [1]. For several years the faculty also offered a Master's programme in Architectural Structures, but it has eventually been canceled. Right now subjects related to architectural structures are being taught mostly as a part of the Architectural study programme throughout the five-year studies.

4.2. Chair for Architectural Structures

All the courses related to architectural structures at the University of Niš are under the jurisdiction of the Chair for Designing Architectural Structures at the Faculty of Civil Engineering and Architecture. At first, this chair was a part of the Chair for Architecture at the Faculty of Technical Sciences until 1968. From 1968 to 1972 this chair was named Chair for Architectural Structures. After this, a few chairs were merged to form Chair for Designing, Urban Planning and Architectural Structures. Since 2005 this chair again becomes independent under the official name Chair for Structures and Structural Systems of Architectural Buildings. Many reputable professors served as the Head of this chair including professor Desimir Dančević, professor Zoran Radović and professor Milisav Damnjanović. Current Head of the chair is full professor Veliborka Bogdanović, and professors of the chair teaching courses in Architectural Structures are full professor Dragan Kostić, associate professor Miomir Vasov and assistant professor Vuk Milošević, with assistants including doctors, doctoral candidates and student fellows.

Since architectural structures are closely related to engineering and the Faculty of Civil Engineering and Architecture had study programmes in engineering and very eminent teaching staff in this field, more than usual emphasis was given to architectural structures. This is usually not the case at faculties that are specifically oriented only towards architecture, because in these cases architectural design or urban planning are paid the greatest attention. However, the approach applied by the Faculty of Civil Engineering and Architecture has proven extremely efficient in practice. Students graduated from this faculty showed remarkable practical skills and were able to work effortlessly with structural engineers around the world. The method of investing more attention to engineering logic than the artistic talent has so far provided architecture students with important competitive advantage at various construction projects.

4.3. Architectural Structures Courses

The Chair for Architectural Structures is in charge of over 30 courses offered at the Faculty of Civil Engineering and Architecture. The courses are mostly part of the five-year Architectural Study programme, but also part of the Bachelor's programme in Civil Engineering, Master's programme in Civil Engineering, Bachelors programme in Construction Project Management and Doctoral programme in Architecture. In these courses video materials are used as teaching aid. Some of the courses are mandatory, while others provide deeper exploration into the topics and are elective. The chair's courses are divided in four large groups:

- Macro designing of Architectural Structures – includes courses Structural Systems 1 [9], Structural Systems 2 [6], Prefabricated Structures 1, Prefabricated Structures 2, Structural Systems and Assemblies, Architectural Structures 3 and others.
- Micro designing of Architectural Structures – includes courses Introduction to Architectural Structures, Architectural Structures 1, Architectural Structures 2, Civil Engineering Structures 1, Civil Engineering Structures 2, Façade Structures and Forms, Finishing in Construction and others.
- Energy Efficiency of Buildings – includes courses Building Physics [16], Energy Efficiency of Buildings, Bioclimatic Architecture 1, Bioclimatic Architecture 2, Green Building and others.
- Other courses – including Real Estate Management, Architectural Design, Sacral Architecture and others.

The courses of the first two groups are directly related to architectural structures. The aim of the courses from the first group is to teach students how to arrange the disposition of structural elements in order to form architectural buildings, most commonly with medium and large spans. The students study the approximate dimensions of the structural elements based on their function and placement within the building, possible connection types between the structural elements and different systems, and forms these elements can create. Structural analysis of these buildings is not a part of these courses, although it is expected that students understand how different loads are transferred through structural elements, and how these elements react to loads.

The courses from the second group are dedicated to smaller buildings or specific parts of architectural structures. The focus is on designing foundations, walls, slabs and roofs with smaller spans. Students are introduced to different construction techniques. Particular parts of the buildings, such as doors and windows, are discussed in detail. Students are taught to design different types of staircases. Layers of walls and slabs are thoroughly discussed and measures for protection against ground water and moisture are explored, along with some measures for providing acoustical comfort. Additional acoustical and thermal protection measures, including teaching of related calculations are a part of the courses from the third group.

5. Virtual Tours in Teaching Architectural Structures

With the topic of virtual tours and topic of architectural structures presented independently, the possibilities for their connection can be explored in the following sections. The written form of this paper presents an important obstacle in showing all the possibilities of this synergy, since it does not allow for showing all the qualities virtual tours have. Due to the dynamic and interactive nature of virtual tours it is not possible to represent their value by showing pictures in this paper instead of the virtual reality, as pictures are a much more rudimentary form of representation. Therefore, the potential for using virtual tours in teaching architectural structures will be elaborated in textual form. First the benefits and opportunities of such an approach will be discussed. The authors find it very important to also investigate the possible downsides of such an approach, because without knowing them, it would not be possible to use this approach appropriately and successfully. Therefore, the problems and limitations will also be investigated and presented.

5.1. Benefits and Opportunities

In teaching architectural structures, visits to construction sites are even more important than they are in teaching architectural design. This is mostly due to the fact that architectural design is a form of art, while design of construction requires application of established rules and processes. However, there are many difficulties in organizing such visits, especially for larger groups of students and during the times of pandemic. Virtual tours solve many of these difficulties. The basic idea is that virtual tours should be used in order to show important architectural structures or their parts to students. The students would then have the possibility to walk around through virtual reality and explore the details and individual parts or the whole structure. Ideally, not only the finished complete structure would be available, but also the possibility to browse through different construction stages of the same structure. This would necessitate having several virtual tours or combining them into one tour.

Today the level of detail and the quality of representation virtual tours offer are excellent and can fully be a replacement for visiting the site physically. Furthermore, visiting of construction site by students is possibly an issue for the construction process or the construction workers. The time and duration of the visit should be carefully planned. In case the virtual tour is used instead of the physical visit, the site can be visited at any time, the duration of the visit can be infinite and the visit can be repeated an infinite number of times. Also, there are no safety risks that exist at the construction site. All of these are huge advantages for the students. Additionally, construction stages only last for certain periods of time, and cannot be repeated on the same site. Contrary to this, if these phases are recorded in virtual reality, they can be accessed at any time in the future.

When organizing physical tours there is inevitably also the factor of costs. The construction site can be far away, which also requires additional time for travel. In some cases, the construction site can be totally unavailable for visits, for several reasons, such as short construction time, huge popularity, or inaccessible places or countries of construction. Other difficulties could also be related to the fact that the construction does not exist anymore, for any of the possible reasons, that the structure of the building is not visible, for example when it is covered with other elements, or that the phase that is of interest for the lecture is already completed in the past. Once again, virtual tours provide solutions to all of these problems. Most virtual tours are web based, so they are only a few clicks away, thus saving travel time and costs. Virtual tours can be created with no obstruction to the construction process. Once created, the tour can be always available to show the specific time point and stage of the construction, and if several tours are made at different times, than a timeline can be created and specific elements can be viewed at different construction stages.

Finally, it is important to point out how easy to use virtual tours are and what their benefits compared to other means of representation are. As previously stated in the introduction, no knowledge in virtual reality is necessary for viewing virtual tours. It will come completely naturally to students that already have skills in creating digital models of their architectural projects. In addition, it can be viewed on devices that architecture students already have, such as smart phone devices and computers. The important question is: why not make a photographic record of everything previously stated? Virtual tours are not just a more modern form of representing spaces compared to photographs or even videos, they are also much more advanced. While photographs are still, virtual tours enable moving through the space, focusing on different parts or the whole. Videos can provide great insight if the information about conducting a construction process is important, but they do not give the viewer any freedom to select her focus, move or view the wider picture. It is not just that virtual tours provide much more data, they can also be used for much more broader purposes, as explained in the section about virtual tours. Lastly, virtual tours allow for creation of 3D models which are of great importance in understanding architectural structures.

5.2. Problems and Limitations

One of the important limitations of virtual tours is that they do not allow for recording of time flow. This limits the possibility to record how certain construction operations are undertaken in real time. Such a possibility would be of greater importance when training construction workers, then when educating engineers and architects. However, it is important to acknowledge this limitation. There are ways to mitigate this by creating virtual tours at the beginning and the end of each phase. Nevertheless, for this specific purpose, it would be better to create videos instead of virtual tours.

Benefits of the virtual tours compared to physical visits are elaborated in the previous section, however, creation of such virtual tours also needs careful planning. It is important to mention that creating virtual tours during construction stages of already built structures is not possible. In order to have such tours, plans must be made to record virtual tours during the construction of new buildings and structures. This requires permits from the construction companies and hiring of experts in recording and production of virtual tours. Creation of such tours also incurs costs for personnel and software licenses, but on the other side, most of the software packages provide free viewing of tours.

Lastly, everything necessary for creation and production of a virtual tour must be available. This means that there should be available experts for recording and production of virtual tours, the equipment and devices for recording and production need to be obtainable, and the software for recording and production should be at disposal. Only a few years ago all of this was very scarce or completely unavailable. However, today all of these are much more available and affordable. In the near future, it is expected that this problem will be completely eliminated.

6. CONCLUSION

This paper presents results of the research about the possibility of using virtual tours as a tool in teaching architectural structures. Architectural structures are a specific part of architecture that is very different from architectural design. Structures are necessary for every building and they have several distinctive roles. Teaching of architectural structures has not changed significantly in the past decades. One of the important parts of teaching architectural structures that allows for better understanding of theory are visits to construction sites. In cases when this is not possible, photos or videos from construction sites are presented to students. With the development of new technologies, digitalization of spaces also became possible. Virtual tours are one of the ways to digitalize physically existing spaces. The idea of innovating teaching methods of architectural structures by utilization of virtual tours has been created and explored.

Advantages and disadvantages of using virtual tours in teaching architectural structures were examined. Particularly, a possibility of replacing physical visits to the construction sites with virtual tours was analyzed. It was concluded that this approach would bring many benefits. The site can be virtually accessed easily and fast at any time, and it can be viewed as many times as needed. There are no costs for viewing the virtual tour. Many sites can be viewed virtually during the same amount of time as needed for visiting the site physically. Virtual tours can show construction stages, as well as the structures that are no longer visible or do not exist anymore. They provide much more freedom to the viewer compared to photographs or video, while having excellent viewing quality, and are much more informative. Nowadays, 3D models of recorded spaces are also created and can be further edited. However, some limitations need to be taken into account. Recording and production of virtual tours may still be costly. They also need to be planned in advance, so that different phases of construction are recorded in different virtual tours. Finally, experts, equipment and software must be available for use.

With all the presented arguments in mind it can be concluded that virtual tours are a promising tool for easier understanding of architectural structures. The advantages of virtual tours as a teaching aid are numerous, and even more significantly, have a huge development potential. On the other hand, the disadvantages are few and expected to be reduced soon with the future development of technology and the expected reduction of costs. Based on such conclusions, it is proposed to include virtual tours, in addition to already used short videos and other novel educational methods, in teaching of architectural structures at the Faculty of Civil Engineering and Architecture of the University of Niš.

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NASTAVA ARHITEKTONSKIH KONSTRUKCIJA UZ POMOĆ VIRTUALNIH TURA

Arhitektonske konstrukcije su jedna od osnovnih komponenti arhitekture. Zbog toga se one izučavaju na svim studijama arhitekture. Građevinsko-arhitektonski fakultet Univerziteta u Nišu nije izuzetak od ovog pravila. Sa dugom istorijom i velikim znanjem u oblasti građevine, ovaj fakultet daje učenju konstrukcija na značaju čak i više nego drugi fakulteti, što se pokazalo kao velika prednost za njegove studente. Sa usponom i razvojem novih tehnologija, inoviraju se i arhitektonske konstrukcije. Međutim, nove metode u nastavi arhitektonskih konstrukcija se još uvek ispituju i za sada ne postoji jasno određen pravac u inoviranju pristupa izučavanja arhitektonskih konstrukcija. Ovaj rad je deo istraživanja o mogućim načinima i sredstvima koja bi bila korišćena za unapređenje nastavnih metoda u oblasti arhitektonskih konstrukcija, u skladu sa savremenim tehnologijama.

U ovom radu će najpre biti predstavljena motivacija za inoviranje učenja arhitektonskih konstrukcija u kontektstu digitalizacije. Zatim će biti analizirane i diskutovane virtualne ture, kao jedan od vidova digitalizacije. Potom će tema arhitektonskih konstrukcija biti ukratko predstavljena i sistematizovana. Uz to, biće prikazana i nastava iz oblasti arhitektonskih konstrukcija na Građevinsko-arhitektonskom fakultetu u Nišu. Na kraju će biti istražene mogućnosti za primenu virtualnih tura u podučavanju arhitektonskih konstrukcija. Posebna pažnja biće posvećena analizi prednosti, ograničenja i mogućih problema ovog pristupa. Na osnovu ovoga biće doneti i zaključci o mogućnosti korišćenja virtualnih tura u nastavi arhitektonskih konstrukcija.

Ključne reči: *virtualne ture, arhitektonske konstrukcije, edukacija, arhitektura, nastavni metod*

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SMALL SHRINKING TOWNS IN THE POST-SOCIALIST CONTEXT OF DEVELOPMENT

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Milica Ljubenović[1], Ivana Bogdanović Protić[1], Ljiljana Vasilevska[1], Jelena Živković[2]

[1]University of Niš, Faculty of Civil Engineering and Architecture, Serbia
[2]University of Belgrade, Faculty of Architecture, Serbia

Abstract. *The process of urban shrinkage is affecting many cities around the world. It is evident in small towns as well, but unlike larger cities, it has not received much attention. Accordingly, this paper analyses small towns' shrinking focusing on post-socialist context of development, which led to new patterns of urban shrinkage in countries of Central and Eastern Europe (CEE). After discussing the specific characteristics of the shrinkage of small towns, their paths of development in different CEE countries are analyzed, in order to highlight the characteristics of urban shrinkage and the influence of post-socialist transition on this process. Thereafter, the shrinkage of small towns in Serbia is analyzed in order to determine whether the identified characteristics are recognized in them and to single out the specifics of that process in relation to other post-socialist countries. Based on the general characteristics of the development and shrinkage of small towns in the CEE countries, it can be concluded that shrinking small towns are not equally represented in all countries, and there are certain differences in terms of dynamics and intensity of shrinkage. The results of the analysis indicate that the previous path of development had a strong influence on their shrinkage after the post-socialist transformation. Three general trajectories of socialist development have been singled out, which influenced different patterns of urban shrinkage. In Serbia, it has also been observed that the shrinkage of small towns is directly related to the unfavourable direction of the urbanization process during socialist development.*

Key words: *urban shrinkage, small towns, post-socialist transition, Serbia*

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Corresponding author: Milica Ljubenović
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: milica.stj@gmail.com

1. Introduction

Shrinking cities have always been part of human civilization, however, in the post-industrial period, the main causes of shrinkage have changed and it has become a global phenomenon [1, 2]. A process of suburbanization and decentralization emerged in US cities after Second World War, emptying the central areas of large cities [3]. The crisis of the Fordist model of development led to the decline of cities in old industrial areas such as the North of England, the Rust Belt in the USA and the Ruhr region in Germany. The new wave of shrinking cities has begun in the 1990s in Central and Eastern Europe (CEE). The collapse of the Soviet Union and the transition from socialist to post-socialist society and economy influenced the dramatic development of the cities of these countries and led to new patterns of urban shrinkage [4, 5]. Post-socialist countries had to catch up with Western countries in terms of political, economic and social development. Post-Fordist changes, which were gradually established in Western countries, acted as 'shock therapy' in post-socialist countries [5].

In Europe, unlike other regions in the world, a large part of the population lives in smaller urban areas. Small towns have not been primarily the focus of urban shrinkage research, however, the largest number of shrinking cities in Europe are small and medium-sized towns [6]. Their shrinkage is evident especially in Central and Eastern Europe (CEE) [7, 8]. In Serbia, the demographic and economic decline is particularly pronounced in small towns, while larger cities are stable or growing [9].

The causes of the shrinkage of contemporary cities are most often attributed to numerous transformation processes, including deindustrialization, suburbanization, as well as demographic changes - population aging and declining birth rates [10, 11, 12]. Small towns have different structure and the causes and manifestations of urban shrinkage differ in them. The reasons for this lie in different conditions of urban and economic development, insufficient resources in the field of education, research and skills, and often in insufficiently developed transport infrastructure.

Accordingly, this paper considers the process of urban shrinkage of small towns, which has not received much attention. Starting from the assumption that due to their specifics, shrinking cities in the post-socialist context can be considered as a separate model of urban shrinkage, special attention in this paper focuses on the process and characteristics of urban shrinkage of small post-socialist towns. The main goal is to examine the influence of the post-socialist development context on shaping the paths of shrinking small towns.

2. Methodology

The methodology of this research aimed to provide an overview of the process of shrinking of post-socialist small towns. At first, the critical analysis of the main international theoretical sources is used in order to highlight the specific characteristics of small towns' shrinkage compared to large cities. After that, the process of urban shrinkage in the post-socialist context is analysed. Despite many similarities in the causes and consequences of urban shrinkage, there are differences in the trajectories of this process, which are related to different local conditions, as well as to national political and institutional frameworks [13]. Apart from that, the contemporary development of post-socialist cities is influenced by the legacy from the socialist period. Starting from these claims, the patterns and paths of urban development and shrinkage in different CEE countries are analyzed in both socialist and post-socialist period. This critical analyses served to highlight the characteristics and trajectories of small towns' shrinkage in post-socialist context. The final part of the paper analyses the shrinkage of small towns in Serbia, as one of the post-socialist countries. This analysis is based on literature review and official national statistical data. It served to determine whether the identified characteristics of post-socialist shrinking small towns are recognized in Serbia and to single out the specifics of that process.

3. Causes of Urban Shrinkage of Small Towns

With the process of deindustrialization and the shift from the manufacturing to the service sector of the economy in the 1980s and 1990s, many industrial cities began to shrink. Therefore, economic decline resulting from globalization and deindustrialization is considered as one of the main causes of urban shrinkage [5]. The internationalization of production has led to the growth of a large number of small markets concentrated in several leading global cities [14] and small towns are generally considered as losers of the globalization process. They are placed in direct competition with other, larger cities and their function as urban centres is less and less secured. As a consequence of global production and product transport, especially food, the role of small towns as markets for local products from rural areas has weakened [15]. In addition, the shrinkage of rural settlements directly affects the decline of service and trade functions of small towns.

Post-industrial urban shrinkage is closely linked to demographic change [10]. The most significant causes of shrinking cities are negative natural increase and emigration. However, these factors are the result of economic, social and cultural changes, and it is difficult to isolate the influence of the demographic factor only. Changes in the demographic structure and aging of the population are particularly visible in Europe's small towns. These processes are especially typical of autonomous small towns, with weak functional links with the environment [16].

Suburbanization is one of the main causes of urban decline in Western countries [17]. However, this process is not pronounced in small shrinking towns, whose surroundings are also shrinking. In contrast, this process has influenced the growth of some small towns on the edges of densely populated agglomerations.

Political change and institutional context have a strong impact on urban development [11]. The post-socialist transformation, which had dramatic effects on the cities of CEE, certainly stands out. The institutional context and the role of public policies are particularly important at the national and regional level. The focus of policies on the development of certain urban centres and metropolitan areas can jeopardize the development of others and lead to their shrinking [18]. The importance of the national urban system and the position of the city in the hierarchy of settlements especially reflects on small towns, whose development according to some authors depends more on the regional context than on the inherited characteristics of the town itself [19]. Small towns located along economically prosperous agglomerations are growing under the influence of suburbanization, while the towns in peripheral and structurally weak areas are facing shrinkage.

4. Post-Socialist Context of Shrinking Small Towns

In the post-socialist cities of CEE, the urban shrinkage was additionally affected by the transition from a socialist to a capitalist state system, and the large part of cities began to lose population after 1989 [20]. The CEE countries are specific due to the lower level of urbanization and the lack of larger metropolitan areas other than the capitals. In such an urban network, small and medium-sized towns play a big role. In peripheral areas, they are the only available urban settlements, which is why their urban shrinkage is even more significant.

4.1. The context of development

The main characteristics of socialist urban development are strict centralized control of the state, politically motivated urban planning and institutionalised political decision-making procedures [21]. The nature of urbanization under socialism was different from the rest of the world, because it was directed by the policy of industrialization. Infrastructural development followed the needs of industry, so the growth and decline of cities depended on their industrial function. In small towns, industrialization was promoted only in the 1980s in order to improve living conditions in rural areas, as well as to prevent the uncontrolled growth of large cities. As a consequence of this development policy, numerous monofunctional small towns and a relatively small number of administrative centers with a diverse economic structure have emerged [22].

In the post-socialist period, political, institutional and economic conditions changed. Measures of economic restructuring at the beginning of the transition particularly affected small towns with the closure of industrial and agricultural enterprises, which is marked as de-economization [23]. Lack of human capital and poor ability to adapt to innovation are major barriers to restructuring small towns. Their overall competitiveness is low. New social conditions have enabled the creation of different norms and the tendency towards individualism. The second demographic transition influenced the choice of housing and the consumption has become the main goal of a large part of the population [21].

The urban environment in post-socialist cities has adapted to the new conditions created by political, economic, social and cultural transformations. However, despite the general tendency towards decentralization, the central (state) level has retained a lot of influence on local urban development through the regulation of public control over market processes. Some elements of direct central political control over local government have been retained and the state has regulated the level of public funding transferred to the local level [23].

Research related to post-socialist transformations in cities has mainly focused on large or capital cities such as Budapest, Prague, Sofia, Belgrade. The analysis of the lower levels of the urban system is not framed in the model of post-socialist transformation [24]. However, not all factors of the post-socialist transition have the same impact on small towns, so the following can be singled out as significant:

- political and institutional transformations: decentralization of power that has brought greater freedom in the decision-making process, but with limited financial resources;
- economic transformations: establishment of a market economy, deindustrialization and privatization that led to the closure of industrial and agricultural enterprises (de-economization), which further led to unemployment, low competitiveness and the emergence of unused facilities (brownfields);
- social transformations: demographic changes (second demographic transition) that had the same effects as in big cities.

4.2. The process of urban shrinkage

Post-socialist transformation has brought many cities into political, economic and demographic instability. In Eastern Europe, every second city has lost its inhabitants [25]. For these reasons, the urban decline of post-socialist cities is associated with political and economic changes and their social consequences [24]. The effects of the post-socialist transition were most pronounced during the 1990s. The process of deindustrialization has suddenly hit industrial areas, especially old previously protected industries that were exposed to a competitive world market (e.g. Donetsk Basin in Ukraine or Kuznetsk Basin in western Siberia) [3]. Most state-owned enterprises have not survived privatization, leading to factory closures and huge job losses. Housing reforms increased socio-economic polarization within cities as well as between the city and the periphery. Economic downturns and existential fears have triggered waves of emigration and declining birth rates.

Small towns have been particularly affected by post-socialist transformation. They were often planned as centres of specific industries, and economic restructuring was much less favourable to them. The withdrawal of state funding, lack of interest from private investors, as well as environmental degradation had a particularly negative impact [27]. These factors influenced the prolonged period of economic stagnation, the reduced income and deteriorated quality of life. The weak position of these settlements in the global economic system has further reduced the chances of their recovery.

The growing social and economic inequalities in CEE countries have led to the peripheralization of non-metropolitan areas [28]. In these countries, there are huge differences in the development of central urban and peripheral rural areas, and there is also a pronounced polarization between their main metropolitan area (usually the capital) and the rest of the country. The population is concentrated in a number of urban centers, which is often encouraged by development policies.

The industrial development of small towns during socialism was delayed and centrally coordinated, which led to the establishment of a weak local network. This short-term development of small towns was forced, as well as urbanization in general, so the process of urban shrinkage can be seen as a ‘withdrawal symptom’, i.e. return to endogenous development path without the support of central resources [24]. Another factor that has contributed to the small towns’ shrinkage is the depopulation of rural areas that have been the main source of migration to them.

4.3. Different paths of urban shrinkage in CEE countries

Despite many similarities in the structure of post-socialist cities, there are differences in the paths of urban shrinkage, which are related to different local conditions, as well as national political and institutional frameworks [13]. In addition, their development is influenced by the legacy of the socialist period as well as the period before socialism. For these reasons, in order to determine the patterns and specifics of the urban shrinkage of post-socialist cities, it is necessary to consider how their development and urbanization during socialism influenced the decline within different post-socialist countries.

In East Germany, during socialist development, the settlement hierarchy was crucial for locating investments. Only a small number of small towns received state support, while a large number lost the importance and quality of life [29]. The population decline in small towns began accordingly before the transition period. Today, very few small towns are stable in terms of population and they are mostly located in suburban areas of large cities or next to busy traffic routes. The neoliberal orientation of regional policy has shifted the focus to larger and more prosperous urban centres, increasing socio-spatial polarization and leading to increasing peripheralization of declining regions [18].

Small towns in Poland also suffer from depopulation, although there are various development paths among them [30]. During socialism, there was a significant emigration of the population from small towns, while after the political and economic changes in 1989, their socio-economic situation improved [28]. In contrast, many geographically remote small towns are shrinking. However, the network of small and medium-sized towns in Poland is uniform and polycentric, which enables the implementation of sustainable development goals [30].

The Czech urban system is based on a dense network of cities and small towns have been a stable category with a constant population throughout the 20th century [31]. Urban shrinkage is most prevalent in late industrialized small towns that had accelerated growth at the beginning of the socialist period and have stagnated or shrunk over the last 30 years [32].

Cities in Slovakia grew intensively from 1970 to 1980, while in the following decade stagnation begun, which also affected small towns [33]. The industry has been largely privatized with varying degrees of success and many towns have high unemployment rates, although the situation has improved since 2000. There was also a process of disintegration of rural settlements that were unjustifiably annexed to cities in the previous regime, which led to a decline in urban population.

In Hungary, the rapid growth of small towns was only during the 1970s and 1980s [7]. During the 1990s, many small towns managed to avoid the decline of demographic, social and economic activities, even in regions with a structural crisis. Thus, small towns were considered winners and not losers of the transition. However, since 2000, a large number of small towns have lost their inhabitants due to negative natural growth, selective migration and industrial collapse [7].

In Romania, spatial planning during socialism was based on the rational distribution of production centres. New cities were artificially created and developed in the period from 20 to 30 years, therefore they could not develop a solid urban structure and territorial position, and many of them retained rural character. Thus, the radical political, social and economic changes of the 1990s led to the vulnerability of certain cities, especially small and medium-sized towns [34].

In Estonia, at the beginning of socialism, large cities grew rapidly, but since the 1970s, smaller towns have received more investment. When Estonia regained its independence in the early 1990s, a short-term baby boom began [22]. The birth rate in peripheral areas was particularly high, however, there has also been an increase in the emigration of young and fertile people to big cities for work and education, and with the enlargement of the EU there has been a strong emigration to Finland.

Until the early 1990s, urban population in Russia grew due to natural increase, immigration, as well as administrative and territorial changes [35]. Administrative boundaries have been expanded in some cities, and rural settlements have often been transformed into cities to receive additional funding from the state budget. During the transition, the urban status of small towns aggravated the privatization of the built land. Administrative reforms have ruralized more than 3 million urban residents [36]. Shrinking small towns have lower significance in the settlement hierarchy or peripheral location.

In order to perceive better the common characteristics of small town shrinkage in different post-socialist countries, Table 1 systematizes the basic factors of this process.

Table 1 The main characteristics of urban development and shrinkage of small towns in post-socialist countries

Characteristics of urban development and shrinkage of small towns	
Socialism	Post-socialism
East Germany	
▪ poor position in the hierarchy of settlements ▪ a small number of cities received state support - politically or economically important ▪ declining population	▪ intensive shrinkage of peripheral, border and former mining towns ▪ small number of towns with stable population Causes of urban shrinkage: ▪ deindustrialization; regional policy focuses on larger centres; de-administration, demilitarization
Poland	
▪ significant emigration from small towns	▪ improved socio-economic situation ▪ uniform network of small and medium-sized towns - polycentricity ▪ shrinkage of geographically remote small towns
Czech Republic	
▪ dense network of small towns ▪ stable category with a constant population	Urban shrinkage: ▪ late industrialized towns since the 1980s ▪ some service towns due to mobility of rural residents ▪ peripheral cities
Slovakia	
▪ stagnation of small towns since the 80s	Causes of urban shrinkage: ▪ deindustrialization ▪ reducing the intensity of daily migrations ▪ disintegration of rural settlements Improved development since 2000
Hungary	
▪ population losses since the end of the 19th century and during the 20th century ▪ accelerated growth during the 1970s and 1980s	▪ shrinking since 2000 Causes of urban shrinkage: ▪ decline in natural increase; weakened power and the role in regional distribution; economic crisis; demilitarization; increased mobility
Romania	
▪ rational distribution of production centres ▪ development of new towns ▪ accelerated urban growth ▪ conversion of rural areas into urban	Causes of urban shrinkage: ▪ changes in the political system ▪ mono-industrial dependence ▪ deindustrialization, globalization Consequences of urban shrinkage: ▪ lack of attractiveness and competitiveness
Estonia	
▪ more intensive growth since the 1970s due to investments	▪ the short-term baby boom in the 1990s Causes of urban shrinkage: ▪ emigration of young people to big cities; economic structural changes; EU integration
Russia	
▪ growth due to natural increase, immigration, administrative and territorial changes	Causes of urban shrinkage: ▪ administrative reform; difficult transition of specialized towns; peripheral position

Summarizing the general characteristics of the development and shrinkage of small towns, some common causes of urban shrinkage can be singled out. These include deindustrialization, political and economic changes, membership in the European Union, national urban policies and administrative reforms. But it can also be observed that the small shrinking towns are not equally present in all countries, and that there are some differences in terms of dynamics and intensity of shrinkage. As it can be seen in the table, in some small towns, population decline has occurred before the transition (East Germany, Slovakia), in others immediately after political changes (Russia), while in some it has taken place from the beginning of the 21st century (Hungary, Estonia). In some countries, such as Poland and the Czech Republic, small shrinking towns are not widespread. However, despite these differences, it is noticeable that the development of small towns in the post-socialist period, and thus their decline, has been conditioned by their development during socialism.

The analyses imply that three basic paths of socialist development of small towns can be singled out:

1) intensive growth, especially since the 1970s due to forced urbanization driven by industrialization - delayed industrial development, centrally coordinated (Russia, Estonia, Romania),
2) stable development with a constant number of inhabitants - dense network of small towns (Czech Republic),
3) population decline from the 1980s or earlier due to poor position in the hierarchy of settlements (East Germany, Hungary, Slovakia).

The post-socialist transition brought the small towns that grew artificially during socialism back to the development path without the support of central resources, which caused a great crisis in them. This way it directly affected their shrinkage. On the other hand, in small towns that were in a bad position during the socialist period, the post-socialist transformation further worsened their position and led to an even greater shrinkage. For small towns that had stable development and well-established position in the national system during socialism, post-socialist transformation did not have a significant impact.

5. Small Shrinking Towns in Serbia in the Post-Socialist Context

5.1. The socialist and post-socialist context of development

Intensive urbanization in Serbia began only after the Second World War. In this period, major transformations in the settlement system in Serbia occurred, influenced by economic changes in the country. After the politically initiated deagrarization, industrialization took place in parallel with urbanization, which was not properly directed in order to achieve a more balanced territorial development [37]. The future industrial centres have become places of rapid development and concentration of people and activities. Spatial and demographic imbalances have been formed in the settlements network in Serbia, as well as significant mismatch in the concentration of inhabitants and the degree of socio-economic development. Small urban settlements grew intensively in the period from 1953 to 1981 attracting the population from rural areas. During the 1970s, small towns underwent rapid economic growth and socio-economic change. At that time, they had the fastest growth of GDP, as well as high employment rates [38]. Although, their level of development lagged behind larger cities.

In 1989 Serbia, as well as other Yugoslav republics, had relatively good political and socio-economic conditions for entering the post-socialist transition [39]. However, the autocratic regime, the disintegration of the country, the wars in the former republics, as well as political and economic isolation have stopped the transitional reforms. These impacts have led to hyperinflation, a drastic decline in industrial production and GDP, and a huge increase in unemployment, misery and poverty [40]. Throughout this period, there were intensive migrations from the war-affected regions and a constant ‘brain drain’, i.e. the emigration of skilled workforce from the country.

After the political changes in 2000, which were reflected in the transition from a political authoritarian regime to a democratic order, the transition in Serbia began 10 years later, in much more complex conditions than in most other European post-socialist countries. Political reforms were not accompanied by reforms in the economy, and in most segments the inherited socialist economic system remained unchanged. The privatization was unsuccessful and the economy was not deregulated, which all led to an economic and social crisis. In addition, there are big regional differences in the development of Serbia with developed north (Belgrade region and the Region of Vojvodina), which accounts for over 60% of Serbia's GDP, and the underdeveloped south. The decentralized system, which was the main achievement of the institutional organization of socialism, was completely disrupted in the 1990s due to the authoritarian political regime. Although the position of local governments has improved significantly since 2000, they remain financially and politically dependent on Belgrade.

5.2. Urban shrinkage of small towns in Serbia

Economic and social changes during the 1990s influenced demographic processes in Serbia, changing the network of settlements and creating demographic imbalances. The large parts of the country were left (eastern, southern and to a lesser extent western) and residents migrated to large cities of the main axis (Novi Sad-Belgrade-Niš) [41]. In the period 1991–2002, the Republic of Serbia had a demographic decline of -4.2%, with depopulation being most prevalent in rural settlements (-9.1%). The influx of refugees in this period somewhat mitigated the depopulation trend in Serbia, which was thus a consequence of the negative natural increase. The decline of the urban population has intensified since 2000, which characterize a number of post-socialist countries. In the period 1991–2002, the negative population trend was identified in 31 out of 81 small towns, and in the following inter-census period, that number rose to 57. Figures 1 and 2 show population changes in small towns in Serbia in the periods 1991–2002 and 2002–2011, together with the degree of development of local self-government in relation to the national average.

In the period 1991-2002, the demographic decline affected mainly settlements in the north and east of the country. There can be noticed, however, a great polarization of demographic and economic development of small towns. The difference in economic development between the Region of Vojvodina and Central Serbia is obvious. In Vojvodina, the towns that lost their population in 1991–2002 are mostly located in well-developed municipalities, while in Central Serbia almost all towns are in less developed or underdeveloped municipalities. In the following period, a large number of small towns lost their inhabitants. At the same time, their economic development has declined, although there is still a significant difference between the north and the south of the country.

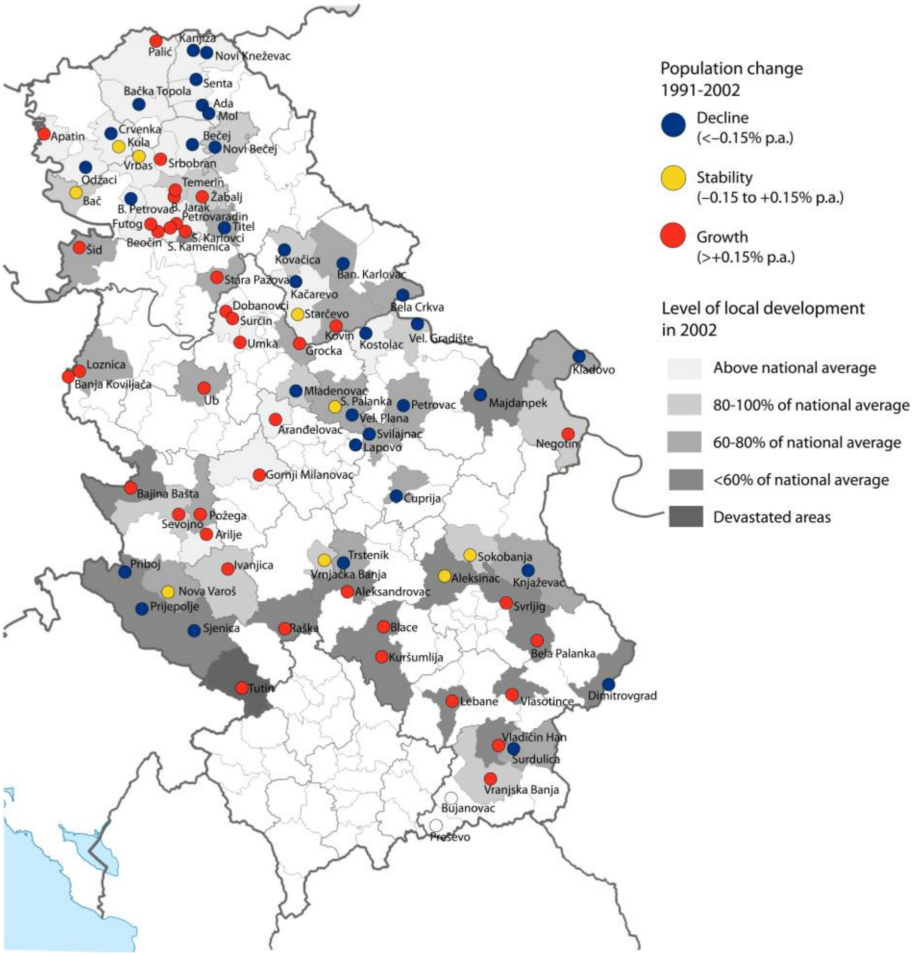

Fig. 1 Change in population and level of development of small towns 1991–2002 [42]

The depopulation of small towns is a consequence of the combined effects of negative natural growth and migration balance, as well as pronounced demographic aging. The trend of negative natural increase began in the municipalities of small towns in Vojvodina, mostly in the 80s, while in central Serbia a decade later. Deindustrialization had a significant impact on the decline of the population in small towns. Former industrial centres (Trstenik, Aleksandrovac, Majdanpek, Prijepolje, etc.) have lost their status due to the inability to adapt to economic transition and gain economic significance in the new context.

Broadly speaking, the problems that small towns in Serbia face today are the result of an insufficiently controlled and directed process of urbanization. After the exhaustion of rural demographic resources, small towns became places of emigration and a source of population for larger cities. Socio-economic changes during the 1990s also affected the population dynamics in small towns and led to a poorer quality of life in them. Due to the centralization of the country, small and medium-sized towns have a weak role in regional and local development [41], and they are often located in areas with pronounced development problems.

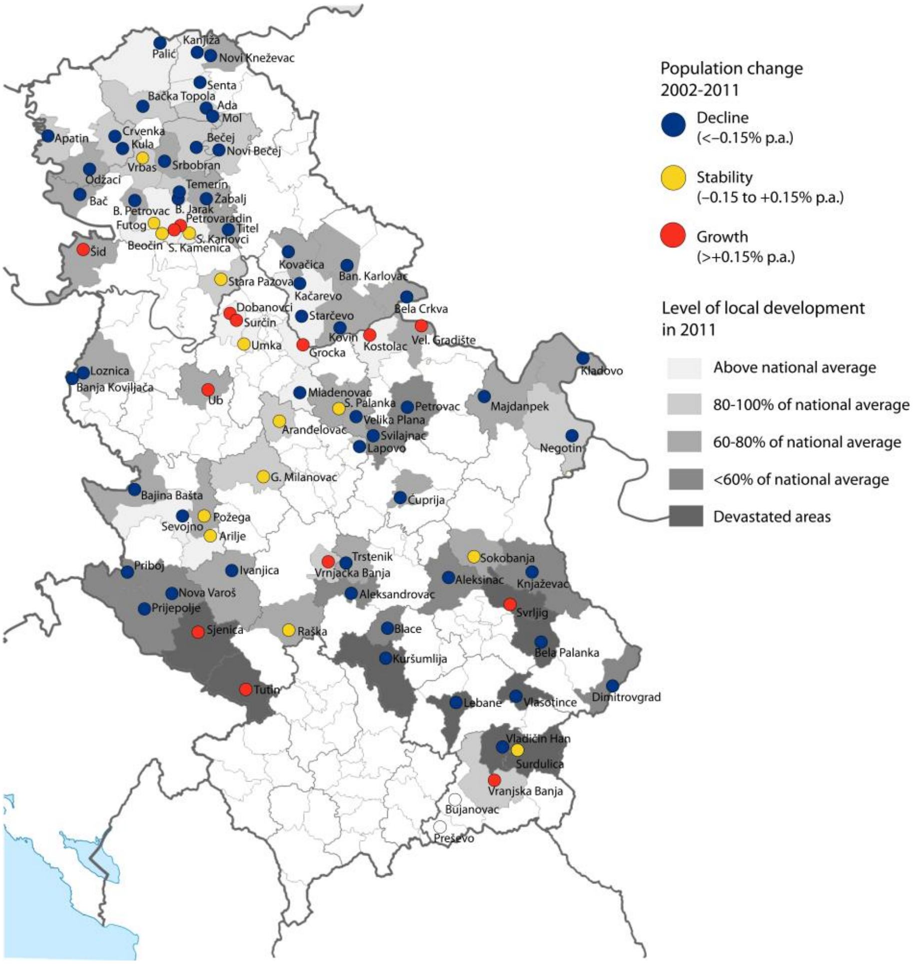

Fig. 2 Change in population and level of development of small towns 2002–2011 [42]

6. Conclusion

Small towns are generally neglected in urban research, and therefore the process of urban shrinkage in them has not gained much attention. However, global socio-economic changes have not affected cities and towns in the same way, which is why there are differences in urban shrinkage. The effects and problems shrinking small towns are difficult to counter and require special planning considerations due to limited capacity and resources for recovery.

Based on the analysis of post-socialist development of towns, as well as the process of their shrinkage, it can be generally concluded that apart from global influences, changes in the social system were the main influencing factor of urban shrinkage, whether acting as a direct cause or catalyst. There are significant differences in the paths of urban shrinkage between small post-socialist towns, which are conditioned by national and local contexts. The results of the analysis indicate that the previous path of development had a strong influence on their development after transformations, which implies to the path dependency. The post-socialist transition has returned small towns to an endogenous path of development without state financial support, which has directly caused an economic crisis in their development or worsen already existing economic and demographic problems. It turned out that only those small towns that had a stable position within the dense network of small and medium-sized towns in the national urban system managed to recover from the current effects of the post-socialist transition.

The urban development of small towns in Serbia has its own specifics, so in addition to many similarities, there are also differences in the shrinkage of small towns. Unlike some CEE countries, where a large number of small towns began to lose population before 1989, in Serbia, except for sporadic cases, population loss in small towns was recorded only after the fall of socialism, and has intensified from the beginning of 21st century. The change of the political and social system in Serbia was the main driver of urban shrinkage, as in other CEE countries, but in Serbia it was more complex. Socio-political circumstances during the 1990s had dramatic effects on the economic and demographic development of cities. The delayed transition has further worsened the position of small towns. On the other hand, the influence of previous development trends during socialism is also noticeable in Serbia. Thus, the shrinkage of small towns is directly related to the unfavourable guidance of the urbanization process during socialist development, and since the 1990s, the effects of polarization of development and centralization in the network of settlements have become even more pronounced.

All of the above indicates the importance of the context in the study of urban shrinkage, whereby it is possible to shape the post-socialist context within the general understanding of shrinking cities. However, the additional influence of national and local factors on shaping the shrinking paths of small towns certainly needs special consideration. This creates a starting point for solving the problems caused by urban shrinkage and planning their recovery, which is important not only for these towns but also for their rural environment, which is directly endangered by their shrinkage.

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MALI GRADOVI U OPADANJU U POST-SOCIJALISTIČKOM KONTEKSTU

Proces urbanog opadanja pogađa veliki broj gradova širom sveta. Prisutan je i u malim gradovima, ali za razliku od velikih gradova, nije izučavan u velikoj meri. Imajući to u vidu, ovaj rad se bavi malim gradovima u opadanju sa fokusom na post-socijalističkom kontekstu razvoja, koji je doveo do novih obrazaca urbanog opadanja u zemljama Centralne i Istočne Evrope (CIE). Nakon izdvajanja specifičnih karakteristika opadanja malih gradova, analiziraju se njihove razvojne putanje u različitim zemljama CIE-e, kako bi se izdvojile karakteristike urbanog opadanja i uticaj post-socijalističke tranzicije na ovaj proces. Posebno se analizira opadanje malih gradova u Srbiji kako bi se utvrdilo da li se utvrđene karakteristike i putanje opadanja prepoznaju u njima i izdvojile specifičnosti tog procesa u odnosu na ostale post-socijalističke zemlje. Sumiranjem generalnih karkteristika razvoja i opadanja malih gradova u zemljama CIE-e, može se zaključiti da urbano opadanje malih gradova nije u svim zemljama podjednako zastupljeno, kao i da postoje izvesne razlike u pogledu dimanike i intenziteta opadanja. Rezultati analize ukazuju na to da je prethodna putanja razvoja imala snažan uticaj na njihovo opadanje nakon post-socijalističke transformacije. Izdvojene su tri osnovne putanje tokom socijalističkog razvoja koje su uticale na različite obrasce urbanog opadanja. U Srbiji je takođe uočeno da je opadanje malih gradova direktno povezano sa nepovoljnim usmeravanjem procesa urbanizacije tokom socijalističkog razvoja.

Ključne reči: *urbano opadanje, mali gradovi, post-socijalistička tranzicija, Srbija*

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PROTECTION OF BUILDING HERITAGE - CASE STUDY OF GREEK BUILDINGS IN DIMITROVGRAD

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Ana Momčilović Petronijević[1], Ivana Cvetković[2], Đorđe Stošić[2]

[1]Faculty of Civil Engineering and Architecture, University of Niš, Serbia
[2]Institute for the Protection of Cultural Monuments Niš

Abstract. *During 2020, the Institute for the Protection of Cultural Monuments of Nis conducted extensive research in the part of the municipality of Dimitrovgrad in order to record buildings, sites or entities with monumental properties. On that occasion, among other things, a larger number of city villas was recorded. The paper presents three selected representative examples of this type of house. An architectural analysis of each of the observed buildings is presented, as well as ortho-photo attachments. The entire procedure of documenting the building is listed and explained, from field drawings, through the elaboration of documentation to the development of 3d models. One of the goals of the entire research procedure, in addition to preparing documentation for further legal protection of buildings, was to educate students in the field of protection of architectural heritage, on specific tasks.*

Key words: *heritage, Greek buildings, Dimitrovgrad, documentation, student education*

1. INTRODUCTION

Institute for the Protection of Cultural Monuments Niš at the end of 2020, conducted a research of the part of the municipality of Dimitrovgrad, within the framework of the Project "Systematic research (recognition) of the part of the municipality of Dimitrovgrad in order to record buildings, sites or units with monumental properties." [1].

The main focus of the entire research was on the area of the upper Ponišavlje, specifically on the city center of Dimitrovgrad. The primary goal was to analyze the preserved architectural heritage of this part of Serbia, which is extremely important for creating the identity of the city. Recognition and mapping of the architectural heritage of the city of Dimitrovgrad was performed, preliminary valorization, historical and

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Corresponding author: Ana Momčilović Petronijević
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: ana.momcilovic.petronijevic@gaf.ni.ac.rs

historiographical analysis of the preserved architectural heritage was initiated, as well as a comparative analysis of archival documents and the current status. [1].

The project consisted of the following parts:

1. Preliminary preparation for research by studying the documentation kept in the Institute, by studying the available archives, spatial planning documentation and relevant literature
2. Collecting data in the field: collecting oral information in direct conversation with locals, architectural surveys in the field and measuring buildings with the preparation of field documentation of the current status, collecting photo documentation, as well as surveying buildings of old urban architecture and architectural entities using 3d photogrammetry. On this occasion, 12 buildings were technically recorded, and 23 buildings, 3 spatial entities and 11 monuments and memorials were photogrammetrically recorded.
3. Systematization and processing of all collected data helped produce the Review of the architectural heritage of Dimitrovgrad [1], a study, which after the project was incorporated into the spatial planning documentation and will serve as a basis for further work on protection and preservation of cultural heritage. The processing of the collected data also included the production of precise 3D photogrammetric models of all recorded structures, which provided reliable quantitative information on the physical condition and appearance of structures.
4. At the subject of Vernacular Construction, at the Faculty of Civil Engineering and Architecture in Nis, the elaboration of drawings and the production of complete architectural 3d models of recorded buildings was performed. This activity represents the final phase of the project, which aims to, in addition to preparing the necessary documentation for further legal protection of architectural heritage, serve the purpose of educating and raising awareness of the value of heritage among new generations of architects, and is a good example of inter-institutional cooperation

Fig. 1 Collection of documents in the field, photo Z. Radosavljević and A. Nikšić, 2020. [2]

The finalization of the project implemented the basic type of protection - protection through documentation, which is the first step in the process of achieving the legal protection (recording and preparation of proposals for determination of immovable cultural property), and the basis for implementing technical protection measures and preservation of architectural heritage.

Heritage protection is also achieved through a planned, continuous process of professional and aesthetic valorization and revitalization, starting from urban units, through rural agglomerations to individual buildings, including those with ambient values.

Research has shown that the city center of Dimitrovgrad is rich in significant architectural heritage, which is insufficiently analyzed, and until the beginning of the project, its precise valorization was not performed by professional services for the protection of immovable cultural property. As a result, the situation is such that there are no protected immovable cultural assets in the city center itself, and one enjoys prior protection. An insufficient number of buildings was identified through spatial planning documentation. The conducted research, in accordance with contemporary principles of conservation, the concept of protection of immovable cultural property has been extended from individual buildings to wider areas – ambient entities. The proposed technical protection measures are not only related to the physical preservation of individual buildings but also to the emphasis on architectural and environmental values of entire entities, so a comprehensive urban renovation of entities with conservation and restoration procedures for important buildings is recommended, while for other buildings the obligation is designing in the context of the ambient [3, 4, 5, 6, 7].

2. A Short Review of Historical Background in Dimitrovgrad

Dimitrovgrad is located in the upper part of the Nisava River, more precisely at the junction of the Ginska River and the Nisava River, and extends across both river banks. It is bordered by hills: Neškovo brdo, Kozarica, Ostri vrh and Mrtvina. Until 1951, the settlement was called Caribrod, and that year, by the decree of the then Government of the Federal People's Republic of Yugoslavia, it was renamed Dimitrovgrad, in honor of Georgi Dimitrov, the Bulgarian president.

The first mentions of Caribrod were recorded by travelers on the Constantinople Road, dating back to the "second half of the Middle Ages" [8]. It is mentioned in the works of many travel writers [9, 10].

After several centuries of slavery under the Turks, Caribrod was liberated by the Serbian army in 1878, and by the decision of the Berlin Congress, it was annexed to Bulgaria. The period after the liberation from the Turks is known as the time of intensive migration of inhabitants from the mountainous regions to the valley of the river Nisava. It ended up in Serbia after the ratification of the border with Bulgaria in 1920.

In 1897, Caribrod was a settlement with about 100 houses. Then began construction of the residential houses and buildings for the needs of state bodies. There are data that Caribrod grew to about 400 houses and about 600 households in one year [1].

The development of the settlement was greatly influenced by the construction of the railway and the railway station. The Belgrade-Niš railway was completed and opened to traffic in 1884 [11], and then construction and connection with the Bulgarian and Turkish railways continued, and in 1888 a connection was established with the Bulgarian railway near Caribrod via a joint Serbian-Bulgarian border station [11].

The urban plan for Caribrod, which was completed in 1893 [9], determined the method of construction, harmonized the heights and disposition of the buildings. The Census Cadastre of Dimitrovgrad from 1951, which is kept in the Cadastre in Dimitrovgrad, is important for understanding the development of the urban matrix of the city [13].

After the liberation from the Turks, a church, a parish home, a gymnasium, but also residential buildings were built. The arrival of a large number of Greek merchant families had a great influence on the architectural design of the city. Carrying their tradition with them, the Greeks (Aromani) built comfortable urban villas which, after their departure, were bought by the well-off local population who continued to live in them. After the First World War, Caribrod became a part of the Kingdom of Serbs, Croats and Slovenes. After the Second World War, there was a period of socialist construction of the country and industrialization [1].

3. Case Study of Greek Buildings in Dimitrovgrad

The architecture of Caribrod (present day Dimitrovgrad) changed significantly with the arrival of a larger number of Greek, trading families, as already mentioned. In this period, urban, comfortable villas were built, especially in so called Small Caribrod - “Strošena češma” [13]. Greek Aromani families left Caribrod in the first decades of XX century, and their splendid buildings were bought by the wealthy -off Caribrod families. These resplendent houses were called by the people after their original or most important owners - Dimitraškovoto, Tukukunskata zdanija, Aginoto or Janćinoto, Bojanćinoto, Mininoto, Daninite, kućata na doktora Boljevskoga (doctor Boljevski’s house) or Gornjite Brezničanje (in accord with the local way of naming things), which remained to theis day, and all together (houses of similar architectural characteristics and period of creation) are called “Grckata zdania” after their builders [1]. In this way, the locals showed respect to them their builders which are not from these areas, and to the important persons from Caribrod who took them over and maintained up to WWII.

What is characteristic of the Old Town architecture of this area is the influence of traditional Balkan architecture, with the presence of architectural styles of European cities. The houses, although with upper floors with decorative elements and decorations characteristic of urban architecture formed under the influence of the Western School of Architecture, were structurally built based on traditional Balkan architecture and local materials. The houses are exceptional architectural examples that show the "collision" of old and new architectural teachings and the incredible ability of vernacular builders to adapt to new influences and needs. They stand out with their architectural massiveness, polygonal foundations and pronounced bays with raised gables. A characteristic element is the top cornice with a frieze decorated with wooden braces and consoles, or vertical profiled decorations in place of the rafters. The facades are basically yellow, and the attics and corners of the building are white. [1,13].

During the field work, expert associates of the Institute for the Protection of Cultural Monuments Nis inspected the condition, and conducted the technical and photographic survey of several buildings in Dimitrovgrad, conducted architectural surveys and measurements of buildings and made graphic plans of foundations and details, description of current condition, characteristic elements, materials and structural assembly of 12 buildings. Precise 3d photogrammetric models of the current condition were made by photogrammetry and orthophoto documents of facades and roof planes were prepared, as a basis for elaboration of field documentation and technical drawings (23 buildings, 3 spatial entities and 11 monuments and memorials underwent photogrammetry). The whole process was accompanied by extensive photo documentation of the general condition of the buildings and characteristic details in the exterior and interior.

The mentioned documentation was systematized, edited and prepared for further processing within the subject of Vernacular Civil Engineering at the Faculty of Civil Engineering and Architecture of Nis, where the files of individual buildings with graphic documents were submitted to students.

- Textual descriptions of structural and aesthetic elements of buildings, descriptions of characteristic details, data on the time of construction, architectural features, historical circumstances, etc.
- Field drawings of the building layouts with dimensions, structural descriptions, cladding and other details.
- Orthophoto views of all façade planes, as well as the fifth façade in true dimensions.
- Precise photogrammetry 3d model of the current condition.
- Photographs of general appearance and characteristic details in the exterior and interior.

Out of a total of twelve processed buildings, we will present three significant ones as case studies: Dzadža's house, Dimitraškovo and Ilkovo buildings, as the most representative examples with a characteristic combination of traditional architecture of this area and the influence of urban design elements.

3.1. Džadža's house

Džadža’s house (“Džadžinoto zdanie”) is a building in 9 Nišava Street, on the cadastre lot no. 645 CM Dimitrovgrad. This is the most representative specimen of city villas – Greek buildings.

It was built in 1903, and its most famous owner is Stojan Dzadzov, a customs officer and commission agent. This luxurious civic house has lavishly finished architectural and artistic elements and details in the spirit of the Neo-Renaissance.

Architectural analysis

The house consists of a basement, ground floor and first floor. The structural system is a classic masonry system. The floor plan is polygonal, measuring 15.5x12m. The basement is partially buried, built of evenly dressed stone blocks, and is accessed from the courtyard, on the northeast side. The ground floor and first floor are made of solid brick. The entrances to the building are diagonally positioned and are accessed via the staircase. The main entrance to the house is facing Nisava Street, set back in relation to the street line, with a magnificent staircase and a porch over which, through a massive double-winged entrance door, the centrally located entrance hall is accessed. The ground floor consists of two independent residential units with three rooms each. The access to the first floor is via a wooden staircase from the hall [1].

Fig. 2 Džadža’s building in Dimitrovgrad, (photo Z. Radosavljević) [2]

The positions of the rooms on the first floor are almost identical to the positions of the rooms on the ground floor, with small departures regarding the openings that connect them. The roof structure of the multi-pitched roof is wooden with tiles as a covering, and large eaves projecting over the edge of the wall. A special feature of the house is given by the richly decorated eaves holders, in the shape of a griffin [14]. Griffins, small "terrifying" stylized figures of fantastic, mythological beasts - dragons, are made of wood, of very stylized shapes. In addition to their functional role in holding the eaves, they are believed to have a role in protecting against evil spirits.

Fig. 3 Eaves detail - griffon, (left) drawing A. Blatnik, 1989, (right) photogrammetry A. Nikšić, 2020, [2]

The decorative plastic on the facade is impressive, and the windows’ design is unusual - with double arches - biforas. The characteristic treatment of the frieze under the eaves is remarkable, as it consists of plaster made of regular squares, with bush hammered finish and even edge, placed between decorative wooden struts in the shape of a griffin. The design of the corners is unique in relation to other houses in Dimitrovgrad. At the ground floor of the house, next to the separating cornice, the decoration is in the form of a pilaster that imitates a pillar, with vertical flutes, base and capital, while on the first floor there is an imitation of masonry with the means of horizontal and vertical quoins [1].

Field documentation, ortho-photo attachments and photogrammetric 3d model of the building

Field documentation of the house was collected on several occasions, and more extensive documentation was conducted in 1989 by the Institute for the Protection of Cultural Monuments of Nis, when the initiative to establish a museum in this building was launched, which was never realized.

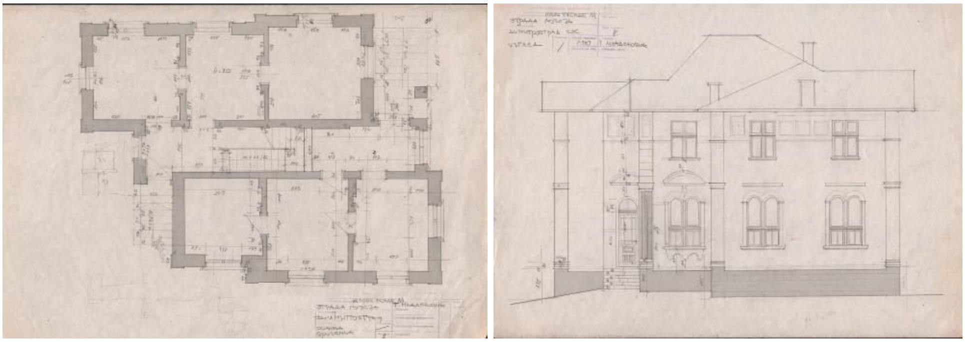

Fig. 4 Ground floor plan (left), drawing by R. Stojanović, façade viewed from Nišava street (right), drawing by T. Mladenović, 1989, [2]

During the field research, a precise 3d photogrammetric model of the building was made, which is available to the public on the Institute's website [15]. By making a 3d photogrammetric model in real dimensions, progress was achieved in the quality of collected documentation, and making technical drawings was greatly facilitated by preparing orthophoto graphic documents of all facade planes, with all details georeferenced, opening positions, heights of eaves, ridges, plinths, etc.

Fig. 5 Ortophoto documents: street (left) and lateral façade (right), A. Nikšić, 2020, [2]

Document elaboration

The students elaborated the documentation prepared in this way within the subject of Vernacular Civil Engineering, sixth semester, at the Faculty of Civil Engineering and Architecture in Nis. With the help of the subject teacher and subject assistant, and on the basis of available field documentation, photographs, orthophoto documents, complete graphic documents were drawn: all floor plans (basement, ground floor, first floor, roof, roof planes), characteristic cross-sections (minimum two), all facades, as well as selected characteristic details. Finally, based on all the data, a 3d model of the building was made, in one of the appropriate software, most often in the software Autodesk 3ds Max.

Fig. 6 Ground level floor plan (left) and façade from Nišava street (right), drawing by Brkić Petar, Drmanac Ivana, Breznik Miloš, based on [2]

Fig. 7 3d model photomontage, Brkić Petar, Drmanac Ivana, Breznik Miloš

3.2. Dimitraškovo zdanie

The civil house of Dimitar Gogova (so called. Dimitraškovo zdanie) is located in Sutjeska Street. 2e, on cadastral lot no. 262 CM Dimitrovgrad. It is positioned on the corner of two streets, and their mutual position caused the irregular shape of the base. The northern wall has a sharp angle in relation to the eastern one. It is noticeable that the urban regulations regarding height of the building, its eaves and cornices are observed [1].

It was built in the spirit of folklore architecture with recognizable decorative roof struts on the facade, with pronounced gables in the dormer area and an attic opening that is decorated and bears the inscription of the investor.

Architectural analysis

The house consists of ground floor, first floor and spacious attic space. The dimensions of the house are 12.5x12m, and the structural masonry system is classic. The ground floor and first floor are made of solid brick, with exactly the same layout. The entrances to the building are positioned on the east side of the house, facing the courtyard. The main entrance to the house with a wide staircase and a characteristic balcony above the entrance part, is recessed in relation to the eastern façade plain. The entrance hall with an accentuated bay and gable on the south façade is accessed through a beautifully decorated double-leafed entrance door [1].

Fig. 8 "Dimitraškovo zdanie", Z. Radosavljević, [2]

The ground floor consists of a central spacious hall that is directly connected to other rooms, while access to the first floor and attic is provided via a wooden staircase from the hallway. Two rooms on the left and right side of the hall, oriented to the south, have a regular square shape, while the other two, in the northern part of the house, have irregular layouts, with acute angle north walls without windows.

The roof structure of the multi-pitched roof is wooden with tiles as a covering, and large eaves projecting over the edge of the wall.

Field documentation, ortho-photo documents and photogrammetric 3d model of the building

Architectural measurements were performed and field documentation was prepared, the focus in the field being on the drawings of the foundations, with the measures necessary for their elaboration, and data on the characteristic details of the construction were collected.

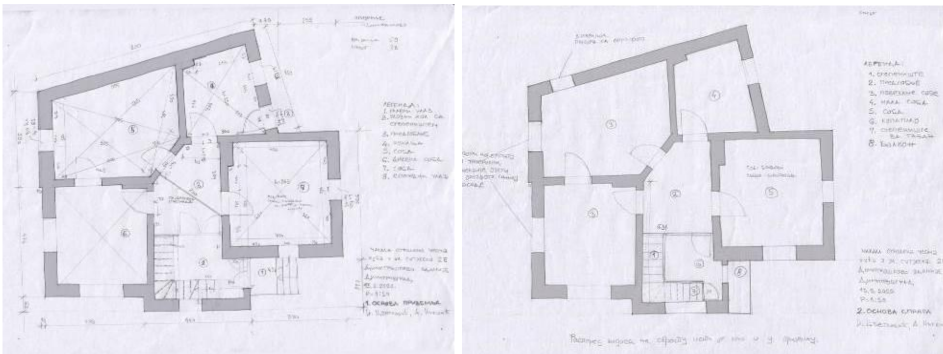

Fig. 9 Ground floor and first floor layouts, drawings I. Cvetković, 2020. [2]

The house of Dimitar Gogov, was also recorded using contemporary methods and orthophoto documents of all façade planes were prepared based on the completed 3d photogrammetry model of the building.

Fig. 10 Orthophoto documents of façades, A. Nikšić, 2020, [2]

Documentation elaboration

As a part of the teaching course, the students, with the help of the subject teacher and assistant, made complete graphic documents: all the layouts, characteristic cross-sections, all facades, as well as selected characteristic details. Finally, based on all the data, a 3d model of the building was made, in the SketchUp software.

Fig. 11 East façade and door detail, Marta Rakonjac and Marijana Ćendić, after [2]

Fig. 12 3d model. Marta Rakonjac and Marijana Ćendić

3.3. Ilkovo zdanie

“Ilkovo zdanie” in Vasila Levskog Street 2. On cl no. 1470 CM Dimitrovgrad, is one of major protected features of the special ambient entity, comprised of the Crkva Presvete Bogorodice (Church of the Holy Mother of God) and Popovska kuća (Priest’s house in the churchyard and the Borisa Breznik house (built around 1890).

Architectural analysis

A two-storey house with peculiar decorations, better known as "Ilkovo", was built in 1910. It consists of a basement, ground floor, first floor and attic. It faces the street with its southern façade, where the construction and street lines coincide. The main (eastern) façade plane faces the courtyard [1].

Fig. 13 “Ilkovo zdanie”, Z. Radosavljević, [2]

The house has an irregular floor plan, with raised and decorative gables and two opposite entrances. Above the main entrance in its original form was a wooden balcony that served as a kind of overhang. The balcony was removed during the renovation of the floor [1].

The structure of the house is a classic masonry system, where the basement is built in a combination of stone and brick, and the ground floor and first floor are made of solid brick. The basement is located below the entire building and is largely buried in the ground. The five rooms around the central hallway are interconnected by arched passages.

Organisation of rooms at the ground floor is identical to that on the first floor and it runs along the basement load-bearing walls.

The mezzanine structure above the basement is the so-called "Prussian vault" and consists of steel "I" sections (rails) at a spacing of about 80cm.

The layout of the rooms on the ground floor and first floor is identical and follows the load-bearing walls of the basement. Centrally, in the east-west direction, there is a longitudinal corridor from which the rooms are accessed from the left and right.

The house has irregular layout in the part of the building towards the street, in order to create space for another gable, on which there is a small rectangular opening – attic vent, under which the initials "V.M." are inscribed. The main (eastern) façade plane with the entrance part is additionally accentuated by a triangular gable with a round attic vent and a decorative plaster finish on the left and right [1].

Field documentation, ortho-photo documents and photogrammetric 3d model of the building

Architectural measurements and preparation of field documentation entailed a tour of the accessible premises of the house, measurements were made and the dispositions of the basement, ground floor, first floor and attic were made. The precise appearance of the house was obtained from a 3d photogrammetric model of the building, i.e. an orthophoto document.

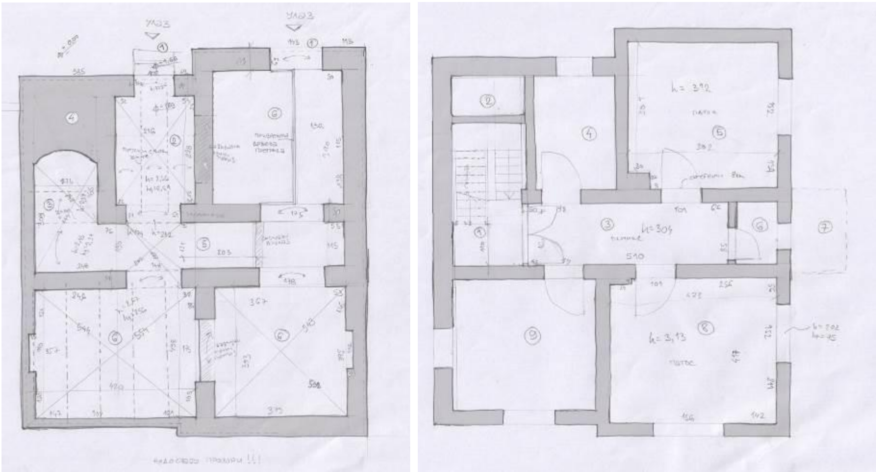

Fig. 14 "Ilkovo zdanie", basement layout (left) and of the floor (right), field drawings, I. Cvetković, 2020, [2]

Fig. 15 Ortophoto documents of facades, A. Nikšić, 2020, [2]

Documentation elaboration

The floor plans of the basement, ground floor, first floor and roof, longitudinal and cross section, detail of the Prussian vault above the basement, detail of the ceiling support above the ground floor, as well as details of the window openings have been elaborated for Ilkov's building. A 3d model of the building in Auto Cad was also made.

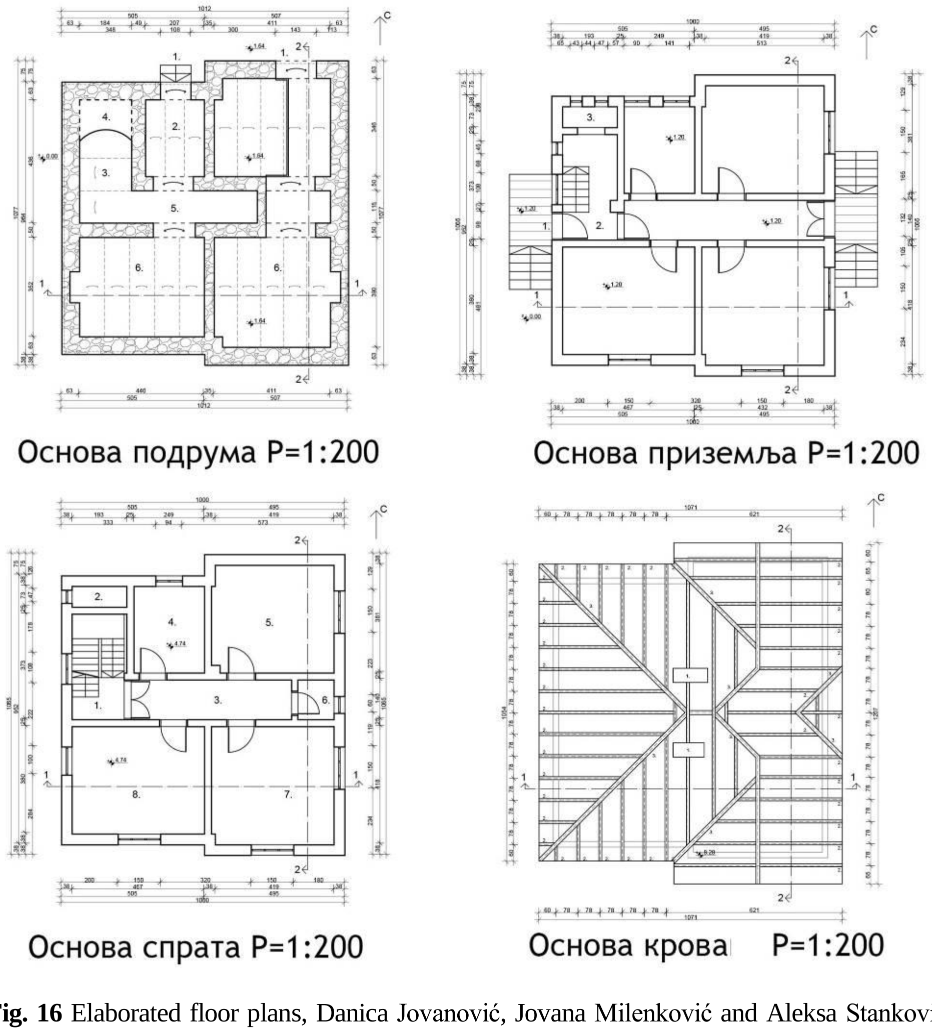

Fig. 16 Elaborated floor plans, Danica Jovanović, Jovana Milenković and Aleksa Stanković after [2]

4. CONCLUSION

The protection of buildings that have monumental properties is the duty and moral obligation of all of us. It is inevitable that many buildings of architectural heritage are deteriorating, due to various factors: unresolved property relations, lack of financial resources, non-recognition by the relevant competent institutions, lack of interest of the owners, unsustainability, etc. The fact is that the buildings of vernacular architecture are more endangered than other types of buildings. Having in mind all the above, protection through documentation is the basic type of protection [5, 6, 7]. An example of good practice is the successful process of recognizing, valorizing, and then completing the documentation of Greek buildings in Dimitrovgrad, through inter-institutional cooperation between the Institute for the Protection of Cultural Monuments Nis and the Faculty of Civil Engineering and Architecture, University of Nis. The prepared documentation will certainly be used for the preparation of proposals for the determination of immovable cultural property, which will also provide legal protection for these facilities. Publishing of the study [1] which is implemented in urban and planning documents of the municipality of Dimitrovgrad will contribute to understanding the value of immovable cultural heritage and raising awareness of the importance of its protection. Educating young people by pointing out these potentials and accompanying problems will create architects in the future who will take care of the cultural heritage.

Note. *During the implementation of the project "Systematic research (recognition) of the municipality of Dimitrovgrad with the goal of recording buildings, sites or units with monumental properties" all photogrammetric surveys of individual buildings, spatial and environmental units and monuments were made by architect Aleksandar Niksic, using drones and cameras, additional verification the dimension of the model was performed on the basis of the collected technical drawings, which achieved precision and a higher level of quality of the made 3d model. All field measurements and technical drawings of the presented buildings were made by the architect Ivana Cvetković as part of the realization of the mentioned project.*

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ZAŠTITA GRADITELJSKOG NASLEĐA – STUDIJA SLUČAJA GRČKIH ZDANJA U DIMITROVGRADU

Tokom 2020. godine su, od strane Zavoda za zaštitu spomenika kulture Niš, vršena opsežna istraživanja na delu opštine Dimitrovgrad u cilju evidentiranja objekata, lokaliteta ili celina sa spomeničkim svojstvima. Tom prilikomje, između ostalog, evidentiran veći broj gradskih vila. U radu su prikazana tri odabrana reprezentativna primera ovakvih objekata. Prikazana je arhitektonska analiza svakog od posmatranih objekata, a zatim su prezentovani orto-foto prilozi. Naveden je i objašnjen čitav postupak dokumentovanja ovih objekata, od terenskih crteža, preko razrade dokumentacije do izrade 3d modela. Jedan od ciljeva čitavog postupka istraživanja, pored pripreme dokumentacije za dalju pravnu zaštitu objekata, je i edukacija studenata u domenu zaštite graditeljskog nasleđa, na konkretnim zadacima.

Ključne reči: *nasleđe, grčka zdanja, Dimitrovgrad, dokumentovanje, studentska edukacija*

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Original scientific paper

PERCEPTION, EVALUATION AND PREDICTION OF THE SHOPPING MALL BUILDING ASSESSMENT

UDC 725.26
69.059.4

Jasmina Tamburić, Jovana Vukanić, Vladan Nikolić

Faculty of Civil Engineering and Architecture

Abstract. *The change in the condition of a building over time in the technical terms can be seen as a deteriorating process of aging of the building elements and the loss of original technical performance. In the economic terms, it is the process of changing the value of the facility and new investments in the maintenance of the facility, as well as servicing the system of equipment and installations, during the service life. The technical dilapidation of the building, or of its elements, can lead to unwanted consequences of endangering the lives and property of people, and of the disruption of functional and aesthetic values of the building, which is very important for the fate of shopping malls. With the exhaustion of the technical life of the building, questions and decisions about the revitalization or demolition of the building necessarily arise. The value of the facility decreases over time, and the costs of maintenance and repairs increase. Over time, regardless of the actual condition, the facility and equipment systems become obsolete when the first needs for modernization arise, which entails new costs. The ratio of maintenance costs is constantly growing, until the moment when the level of profitability of further investment in the renovation of the facility and the system is reached, i.e. until the moment of exhaustion of the economic life of the facility. The paper presents the relationship between preventive, reactive and predictive maintenance costs as well as methods of monitoring, prediction and evaluation of the durability condition of shopping mall facilities.*

Key words: *perception, evaluation, prediction, building condition, shopping malls*

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Corresponding author: Jasmina Tamburić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: ministo@yahoo.com

1. Introduction

Building Condition Assessment (BSC) is based on monitoring the economic performance of the building, on the formation of a database on investments over time based on the procedures of asset management AM, where the strategy of investments and risks and the way of further functioning of operational work on the maintenance of the facility is being conceived. In shopping malls, both the proper technical condition of the facility and the flawless functioning of the equipment and installation systems are very important, along with the regular maintenance of the level of aesthetic characteristics and comfort, which requires increased costs. Remodeling is a way to restore and improve the technical, functional, aesthetic and economic performance of a building. The economic life of shopping mall buildings can be shorter than the technical service life in conditions of changes in market conditions, changes in supply and demand, competition, unemployment and declining purchasing power, so possible solutions are: remodeling, conversion or sale regardless of technical condition of the buildings. In the architectural sense, the disruption of the functional and aesthetic values of the building, outdated forms and shapes is of great importance in the remodeling of shopping malls. This includes changes in the state of functioning of devices and equipment of the facility, their obsolescence and maintenance. The modeling of deterioration and the calculation of the service life of buildings is based on theoretical models of deteriorating changes that occur in the aging process or caused by physical, mechanical and chemical actions of the environment over time. Models contain relevant parameters important for describing changes in the performance of an object or some of its elements over time.

Predicting the future condition of the facility is based on collecting and forming a database on the current condition and behavior of the facility, on the basis of which probabilistic prediction models are developed. From an economic point of view, it is necessary to monitor the costs of operation, which in practice are often the decisive factor in deciding on further financing or termination of the facility, its demolition or conversion. In shopping malls, from the architectural aspect, it is especially important to maintain visual, functional and aesthetic values at every moment of the life cycle of the observed building.

2. Monitoring, Evaluation and Prediction of the Durability Condition of Shopping Mall Buildings

Condition prediction methods can be traditional, which are based on the empirical data (experience), methods of condition monitoring and integrated methods. Condition monitoring method can be an expert report (Fig. 1a), when it comes to the material condition of the building or a report obtained by a survey (Fig. 1b), especially when it comes to the non-material features such as: functionality of the building, esthetics, features related to entertainment, sport, cultural and other social events. Building condition assessment can be also based on:

1. Information of event data about the building behavior over time or
2. Information of the building condition monitoring data - measurements.

The method based on event data information involves the study of the interaction between different data such as: data on the building, the environment, the characteristics of the building from the existing documentation, interventions on the building, etc. In addition to these data, the condition monitoring method and integrated methods require data obtained from visual inspections, laboratory or in situ testing data. The first step in data collection is to assess the condition of the building by routine visual inspection, based on which it is decided to plan a more detailed research if necessary. The second step involves detailed research - special testing of materials and analysis of deterioration processes to assess safety, durability and identification, detection and prediction of corrosion processes and the degree of damage. If necessary, the third step is the examination of structures (testing the response of the structure) and research related to the analysis of actual effects, determining the bearing capacity and safety assessment. The prediction of the remaining service life of the facility, while ensuring safety, serviceability and functionality, is based on data on the condition of the facilities of the considered stock. On the basis of the database, further decisions are made on the type and manner of maintenance of facilities and priorities for repairs, rehabilitation, reinforcement of facilities, for the same or increased effects in further service are determined.

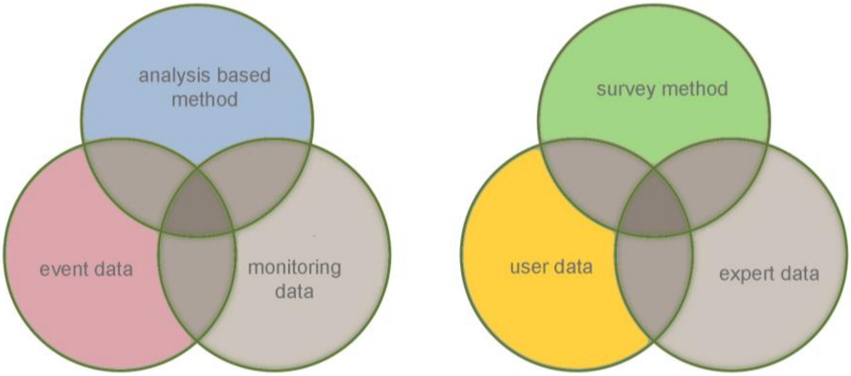

Fig. 1 Methods of monitoring and prediction of the condition a) based on the expert report, b) based on the survey

2.1. Monitoring

Sustainable architecture is based on the application of new design concepts, the introduction of new materials, the application of more complex systems, monitoring the condition of the building for a certain period of time (service life of the building). The architectural concept of the building should anticipate possible changes during the operation, i.e. to predict the possibility of remodeling in terms of changing the function, expansion of the building and replacement of individual elements. The building conditioning method can entail monitoring. Monitoring is a systematic, continuous and incessant process of monitoring of the building condition during a certain time period in respect to the planned investments, activities and outcomes. Monitoring is a routing collection of information on the building, i.e. incessant, systematic and purposeful monitoring, observation, recording and assessment of the building condition with a goal of forming a database.

2.2. Building durability curve according to Schroeder

The performance of a building or of its elements changes over time. When it comes to the aging process, then these are values that are constantly declining over time. The decline in value over time can be defined in several ways. The state of a building according to Schröder is defined by the degree of state W which is mathematically expressed by a function:

$$W = 1 - ŧ^{a} \quad \text{where:}$$
$$W \leq 1,$$
$$0 \leq ŧ \leq 1$$

Whereby ŧ does not represent the real time but it is given in the function of the unit service life. The value W is given in relation to 1, but it can be presented in percents in relation to 100. The maximum value of the time is the service life which is also expressed in units. The modified method, by introducing the real time and the building duration time – technical service life T, can be presented by the expression: $W = 1 - ŧ^{a}$, whereby $W \leq 1$, is the value depending on the current time t and technical service life T.

$$ŧ = t/T \text{ , whereby:}$$
$$0 \leq ŧ \leq 1, \text{ i.e. } 0 \leq t/T \leq 1, \text{ ili } 0 \leq t \leq T$$

Element condition change over time, in a favorable environment is represented with the square function, i.e. with the exponent a=2

$$W = 1 - t/T)^{2}$$

Element condition change over time in a medium favorable environment is represented with the linear function, i.e. with the exponent a = 1

$$W = 1 - t/T)^{2}$$

Element condition change over time in an unfavorable – aggressive environment is represented with the function, i.e. exponent a = 0,5

$$W = 1 - \sqrt{((t/T))}$$

Technical life of the building elements T is defined depending on the type of building elements and material they are made of. (Simon, 1991)

The remaining service life is the time

$$t' = (T - t)$$

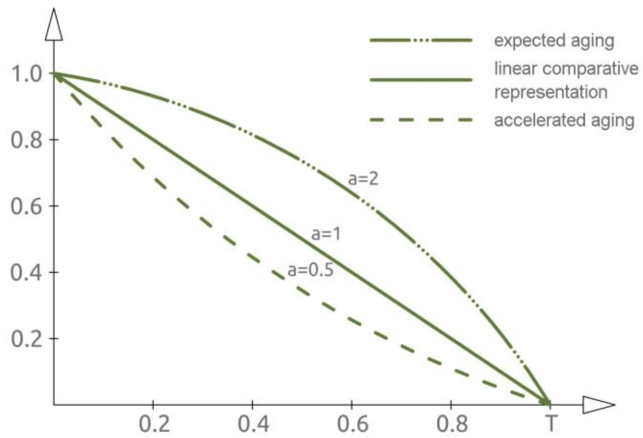

Fig 2. Element condition change over time t up to the value T

2.3. Monitoring and prediction of the maintenance condition of shopping mall buildings

Building maintenance can be realized either through the momentary intervention with a goal of removing the malfunctioning of the building or as Time-Based Maintenance (TBM) according to the plan or as Predictive Maintenance (PM) according to the building condition CBM (Condition Based Maintenance), which is based on the expert monitoring of the evaluation of the condition, maintenance, and predicted potential interventions over time, in order to avoid unforeseen material damage of the building or consequences of the risk to the property and lives of people. Building maintenance can be: reactive RM (Reactive Maintenance), where the intervention is undertaken at the moment of malfunction or failure of some building element of equipment; preventive PM (Preventive Maintenance), where it is intervened for the purpose of regular maintenance according to the time plane or service life, and predictive PdM (Predictive Maintenance) which is based on monitoring and prediction of building condition, where it is intervened according to the actual condition of the building and equipment (on whose basis the maintenance priorities are determined). For redistribution and reduction of maintenance cost are used modern computer systems such as BMS (Building Management Systems), where the predictive maintenance is given advantage over reactive maintenance. According to the research data from USA (Sullivan, Melendez, Pugh, & Hunt, 2010) reactive maintenance of buildings RM is 55% of all maintenance cost, while preventive maintenance PM is 31% and predictive PdM maintenance 12%, and other 2%.

Table 1 Share of individual types of maintenance

RM *(Reactive Maintenance)*	55%
PM *(Preventive Maintenance*)	31%
PdM *(Predictive Maintenance*)	12%
Other	2%

Total cost of building maintenance include the cost of Maintenance 35%, Utilities 37% and Janitorial 28%. (IFMA, http://www.ifma.org/, 2009)

Table 2 Distribution of building maintenance cost

Maintenance	35%
Utilities	37%
Janitorial	28%

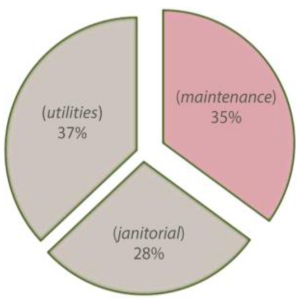

Fig. 3 Distribution of building maintenance cost

Preventive maintenance, against reactive maintenance can save 12-18%, and predictive maintenance against preventive maintenance can save 8-12% of total maintenance cost. Based on the conducted further research, a ratio of these types of maintenance is proposed:

$$\boldsymbol{RM : PM : PdM = 1 : 5 : 10}$$

Predictive maintenance is based on the collection of expert data, measurement or periodic reviews, monitoring, as well as processing of this data in order to make conclusions and decisions about maintenance. The cost of maintaining a facility, over time until the final exhaustion of its service life, exceeds the investment value of the facility (Kriegesmann, 2002). After only 7 years, the maintenance costs of the facility reach the investment value of the facility, and after 40 years, they reach five times the value of the facility. Maintenance costs are a relevant factor in determining the economic service life of a facility (Figure 4).

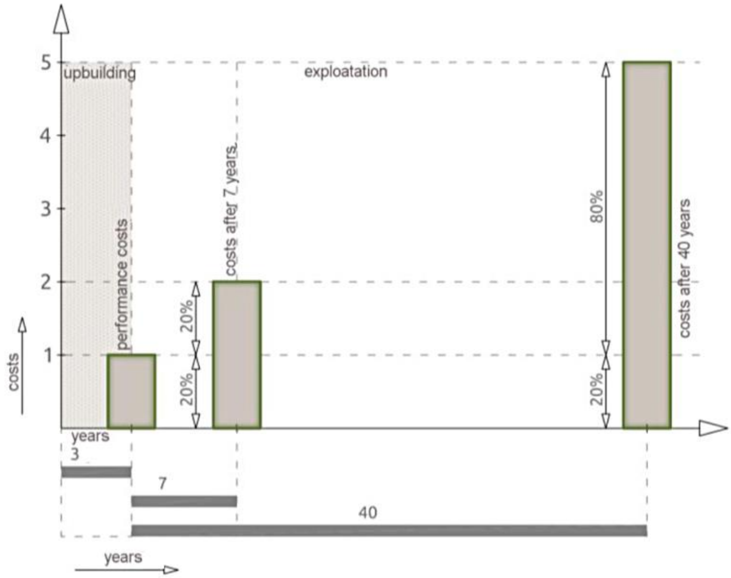

Fig. 4 Maintenance costs as a relevant factor in determining the economic service life of a facility

3. Methods and Techniques in the Realization of the Goals of Shopping Malls Remodeling

3.1. Prediction Method

The strategic goals of remodeling the facility in the technical sense are to obtain: safe, usable, durable, functional, attractive, environmentally friendly and healthy facility. In the sense of energy, it is getting a more efficient facility in terms of energy consumption, and in the economic sense, getting an increase in sales levels and levels of visits to the SM, as well as reducing maintenance costs. Decision-making in order to realize the goals in revitalization planning, i.e. remodeling, is based on research methods. The most well-known research methods used today are: SWOT, portfolio, benchmarking and prediction methods, (Table 5.3)

Table 3 Distribution of building maintenance cost

RESEARCH METHODS			
SWOT	Portfolio	Benchmarking	**Prediction Methods**

Further research will use prediction methods based on the building condition, in technical, functional and aesthetic terms, which are variable over time. A stochastic analysis will be used to predict the future condition of the building (Table 5.4). With this method, which is based on the irreversible process of aging of the building, it is possible to determine the time in which a decision must be made on the further fate of the building (revitalization, conversion or demolition).

Table 4 Methods of building condition prediction

PREDICTION METODS		
Mathematical methods:	Qualitative methods:	Explorative methods
Stochastic analysis	Brainstorming	Scenario Method
Method of the trend	Delfi method	Modeling and simulations
Correlation and regression analysis	Expert analysis	Morphologic analysis
Sensitivity analysis	Interview Method	

Further research in this paper employ the mathematical probabilistic method – “Markov”, based on random, i.e. stochastic variables.

3.2. Methods of building condition evaluation

Evaluation is a systematic analysis of the process in relation to the planned outcomes, with the application of previously established criteria, in order to improve efficiency. (Detels, Holland, Mc Ewan 2004), (AEA, 2005) In previous research, as well as in the current technical regulations, the assessment of the condition of buildings is related to irreversible aging processes of materials. In the technical sense, it is related to the change of the structure of the material and the change of its characteristics, the change of appearance and the change of mechanical, physical and chemical properties, and in the economic sense to the increase in the value of maintenance costs and the decline of the building value over time. Maintaining a high level of comfort - maintaining cleanliness, maintaining temperature and humidity with the requirement that there is no sense of difference in air quality in any part of the indoor space, which is a common requirement in shopping malls. It is necessary to sustain the light levels and sound insulation, which requires constant monitoring of the equipment system condition and require additional costs. Much attention is paid to this part of the functioning of the system, equipment, maintenance of the facility and related costs in the SM, because these costs during the service life of the facility are very high and quickly exceed the cost of the facility itself.

There are no uniform criteria for assessing the condition of a building. Evaluation of the condition of the building is most often based on the assessment of the level of the condition (assessment of the condition) or on the indices of damage. Condition evaluation can be based on technically or economically relevant parameters. In practice, damage indices or building condition indices are used, which technically represent the ratio of the condition of the condition of the damaged and of the new building, or economically speaking, the cost of repairing the damage in relation to the value of the building. The contemporary approach to this problem is based on the formation of priority condition matrices, age condition matrices and energy state matrices, on the basis of which the Facility Condition Index (FCI) is determined (IFMA, http://www.ifma.org/, 2009). Evaluating the condition of a building in some methods comes down to determining the class or code of the condition of the building. The procedure for determining the assessment of the condition and maintenance of the facility is based on direct and indirect methods.

Direct methods are based on the standard of direct determination - by measuring and forming a database of damage and on the basis of permissible tolerances of elements in high-rise buildings, their condition is determined according to German standard DIN 18202:2005-10, so that each element of the building is able to meet the requirements facility, with the required security.

Indirect methods relate to the determination of the characteristics of the building condition in terms of the quality properties of the building function and purpose, in all as stipulated in the standard EN 15341:2005-10

4. CONCLUSION

The paper presents the interrelationships of preventive, reactive and predictive maintenance costs, as well as methods of monitoring, predicting and evaluating the durability condition of shopping center facilities. These methods and techniques are presented in the function of realizing the goals of remodeling of shopping malls. The need for remodeling of shopping malls arises during the operation of the facility. Usually, the first interventions on the building are aimed at its modernization, improvement of functional or other characteristics. Each stakeholder has its own role and sphere of interest, the reciprocity of which results in overall quality. Shopping malls in terms of quality depend on the fulfillment of three basic requirements, in terms of technical characteristics of buildings and equipment, building management and architectural qualities.

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PERCEPCIJA, EVALUACIJA I PREDIKCIJA STANJA OBJEKATA TRŽNIH CENTARA

Promena stanja objekta tokom vremena u tehničkom smislu, može se posmatrati kao deteriorativni proces dotrajavanja (starenja) elemenata objekta i gubitka prvobitnih tehničkih performansi. U ekonomskom smislu to je proces promene vrednosti objekta i novih ulaganja u održavanje objekta, kao i servisiranje sistema opreme i instalacija, tokom upotrebnog životnog veka. Tehnička dotrajalost objekta, ili njenih elemenata, može da dovede do neželjenih posledica ugrožavanja života i imovine ljudi, do poremećaja funkcionalnih i estetskih vrednosti objekta, što je za sudbinu tržnih centara veoma važno. Icsrpljenjem tehničkog veka trajanja objekta, nužno se nameću pitanja i odluke o revitalizaciji ili rušenju objekta. Vrednost objekta vremenom opada, a troškovi održavanja i popravki rastu. Vremenom, bez obzira na faktičko stanje, objekat i sistem oprema zastarevaju, kada dolazi do prvih potreba za modernizacijom, što povlači nove troškove. Odnos troškova održavanja stalno raste, sve do trenutka kad bude dostignut nivo isplativosti daljeg ulaganja u obnovu objekta i sistema, odnosno do trenutka icrpljenja ekonomskog veka objekta. U radu je prikazan međusobni odnos preventivnih, reaktivnih i prediktivnih troškova održavanja kao i metode praćeanja, predikcije i evaluacije stanja trajnosti objekata tržnih centara.

Ključne reči: *percepcija, evaluacija, predikcija, stanje objekta, tržni centri*

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Original scientific paper

FROM INVARIANCE TO DIFFERENCE: ARCHITECTURAL DRAWING IN THE DIGITAL AGE BETWEEN STRUCTURALISM AND POST-STRUCTURALISM

UDC 72.02:7.038.542

Hristina Meseldžija

University of Belgrade, Faculty of Architecture, Belgrade, Serbia

Abstract. *Radical changes in architectural thinking resulted in shifting the role of drawing in the architectural design process. This paper examines the act of reading the architectural drawing in contemporary design practice. Focusing on the field of humanities, this paper aims to define different perspectives of understanding and interpreting the work of drawing. Various positions of contemporary architectural drawing can be traced by following two parallel lines of development, whose theoretical settings are still important and relevant in the present-day. These pathways share their common ground in Ferdinand de Saussure's setting of linguistic theory from the late nineteenth century. Architects engaged in the academic work, as well as practitioners, showed great interest for philosophy and new philosophical practices, which later contributed in re-examining the architectural discipline and establishing a new theoretical framework. In the 1960s, due to a change in the architectural paradigm caused by the current anthropocentrism and the breakthrough of the humanities into the architectural discipline, architecture articulated its own trends, building on the premises of French philosophers. The rising interest for philosophers who based their doctrines on the development of linguistic theory generated two overriding methodological directions – structuralism, with a focus on the idea of establishing universal internal structures as cultural foundations, and poststructuralism - as its critique, which shifts focus to radical articulation of the specificity of individual elements. Considering the terms invariance and difference as the basic concepts, the subject of analysis of this paper is an architectural drawing which in the contemporary architectural education as the most meritorious field of research in architectural design, occupies different forms and enjoys manifold interpretations in different contexts.*

Key words: *architectural drawing, structuralism, post-structuralism, digital paradigm, architectural education*

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Corresponding author: Hristina Meseldžija
University of Belgrade, Faculty of Architecture, Bulevar Kralja Aleksandra 73/II, 11120 Belgrade, Serbia
E-mail: hristina.stojanovic@arh.bg.ac.rs

1. INTRODUCTION

The discipline of architecture in the post-war modernism crisis, has been reshaped under the influence of deconstructing the former linguistic concepts and the emergence of structuralism on the basis of semiotics. Building on the premises that the architectural drawing is one of the basic and, at the same time, the fundamental authorial work of the architect, the subject of this paper focuses on understanding and defining its various **forms** and **positions** within the contemporary architectural practice. The contemporary context shaping the discipline of architecture is constantly reinterpreting and collaborating with analytical strategies of structuralism and post-structuralism. Following the changes in architectural paradigms, the role and importance of architectural drawing as a design tool, means of communication and/or representation, is changing. These radical changes are reflected in all forms of architectural activity – in architectural practice, yet more in architectural education.

In the first section of this paper, the notion of drawing will be analyzed and defined in the narrow disciplinary framework of contemporary architectural practice, above all, focusing on its role in the architectural design process. In this sense, it is of great importance to understand and differentiate between the use of drawing in the architectural discipline and fine and applied arts, hence, to understand the concept of architectural drawing, and its differences in relation to drawing as a separate term. After defining the concept of architectural drawing, the second section of the paper will consider the process of reading the architectural drawing through the lens of paradigmatic changes and aforementioned strategies - structuralism and post-structuralism. This part will also consider the status of drawing in the postmodern society being shaped by digital technologies. The third section will serve as an introductory chapter to the case study analysis, as it will explain the analytical methods following the intentionally designed critical apparatus. Referring to the authenticity of the drawing, its structure and potential, and set of parameters considering the question of focus, scale and technique, the next and the last section will conduct the analysis of three Master projects from students of the Faculty of Architecture, University of Belgrade, who participated in the international student competition The RIBA President’s Medals Student Award.

2. THE LANGUAGE OF DRAWING

Despite numerous technological discoveries and paradigmatic shifts in the field of architectural theory and design, the drawing still remains the fundamental tool for communicating and representing crucial ideas and concepts in architecture. The long and rich evolutionary path of architectural drawings established several roles of drawings that were always in the service of understanding and thinking about space as the basic architectural concept. Nowadays, architectural drawing is used in various ways. From a historical perspective, in the greatest scope of its application, drawing represented a communicative apparatus between the architect and the builder by transmitting all objective attributes of the architectural object necessary for its understanding and construction. An architectural drawing can also convey the objective or subjective attributes of an existing building, as well as of a building or space devoid of ever being constructed. This particular field opens up the potential of drawing to critically observe, represent, and most importantly, explore concepts of architectural space by navigating critical thinking in the phase which precedes the architectural design process. Therefore, this section starts from the assumption that the drawing in the digital age, in the process of architectural design is becoming a versatile, multi-layered and hybrid tool which, in addition to its primary roles, has an increasingly important position in researching architectural design concepts.

2.1. Exploring the term: Drawing or Language?

The English term for design comes from the Italian, or Latin, word *disegno*, which means both drawing on paper and emphasising an idea. (Hill, 2006) Although the process of architectural design coincides with the work of drawing, the basic difference between drawing and designing is that design implies drawing, but not vice versa - drawing does not imply designing. Therefore, drawing can be understood as the primordial activity of an architect. Nevertheless, drawing (n.) as an evident product of the activity of drawing, is silently considered being a by-product or auxiliary tool of architectural activity, whose only meritorious legacy is actually an architectural object. Speaking of, according to Christoph Hubig, the term tool can be understood as a resource for materializing ideas about future objects, things or spaces which remain immaterial intellectual constitutions. "By using a tool, the subject enters into a relationship with external and internal nature, which thus becomes its subject". (Hubih, 2014) Therefore, drawing considered as a tool in architectural design process accumulates ideas of an architectural object or space and connects them with reality, whilst balancing between sustaining imaginative constitutions in the architect's mind and material ones drawn on paper. Robin Evans introduces the phrase architectural drawing, explaining the relationship between the architect as the author of the drawing and the drawing itself, noting that architects, unlike other artists, never work in direct contact with the designed object, but always indirectly, through drawings. (Evans, 2003:156) Furthermore, Evans relies on Alberti's statement that architects do not make buildings, but drawings of buildings. (Evans, 2003:156) It can be said that drawing as an author's work has two original forms - when it is created before what it represents, most often an architectural object, and is given the title architectural, and yet, when it is created on the basis of an existing building or space, remaining in the domain of architecture but gravitating towards fine or visual arts. (Evans, 2003:156)

Explaining the terms architectural drawing and the act of drawing, one can further initiate a discussion on the similarity of drawing and language and also on the distinction between the use of language and drawing. The rising presence of the opinion that the drawing can be evened with language follows the period of the philosophical shifts that changed the leading discourse on the language structure and understanding of language as a universal knowledge. Starting with late 1960s, speech and writing were no longer understood as an a priori communication tools. From Saussure's point of view, language is a social construct built on the basis of collective knowledge, founded on universal ideas in every human's mind. Likewise, to name drawing for language, means to declare its origin in human's mind as a universally implemented idea, hence to base its appearance in the external world on rules, standards and norms of the act of drawing that are adopted as general or global. Saussure distinguishes language as a social construct and speech as a current form of language or its final outcome. (Mitrović, 2011:148) At the same time, drawing in architecture can be defined diachronically - as a technical construct, based on norms and rules of its creation and, synchronously - as an individual interpretation of these rules, which as the final outcome offers an image or a series of images. Furthermore, Marco Frascari in his paper *Splendour and Miseries of Architectural Construction Drawings* distinctly separates two types of drawings, naming them both as architectural. He focuses on explaining the difference between drawings as carriers of ideas about architectural space and drawings as instructions for building an architectural object. Frascari writes about the insurmountable gap between two types of drawings that are equally present in architectural activity - architectural drawings characterized as being subjective and rather suggestive, and construction drawings as being objective and neutral. (Frascari, 2010) "Architects express their hopes and desires, their vision of society and humanity not only in their design drawings but also through construction drawings..." (Frascari, 2010:108) On the other hand, returning to Evans as he elaborates on the closeness between architecture and language, he believes that architecture is not a language after all, still it shares many similarities with it. The force of drawing, as well as the power and force that language has as a communicator is in its diversity and distance from what it represents. (Evans, 2003:154) It is this distance that opens the spectrum of possibilities of reading and understanding the drawing during its interpretation - which is proportional to the degree of abstraction of the represented object.

3. Paradigm Shifts: Positioning the Drawing Somewhere In-Between

The evolutionary path of drawing can differ in relation to two aspects – the way architectural drawing is being produced and the way architectural drawing is being interpreted. Concerning the former one, it is important to mention two fundamental paradigm shifts shaping the production of drawings – from a construction site to paper in the fifteenth century and from paper (manual or hand-drawing) to computer drawing in the late twentieth century. (Carpo, 2011) The changes that preceded the development of architectural drawing in the twentieth century were debated from two points of view. While traditional media theorists, such as William Ivins, linked one of the most important changes to the invention of printed image and linear perspective, on the other hand, new media theorists, such as Lev Manevich are linking them to the discovery of photography and the evolution of cinematography. (Carpo, 2011:11-12) However, the paradigmatic changes related to the subject of this paper imply key technological innovations that shaped the drawing at the beginning of the twenty-first century. The emergence of information technologies in the 1990s changed the way the work of art is being produced. This led to the creation of variable products and the use of parametricism in the architectural design process, which positioned the discipline of architecture within the digital framework and opened up a spectrum of new possibilities in exploring the language of architecture.

Speaking of the former evolutionary path, the one related to reading and interpreting the architectural drawing, its pivotal momentum can be tracked down to the period of 1970s. The shift in the linguistic structure by establishing the relationship between denotative and connotative meaning, indirectly changed the essence, that is, the meaning of the drawing itself. The second half of the twentieth century, especially the seventies and the eighties, in addition to adopting and consuming the doctrines of linguistic, as well as philosophical and anthropological theories, placed the architectural drawing, which had undergone continuous re-examinations, in the centre of attention. On the one hand, the presence of the drawing became commercialized, while on the other, the drawing started to move away from its previous role – of representing architectural objects and space, and started to build its own autonomy, by representing only itself.

On the threshold between the changing spirit of an ending epoch, in the desire to establish a critical attitude towards the architecture of modernism, avant-garde architectural groups commenced using new forms of drawing. The early stages of postmodernism and deconstructivism, congested with the previous ideology, began to offer new solutions following the radical changes that were seizing the everyday life.

3.1. Drawing parallels with structuralism and post-structuralism

New intellectual discourse that was shaping the world drew great attention of semioticians, philosophers and critics of the linguistic theory from the end of the nineteenth century. In its intent to extend or re-define the meaning of terms such as architectural *space* and *form*, the architectural theorists started leaning on semiotic perspectives that sought to define *codes* as universal frameworks for textual analysis. In the desire for defining text as a construct of interconnected codes and sets of codes, semiologist Roland Barthes and anthropologist Levi-Strauss set on a quest for tracking the invariable element hiding behind the surface covered in differences. Barthes claims, referring to Saussure, that universal ideas are embedded in signs - behind every sign there is a universal metanarrative that should be sought during every reading of the text. This metanarrative is omnipresent in the author of the text, as well as with every reader, and is the only key to understanding and interpreting the meaning of the text. In the domain of architectural practice, this position, named structuralism, is accompanied by a shift in the status of drawing. Drawing in this sense, becomes an indicator of a new, anthropocentric trend evolving in architecture. On the other hand, drawing, as seen as a tool in the architectural design process, now serves to discover universal truths and solutions using analytically-deductive method to purify the reality from redundancy and pave its way for creating metanarratives.

The other, following position, post-structuralism, started developing on the basis of Saussure's viewpoint that signifiers should be freed from direct annotations with world and from ultimate truths and realities. This doctrine refuses to claim rights to a single, authorized meaning, but encourages language to be in the shape of constant enrichment with its own determinants. (Belsi, 2010:95) Unlike its predecessor, post-structuralism moves away from the idea of providing final answers. Instead, it emphasizes the uncertainty of providing any answer at all and even enhances it by asking the question over and over again. Moreover, there is no definitive answer to the question of what the ultimate meaning of a text is, just as an image does not answer any question. Instead, it leaves its possibilities open, "... keeping the secret of the infinite signified." (Belsi, 2010:20) Structuralism, although extremely seductive, speculative and far-reaching - promising the key to all human practices by mastering one principle that would unite different aspects of all cultures, it neglected the crucial term of Saussure's linguistic theory, and that is - *difference*. (Belsi, 2010:45) Yet, this omission served as a key term for defining new, not opposite, but rather advanced position in the interpretation of the meaning of language and image in the post-modern society.

From the closeness of drawing and language elaborated in this section, we can single out different criteria necessary for the process of interpreting architectural drawings. These criteria rely on the two represented analytical strategies:

Structuralism	**Post-structuralism**
Thoroughness, depth	Capriciousness, suspicion
Patterns, parallels, symmetries	Contradictions, paradoxes
Equilibrium, balance	Pause - hiatus - deviation
Determinant, constant	In conflict, inconsistent
Invariance	*Difference*

3.2. Architectural drawing in the digital age

Another important leap in the field of architectural design happened with the immergence of information technologies and their influence on the architectural profession. After inventing the linear perspective, the question of instrumentalization and representation in architecture was once again re-examined and reshaped. However, digital revolution did not change the semantics of architectural language but the way in which architectural drawings are being produced. Nevertheless, the drawing remained an analogue representation of the depicted object or space, although it was being created digitally. This shift paved the way for new possibilities of experimentation and research in the world of new and virtual media.

The outcome of these changes can be traced both in architectural practice, and even more in architectural education. Although educational methodology is not standardized worldwide, current paradigmatic tendencies have primarily been manifested and discussed in architectural schools. On this basis, certain architectural schools have become breeding grounds of certain architectural thoughts. For instance, UCL Bartlett emphasizes the importance of architectural drawing as a fundamental research tool in architecture, and in the 1990s it formed the common ground towards establishing its autonomy. Furthermore, drawing as one of the foundations on which Bartlett as an academic institution builds its educational programme (research-led design) is responsible for the authentic position of the present-day drawing in the field of architecture. This, supposed, autonomous position of drawing can be understood as a critical divergence from the building practice, focusing on its experimental potentials, and therefore evolving to become self-sufficient. Finally, drawing as a research tool in architectural education can become the ultimate research result, the supreme apparatus in the research process and/or the representational tool linking the process and the final result.

The theoretical settings that have developed around linguistic theories have had a much more far-reaching impact on architectural design at the beginning of the twenty-first century than the decade in which they were actively developed. After the rise of digital technologies, the focus of architectural design was altered on new possibilities of articulation of form using the emerging computer software. Moreover, in relation to moving away from a purely formalistic approach to design, the field of architectural education developed dominant design tendencies based on narratives and the meaning (truth) hidden behind the surface.

4. Reading the Architectural Drawing

Reading the architectural drawing is an analytical procedure of tracking certain elements of the observed image, understanding their specificities and assembling them into an integral impression. This step is followed by the process of merging drawing elements from one drawing image to the other, creating a comprehensive impression of the analyzed project. In practical sense, this operation begins with defining a critical apparatus for future analysis that consists of three steps – determining criteria for the analysis, conducting the analytical procedure and evaluating the given results. The criteria set for the analysis refer to the *veracity* of the drawing, its *structure* and future *potential*. The term of the drawing's *veracity* refers to the truthfulness, that is, the validity and reliability of the information that the drawing holds. The notion of *structure* refers to the composition and construction of drawing elements and their mutual relations, while the term of *potential* refers to the overall developmental or creative capacity hidden in the meaning of the drawing. Andrew Benjamin refers to the notion of the research capacity, naming it a research potential, with the term borrowed from the philosophical discourse. He goes on to say that the greatest value of drawing is in seeking the meaning of the line itself, which, since it conveys information about something that is not built, hence, does not exist, it opens up the possibility of complex interpretations. (Benjamin, 2014:471)

4.1. Building the Critical Apparatus

The first step of the analytical procedure begins with identifying the aspects of the drawing related to its form (plan, axonometric view, collage, montage, diagram, bricolage ...), scale (global, urban, architectural, human ...) and correlations of drawing elements (juxtaposition, superposition, interpolation, mimesis, eloquence ...). The second step, the analytical procedure, involves applying determined criteria for tracking important and rejecting redundant aspects of the drawing. This process takes place in the observer's mind and is subjected to subjectification and intuitive classification of all elements of analysis. The final step, evaluation, searches for a comprehensive attitude moulded from the reader's personal preferences, his emotional reaction to the observed image, the accuracy of all the information a drawing conveys and of its potential to grow on the idea it holds.

Given the explication, the following criteria and evaluation results are listed:

Criteria	Results
veracity – truthfulness, credibility, validity, reliability	**merit / narrative**
structure – composition, construction, order	**framework / fashion**
potential – capacity, strength, competence intensity of the (hidden) force	**developmental / creative**

5. Case Study: Architectural Drawing at AFUB

Case study analysis was conducted by presenting three selected Master's Projects within the official selection of the University of Belgrade, Faculty of Architecture for Part 2 representatives in the international competition for the best student works of the Royal Institute of British Architects, The RIBA President's Medals Student Awards. Student works are chosen by a commission consisting of academic professors from the Department of Architecture in the field of Architectural Design and Contemporary Architecture. The presentation of all competing works is limited to a short textual description by the author and ten images of individually combined architectural drawings that, according to the author's choice, best communicate the project.

The Master Project is a one-semester course in the final semester of the second year of Master studies. The course was implemented for the first time in 2005 as part of the application of the Bologna Process. This course represents the most comprehensive and most challenging part of the architectural studies, which builds on the work of the Master Thesis course as an extension of the scientific research, being the topic of previous course. The three selected projects, analysed below, represent the litmus tests of the interpretive strategies described in the previous sections. With the aim of identifying and defining the position of the drawing in the contemporary architectural context by separating the opinion of the person reading the drawing and the intentions of the author of the drawing, this section will search for universal certainties, an invariable element behind differences, hence, for these precise differences.

5.1. Application of interpretative perspectives

1) First project, entitled *Museum of the Immortal, A City's Claim to Immortality* represents a Museum Building design within the Slobodište memorial complex which speaks about the local historical events that took place during the World War II. The project for the Museum represents a link between the world of the living and the dead, trying to portray the story of both.

Fig. 1 Site plan
Anđela Karabašević. "Museum of The Immortal – A city's claim to immortality". RIBA President's Medals Part 2 Project. 2012. http://www.presidentsmedals.com/project_details.aspx?id=3000

The presentation of the project relies on the documental aesthetics which emphasizes the importance of the historical context as the thematic framework of the project. The form of the museum building is put in the background - it imitates the terrain's topography and is indeterminate in terms of materialization, which leaves a vast ground for multiple interpretations. The visual language of the project combines three drawing techniques - collage, montage and diagram. It successively speaks of the historical context of the chosen location site, spirituality of memorial architecture and genesis of form, whilst synthetically building on the historical narrative, monochromatic reminiscence and material incompleteness. It can be noted that there is a dominant presence of the narrative structure in the form of historical interpretation - from a series of historically-documental photographs that speak about local sufferings, through the memorial ambience in montages, to diagrammatic plans that suggest the organization of a museum building.

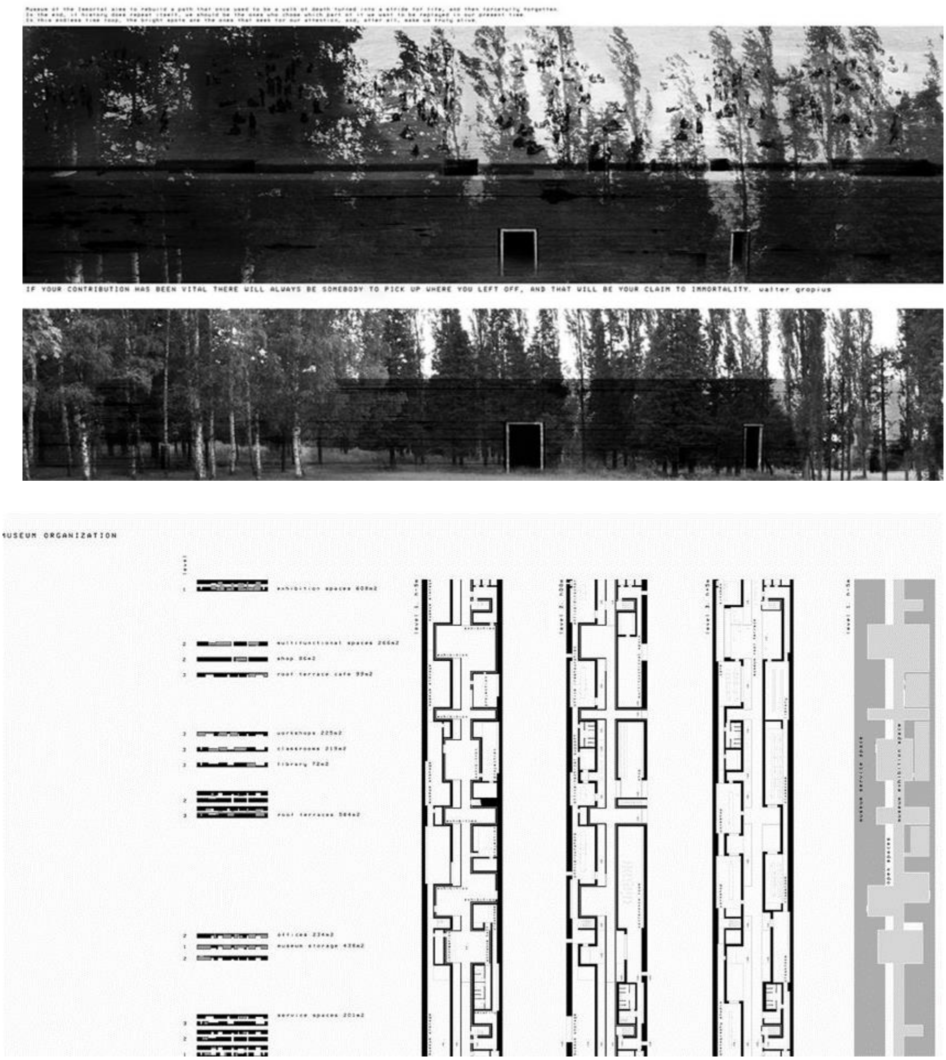

Fig. 2 Materialization and programme
Anđela Karabašević. “Museum of The Immortal – A city’s claim to immortality”. RIBA President’s Medals Part 2 Project. 2012.
http://www.presidentsmedals.com/project_details.aspx?id=3000

2) The second case entitled *Threshold of the Dream – Philharmonic – Natural Core of Belgrade* is a visual representation of the phenomenological research on the concepts of dream and infinity synthesized within the specific design methodology. Design methods deal with dematerializing the existing built and natural environment of the Kalemegdan Fortress and the imprinting of the programme structure of the Belgrade Philharmonic.

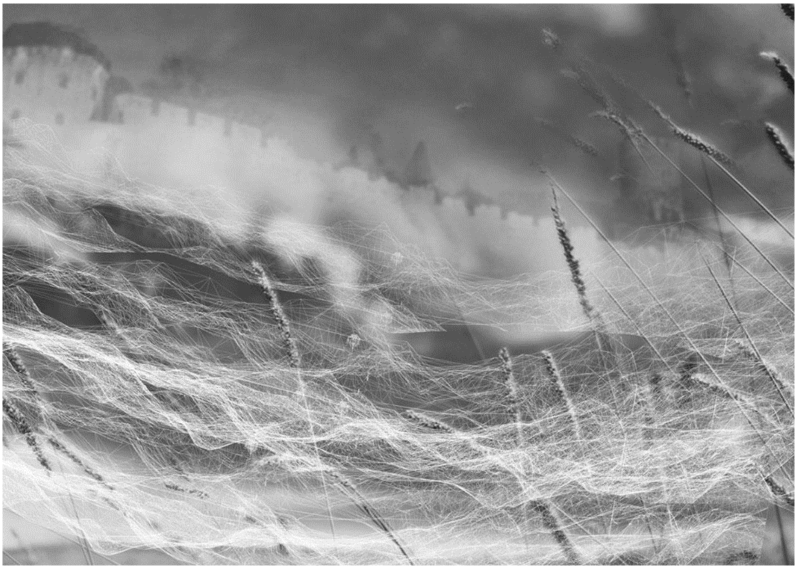

Fig. 3 Kalemegdan – Threshold of the Dream
Nastasja Mitrović. “Threshold of the Dream – Philharmonic – Natural Core of Belgrade”. President’s Medals Part 2 Project. 2013.
http://www.presidentsmedals.com/entry-32541

What is pointed out in the presentation of the project is the structural representation of soil that lies below the Fortress, which than serves as a foundation for designing the Philharmonic and concert hall as a natural continuation of that structure. Drawing projections function as independent images while the dominant motif of the soil structure is repetitive and is present in every image as a series of graphic interpretations of notions such as movement, wind, stretching, network and energy. The architectural attributes of the Philharmonic are presented using the *bricolage* (French) technique – superimposing and juxtaposing drawings of plans, three-dimensional models, photos and diagrams, whilst the use of architectural montage communicates exclusively the atmosphere of the chosen location site. The nexus of these two representational techniques can be read in the architectural plan situated in the core of each bricolage as a result of mimesis of the natural environment surrounding the Philharmonic.

Fig. 4 Horizontal Plan 2 – Concert Hall 2700 Seats
Nastasja Mitrović. “Threshold of the Dream – Philharmonic – Natural Core of Belgrade”. President’s Medals Part 2 Project. 2013.
http://www.presidentsmedals.com/entry-32541

3) The last selected case entitled, *Ultrastructure of the Third City*: *District III* anticipates the problem of the town’s (over)population and mass urbanization, placing it in the hypothetical dystopian future of the City of Third Belgrade. The project explores a vertical mixed-use typology in which dwelling and the production of recycled resources are inseparable. The specific character of the visual presentation of this project is the persuasiveness in representing the designed structure and its imagined environment. The presentation is at the same time informative, convincing and intimidating. The most prominent role is played by the bricolage of three-dimensional models and photos. Elaborating on the topic of dystopian future as setting a hypothetical landscape, relies on the process of narration, as it, therefore, opens a spectrum of possibilities in its understanding and interpreting. On the other hand, the juxtaposition of plans, hyper-realistic renderings and axonometric projections gives the impression that the design solution is definite and unchangeable. Horizontal plans remain in the domain of conventional representations that explain the functionality of the designed space, from human scale to the city scale, while on the other hand, vertical plans, in addition to the representation of structural elements of the project, speak much more about the character of the imagined environment. Using narration, the diagram connects the basic elements of the hypothetical landscape into a functional whole, while hyper-realistic renderings contribute to the persuasiveness of the entire presentation.

Fig. 5 District III – Waste Towers
Marko Dragićević. “Ultrastructure of the Third City : District III’’.
RIBA President’s Medals Part 2 Project. 2017.
http://www.presidentsmedals.com/entry-43761

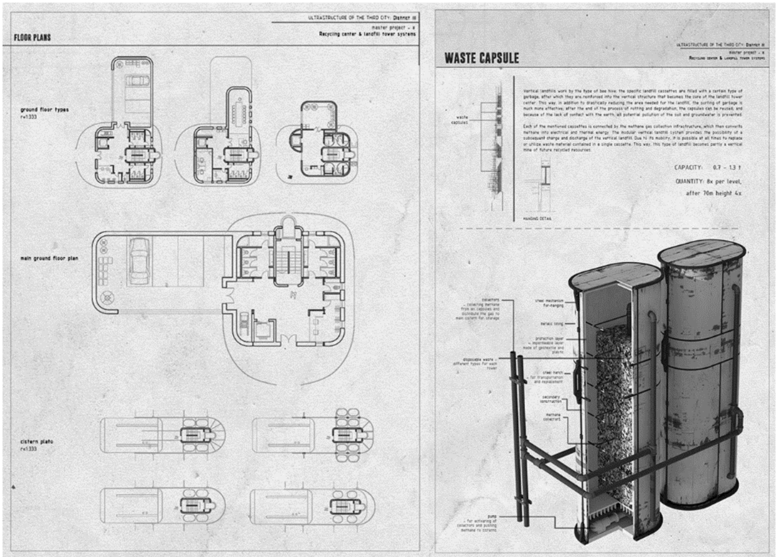

Fig. 5 Floor Plans and Waste Capsule Axonometric View
Marko Dragićević. “Ultrastructure of the Third City : District III’’.
RIBA President’s Medals Part 2 Project. 2017.
http://www.presidentsmedals.com/entry-43761

6. On Results: Frolic or Frailness?

In the first place, it must be noted that the chosen projects were singled out from the long-standing AFUB selection of student's master projects for RIBA's competition. From 2010 to 2020, three chosen projects have undergone comparative analysis as being relevant for understanding different approaches in the scope of architectural education. The drawing in all these works testifies to the richness of form, scale, roles and techniques of drawing and imply a strong competition in the distinction of meritorious examples. Analysed through the lens of previously defined strategies, three isolated examples testify to the pluralism of drawing techniques, aesthetics of graphic representations and approaches to drawing that synthetically build a specific architectural language. In the presented works, the author's ubiquitous attitude towards manifesting the research potential in the visual communication of drawings is imposing. The analysed works are examples of distinct approaches whose sources can be projected in certain theoretical levels, without the author's commitment to any of them.

Given the comparative analysis of the students' projects, the following observations were made:

- Comparing the first two presented works, it can be concluded that the differences in the status of architectural drawing belong to different theoretical levels – structuralist, a drawing focused on presenting and/or solving the problem, and poststructuralist, a drawing predominantly in its representational role.
- At the same value level, we find a project that seeks to deny physical reality by ignoring function, scale and context in the service of aesthetics, as well as a project that is undoubtedly surgically precise in articulating form, function and construction in all scales and directions.
- Comparing the second and the third project, it can be noted that the degree of truthfulness of the drawing that gravitates towards standardization is inversely proportional to the creative potential, and that in this case the presence of a textual explanation by the author is redundant.
- Surrendering to aestheticization as a formalistic manner of composing a drawing suggests a dual potential that, whether creative or developmental, is manifested through the variability and multiplicity of output solutions. In this sense, the second project indicates the dominant poststructuralist character of the drawing - the interpretation is directed on individual elements of the drawing.
- However, the possibility of accessing a textual explanation of the work, to some extent eliminates unnecessary aporia and directs further connotations, reducing them to subjective interpretations. Furthermore, in each of analysed cases, the observer produces an interpretation for which no final guarantees can be found anywhere.

It comes to the point that the presence of both presented theoretical positions is equally visible, both in the context of design and in the matter of interpretation. Solely speaking of detaching the process of design from theoretical settings is a recognizable attitude in post-modern, precisely in Deleuzian philosophical discourse. Although in some projects one can feel the presence of Derrida's attitude that meaning is never present in its final form, but is always delayed and scattered in different directions. However, according to Derrida, drawing does not deal with the experience of blocking vision, but with re-examining and constantly researching for meaning in its smallest and most distant fragments. In this respect, drawing is never considered a communicator, instead as a seeker, which therefore implies undeniable importance of the research role it obtains.

Finally, we can come to the conclusion that structuralism and post-structuralism, not as successive, but parallel discourses, are omnipresent in the contemporary culture of visual communications and architectural design. This brings up the question whether the society acknowledges these strategies as a contemporary world's frolic or frailness?

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OD INVARIJANTNOSTI DO RAZLIKE: ARHITEKTONSKI CRTEŽ IZMEĐU STRUKTURALIZMA I POSTSTRUKTURALIZMA

Radikalne promene arhitektonske misli direktno su se odražavale na oblike i primenu arhitektonskog crteža u procesu arhitektonskog projektovanja. Radi razumevanja današnjih tendencija i značenja arhitektonskog crteža, zadatak ovog rada jeste definisanje pozicije crteža kao proizvoda aktuelne arhitektonske misli koja se u drugoj polovini dvadesetog veka nadovezivala na premise francuskih filozofa. Popularizacija i aktuelnost filozofa koji su svoje mišljenje zasnivali na razvoju lingvističke teorije sa kraja devetnaestog veka iznedrilo je dva nadovezujuća metodološka pravca, strukturalizam, sa fokusom na ideju o pronalaženju univerzalnih unutrašnjih struktura kao kulturoloških temelja, i poststrukturalizam, kao njegov derivat, sa fokusom na radikalnu artikulaciju specifičnosti spoljašnjih elemenata strukture. Sa polazištem koje za ključni pojam uzima invarijantnost, odnosno razliku, predmet analize ovog rada je arhitektonski crtež koji u savremenoj arhitektonskoj edukaciji, kao najmeritornijoj istraživačkoj oblasti arhitektonskog projektovanja, zauzima različite uloge i oblike i konsekventno učitava raznovrsna značenja. Sa ciljem evidentiranja sličnosti, repetitivnih postavki, pravilnosti ili zakonitosti, u crtežu će se, sa aspekta referencijalnog, odnosno, diferencijalnog značenja, tragati za univerzalnim istinama, nepromenljivim elementom iza razlika na površini, odnosno, upravo za tim razlikama.

Ključne reči: *arhitektonski crtež, strukturalizam, poststrukturalizam, digitalna paradigma, edukacija*

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