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University of Niš, Serbia, Faculty of Civil Engineering and Architecture
18000 Niš, Aleksandra Medvedeva 14, 18000 Niš
Phone: +381 18 588 181, Fax: +381 18 588 181

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EFFECT OF EGG WHITE, PERLITE, GYPSUM AND FLY ASH IN ENVIRONMENT FRIENDLY INSULATION MATERIALS

UDC 691.1

Hanifi Binici[1], Orhan Aksogan[2], Rifat Resatoglu[3]

[1]Oktem Construction Company, Kahramanmaras, Turkey
[2]Maltepe University, Department of Civil Engineering, Istanbul, Turkey
[3]Department of Civil Engineering, Near East University, Nicosea, North Cyprus

Abstract. *In this study, engineering features of insulation materials produced from egg white, perlite, gypsum and fly ash were investigated. Densities, water absorption ratios, ultrasonic velocities and thermal conductivity coefficients of samples were determined. Furthermore, linear absorption coefficient were measured by gamma ray saturation levels at 17.7, 26 and 60 keV energies. Thermal conductivity coefficients of the produced composites were found to be in the range 0.0882- 0.0995 Kcal/mh°C. Egg white decreased the linear absorption coefficients. Unit weights of samples were found to be dependent on their contents. As gypsum rate increased, unit weight also increased. As perlite rate increased thermal conductivity coefficient decreased. As egg white decreased the linear absorption coefficient decreased, also.*

The most important benefits of these types of materials are their being impermeable and perfectly compatible with the environment. These lighter type materials were/are compatible with Turkey and the Middle East environment. Egg white has been resistant to radiation. Hence, it is highly compatible with the environment. The compressive and flexural strengths of mortars decreased with the use of egg whites in mortar. So, egg white enhances the binding property of samples. In most cases, some organic and/or inorganic additives are used as well, to improve the physical and mechanical properties of mortar, such as egg whites and others. Finally, this study shows that it is possible to produce an insulation material resistant to sound and radiation by using egg white, perlite and fly ash. It is seen that the samples incorporating egg white could be used at hospitals, military and industrial facilities and shelters which are under radiation hazard. Furthermore, this insulation materials will be put to use in industry in Turkey after many experiments have been done on laboratory.

Key words: *Egg white, fly ash, perlite and insulation.*

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Corresponding author: Hanifi Binici
Oktem Construction Company, M.Ali Kisakurek Street, No: 285, Kahramanmaras, Turkey
E-mail: hanifibinici@gmail.com

1. INTRODUCTION

Intensive works are still performed on the alternative energy production methods due to the rapid decrease in energy resources. In this context insulation has an important place in terms of energy saving. Energy loss can be minimized through insulation technologies. Buildings and settlements are responsible for the 40% of CO_2 that is the primary cause of the global warming. For this reason, in order to minimize the energy required to heat buildings various insulation systems and materials are used [1, 2]. In recent years new environment friendly gypsum materials with perlite are being developed. Usage of light natural aggregates in different industrial fields is becoming widespread. In addition, it is stated that expanded perlite aggregate additive has a positive effect on gas concrete features. Perlite is a natural building material whose usage in construction industry as concrete aggregate has a positive effect on national economy and global warming. Because of its thermal insulation and lightweight features [3, 4]. As in building elements, light gypsums are becoming widespread in civil engineering works for the purpose of construction of wall cross-sections particularly for heat and sound insulation properties. Natural, porous, and light aggregates can be used as primary raw material to obtain such mortars. Among these, natural materials such as pumice, volcanic ash, expanded perlite, scoria, opened vermiculite, and tuff can be counted as the most popular ones.

Mortar is an important material which has been present in structures dating back thousands of years. The use of mortars began with mud and clay-based mortars as low-cost and easy to use natural materials used by the early civilisations. In Egypt this progressed to mortars made with gypsum, the natural material produced by heating on small fires. The use of the resulting mortar (really a gypsum) was acceptable in this relatively dry climate, but gypsum is somewhat soluble, so its use elsewhere in wetter conditions was a problem. Bio-based admixtures have been used in construction and building materials for centuries. Furthermore, in India and Ottoman empire, many indigenous materials such as crushed bricks, sweet sugar drops, white lentil, egg white, cream, juice of tobacco were largely used as a additives to mortar which were introduced in Akbar‘s period but extensively used as adhesives [5-7].

The mass spectrometry creates the possibility to distinguish the main groups of protein acetous additives which are, usually in extremely low concentrations, often present in historical mortars. The two types of these additives were identified in the mortars in the rotunda of Saint Catherine in Znojmo (12^{th} century) [8]. The ancient history of using natural polymers including asphalt to modify lime and clay mortars goes back to the Babylonians, Egyptians and ancient India. Europeans in the Middle Ages knew how to use oxblood and egg white to increase the toughness and durability of lime mortars[9,10].Egg-containing mortar (Sarooj) was used in Kabar dam, which was built during the Sassanid Empire and also in Bandben Castle in Gilan (in the north of Iran)[11]. Archaeologists believe that egg could enhance the mortar strength. Common ingredients in most other lime-based mortars are slaked lime, water, fibre as reinforcement and sand, but the rest of the ingredients such as milk, egg specially albumin, fertilizer, dung (manure) made Sarooj slightly much different [12], In order to modify and/or improve some of the properties of the mortars, traditionally they have been mixed, with some different products or additional constituents. These products have evolved for a long time. In the beginning the admixtures were composed of natural substances such as blood and egg, etc. The current admixtures are generally industrial by-products, like fly ash or blast furnace slag or other more elaborated products, like organic polymers, acrylic resins, epoxy resins, etc. [13]. According to the

mechanical tests, it is identified that egg white and yolk have positive impact on mechanical strength of lime mortars and this impact relatively decreases on the basis of increasing mixture rate; whereas, other additives have a retarding effect [14].

Ionized radiation that can be specified as radioactive is the most dangerous radiation type as it can easily pass through human body and it destroys human cells and genes. Even low amounts of radiation can be harmful [15, 16].Nowadays radiation is widely used in medical, energy, and military fields. Frequent use of radiation negatively affects human health. The most effective way to prevent the harmful effects is armouring of places. Heavy concretes are used to prevent carcinogenic effects of radioactive rays from harming living beings and to avert leakages that might happen in radioactive buildings [17]. Egg white and waste battery coal were identified as radiation absorbent materials [18]. In the last century, there was an increase in the levels of natural radiation due to X-rays used for medical, agricultural and industrial purposes. [19]. It was found out that insulation materials that would be produced from organic and inorganic materials with thin sections instead of thick sections can be used to provide protection against radiation [20, 21].

In all of these studies, egg whites were used as binder instead of cement in masonry wall mortars. We focus on the study of the different steps of the gypsum and egg white as a conceptual framework to underline past applications and performance of these binders, and their current use in building construction. For the first time, this material was also used as a binder, such as plaster, cement or epoxy, in insulation materials. Both the binding and other durability properties of egg white were investigated in samples produced with egg white. Densities, water absorption ratios, ultrasonic velocities, thermal conductivities of samples were investigated. Furthermore, linear absorption coefficients were measured by gamma ray saturation levels at 17.7, 26 and 60 keV energies.

2. Material and Method

2.1. Materials

2.1.1. Egg white

Egg white has been used in mortars as a binder together with lime. Carbonation rate is around 10% in samples produced with lime binder in addition to egg whites. Increasing the egg white additive ratio much more did not increase the carbonation speed so much, but had a retarder effect. However, 28-day compressive strengths of these samples had higher values in comparison to lime mortar [22, 23]. On the other hand, egg white, lime and sand were used to produce mortar by the Turks in Central Asia with the name "Horasani Mortar." Presumably, a similar mortar model was used in the central Anatolia also [24]. Eggs and egg whites used in this work are demonstrated in Fig. 1.

Fig. 1 Egg white

Essentially water contains around 11% protein and substantial amounts of sodium, potassium, and chlorine. Egg white contains more than half of the niacin and riboflavin of

the whole egg and most of the carbohydrates are found in egg white. 63% of egg white proteins consist of ovalbumin.

2.1.2. Perlite

Perlite is the name given to naturally occurring siliceous volcanic rocks. It contains 74% SiO_2 and 15% Al_2O_3. The most important feature which makes it different from other volcanic glasses is that it can expand its volume up to twenty-four times when it is heated around its softening temperature. This expansion depends on the sap that is found in raw perlite around 2-4%.When rapidly heated, at 870 degrees it explodes like corn grains due to the evaporation of the sap in its structure and many pores are formed on the heat-expanded perlite. Expanded perlite is a perfect heat and sound insulation material. Perlite particles smaller than 1mm was used in the work.

2.1.3. Gypsum

Gypsum is a building material that is obtained by evaporation and grinding of the gypsum that has two molecules of crystal water in its compound ($CaSO_4\,2H_2O$). When it is heated it leaves half molecule of water. Then, being mixed with water it gains a binding property by re-solidifying. Dehydrated gypsum powder was used in this work.

2.1.4. Fly ash

Fly ash is formed by holding the particles present in chimney gases on electro-filters when pulverized coal is burnt alone in thermal plant boilers. Ashes being collected by mechanic and electrostatic methods are stored in convenient places. As time passes, these ashes begin to cover large places and become a problem for plant management. Presently, fly ash amount generated around world is around 600 million ton per year. Ash used in this work was provided from Kahramanmaras Afsin-Elbistan thermal plant.

2.1.5. Water

Tap water was used in this study.

2.2. Method

In this study, it is aimed to produce an insulation material that is light and resistant to radiation, and that provides heat and sound insulation. Accordingly, materials used were egg white and fly ash against radiation, sand size perlite as it is light and perfect for heat and sound insulation, and egg white and gypsum since they are good binder materials. Chemical and physical properties of materials are given in Table 1. Water and egg whites were used with different amounts to obtain sufficient consistency in the samples. To determine these amounts (g) the following formula was used:

$$[\text{Water} + 0.5\ \text{egg white}] / [\text{binder (perlite} + \text{gypsum} + \text{fly ash)}] = 0.5 \quad (1)$$

For this purpose, samples, 160 x160x 40 cm in size, were produced and the amounts (g) used are given in Table 2.

Table 1 Chemical and physical properties of materials used

Materials	Component (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Ignigation loss
Fly ash	18.8	9.17	3.37	53.48	1.78	10.43	-
Perlite	67.0	11.8	3.73	1.25	0.16	2.25	2.05
	Physical properties						
	Density (g/cm^3)		Blaine (cm^2/g)	Fineness			
				Residue on 90 μm, %		Residue on 200 μm, %	
Fly ash	2.684		4000	0.4		0.04	
Perlite	1.641		-	-		-	

3. Experimental Study

3.1. Mixture preparation

Materials used in this work are egg white, perlite, gypsum and fly ash as a binder (Table 2). Various samples were produced by using different amounts of materials (Fig. 2).

Table 2 Components of Composites (g)

Sample	Egg white	Perlite	Gypsum	Fly ash	Water
S1	100	150	250	-	160
S2	100	160	250	-	170
S3	100	180	250	-	165
S4	200	-	400	-	100
S5	250	-	500	-	125
S6	300	-	600	-	150
S7	200	150	300	90	170
S8	250	150	300	100	150
S9	300	150	300	130	140
S10	200	150	300	130	190
S11	250	150	300	130	165
S12	300	150	300	130	140

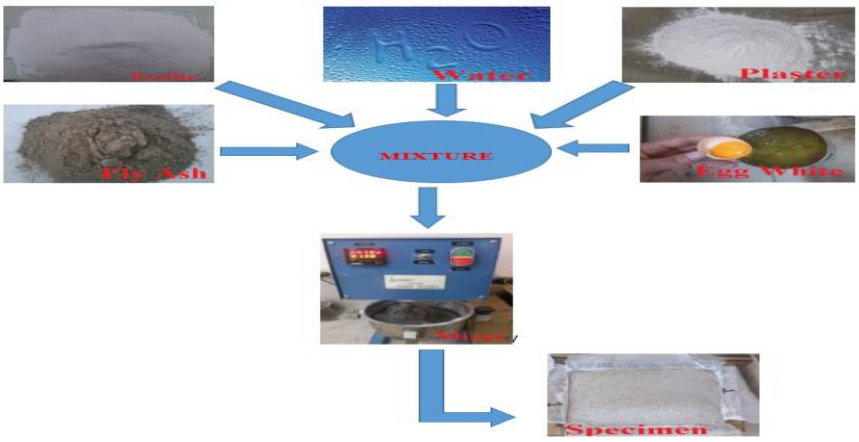


Fig. 2. Sample preparation scheme

3.2. Material characterisation

At the initial stage, the optimization of the egg white to be used in the samples took into account the characteristics of the available raw materials and the existing laboratory infrastructure. Gypsum was, also, added to ensure the adhesion of the particles and manufacture the samples with adequate strength (0.1 MPa). The work also considered the experience accumulated from previous studies in similar fields. In this context, perlite was added to the ingredients to ensure thermal insulation. Thus, all components of samples were mixed as shown in Fig. 2. Perlite was added to the mortar to improve thermal insulation, gypsum to act as a binder and egg white and fly ash to increase radiation resistance. The mortar obtained were poured, under their own weights, into steel moulds of 160 x 160 x 40 mm dimensions. After being poured in moulds, the mortar was compacted with a hydraulic press at 5 MPa and then, kept at 130°C there for approximately 24 hours. During this time, a good bond between the egg white and the other components is expected to have taken place. In addition, the samples were, presumably, dried and hardened.

3.3. Unit weights

Unit weights of all dry samples were found using the following formula:

$$d=M/V \tag{2}$$

where m= sample weight (g), v= sample volume (cm^3) and d= sample unit volume.

3.4. Water absorption

Water absorption is the capacity of a material to absorb and retain water; .Dry material is fully immersed in water and water absorption is defined either as % of weight or % of volume of dry material. In this work the following definition has been used:

$$\% \text{ of water absorption} = ((W2–W1) / W1) \text{ X } 100 \tag{3}$$

where W_2 =wet weight and W_1 = dry weight.

3.5. Ultrasonic pulse velocity

The composites produced in this work were investigated for their ultrasonic pulse velocity. There are two steel discs on the test machine setup, one conveys the sound, and one receives the sound. Before testing the samples the surface of these discs were greased. Sound permeability times of all the samples were measured longitudinally on the device and, thus, ultrasound speeds (according to EN 14579 standard) were identified (Fig. 3).

Fig. 3. The experimental setup for measuring ultrasonic pulse velocity

3.6. Thermal conductivity coefficient

According to the Turkish Standards TS 825 and German DIN norm 4108 a material with thermal conductivity value below 0.1 Kcal/mh°C is called to be a thermal insulation material. The results given in Fig. 7 were found in the thermal conductivity coefficient device in Fig. 4.

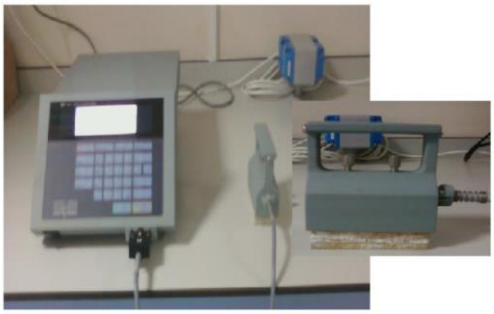


Fig. 4. The experimental setup for measuring thermal conductivity coefficient

3.7. The linear absorption coefficients of the samples

First of all the dimensions of each sample were measured. The linear radiation absorption coefficients were measured in the Radiation Laboratory of the Physics Department of Kahramanmaras Sutcu Imam University using the radioisotope source of the Am-241 as a source of radiation. In this study, an Si(Li) solid state detector with 60, 26 and 17.7 Kev resolution was used. The spectra obtained were counted and an S 100 card was used to evaluate the results. The linear absorption coefficients were determined by measuring what percentages of the rays coming at two different energy levels were passing and what percentages were absorbed while traveling through the samples

3.8. Compressive and flexural strengths

The Diwick Roell Z010 Universal test device was used to determine the compressive strengths of the samples having dimensions 120 x 120 x 20 mm and the flexural strengths of the samples having dimensions 2.5 x 2.5 cm. According to the Turkish standard, which is similar to the European standard BS EN 310, the flexural strength at rupture tests were conducted by using a three-point bending test with the universal testing machine Emic DL 30000, with a load cell capacity of 5 kN. The tests were carried out with a span of 200 mm at a loading speed of 9 mm/min.

4. Results and Discussion

4.1. Unit weights and water absorption

Unit weights and water absorption values of the samples are shown in Figs. 5 and 6, respectively. The unit weights of perlite added samples were found to be lower. As the amount of gypsum additive increases, the unit weights of the samples also increase. The

unit weight values of the samples meet the required limit values in the Turkish standards. Since insulation materials are lightweight, it is important that they do not cause additional load. During earthquakes, the weights of buildings also affect collapsing. Furthermore, lightweight buildings are affected by smaller earthquake forces than heavier ones under the same earthquake acceleration [25, 26].

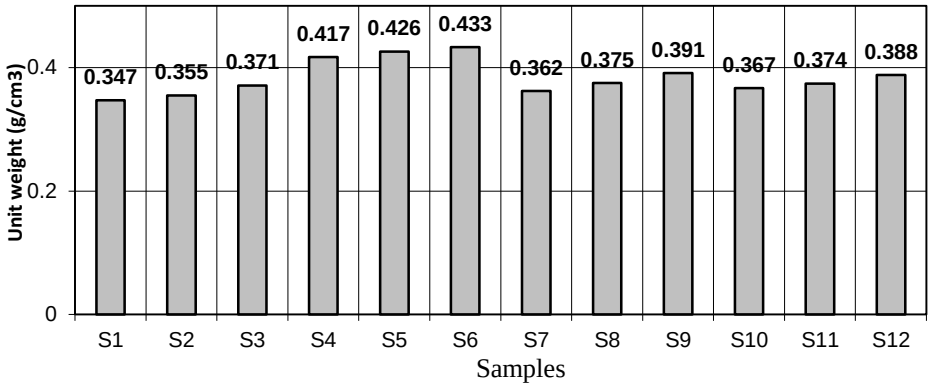


Fig. 5. Unit weights of samples

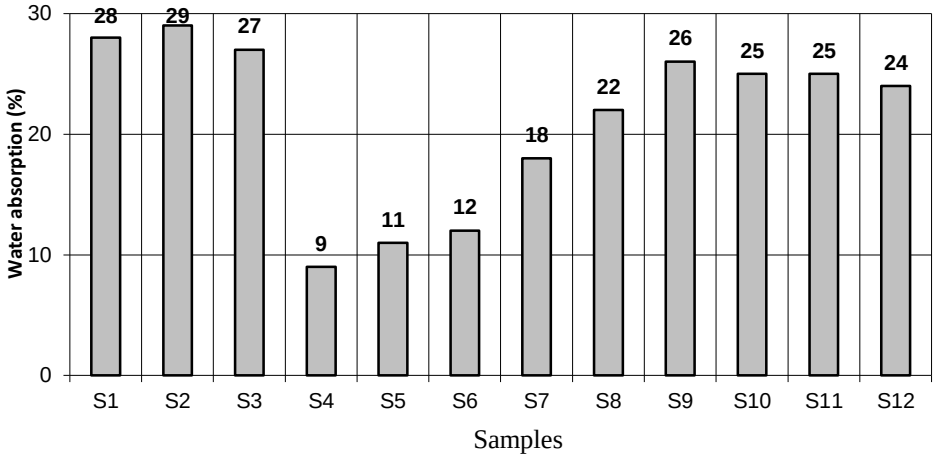


Fig. 6. Water absorptions of samples

4.2. Ultrasonic pulse velocity

Ultrasonic pulse velocity values of the samples are shown in Fig.7. Ultrasonic pulse velocity rates were similar to the unit weights. In other words, samples with low unit weight values were found to have low ultrasonic pulse velocities. This can be explained via voids inside the samples. The actual velocity in these materials may vary significantly due to a variety of causes such as specific composition or microstructure, grain and porosity.

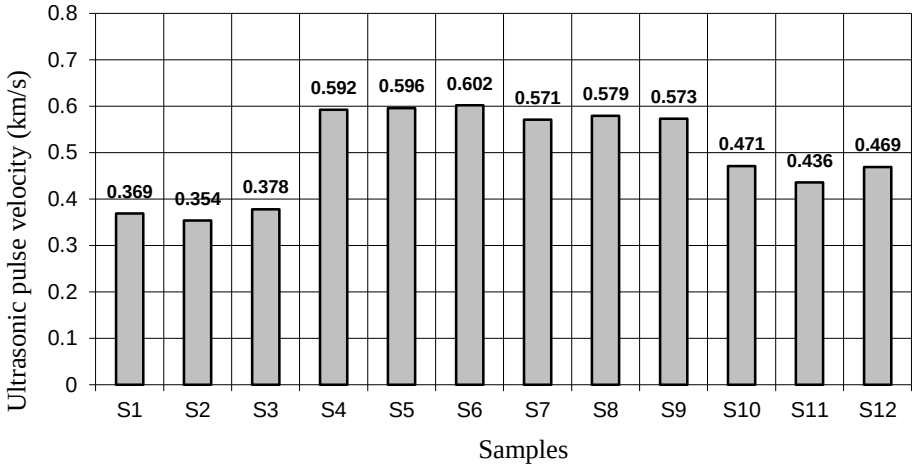


Fig. 7 Ultrasonic pulse velocities of samples (km/s)

Ultrasonic sound waves from egg white with low water rate was found to have higher velocity. This can be explained by the presence of fewer pores in the micro- and macro-structure of egg white-added samples. The ultrasonic sound velocity test showed similar results with thermal conductivity coefficient test. Because both of these results are associated with the density and porosity of material. Egg white addition increased the ultrasonic pulse velocity of composites because it creates a dense and compact structure.

4.3. Thermal conductivity coefficients

The thermal conductivity coefficient tests of samples were performed and the results obtained are given in Fig. 8. The thermal conductivity coefficient of perlite added samples was found to be lower. This is explained by the pore structure of perlite. On the other hand, the thermal conductivity coefficients of samples with less voids and egg whites were found to be higher. When the amount of perlite was kept constant, the thermal conductivity coefficients of samples with higher egg mass was found to be lower. On the other hand, the thermal conductivity coefficients of the samples with the same amount of egg whites were found to be lower than those of the samples with more perlite. These results suggest that both the egg white and the perlite decrease the thermal conductivity coefficients of the samples. According to the Turkish standards, the thermal conductivity coefficient of a material must be less than 0.1 in order to be accepted as an insulation material. In this case, all the samples in this study can be accepted as insulation material.

High performance thermal insulators are materials with a thermal conductivity lower than 0.02 Kcal/mh°C. However, this value for insulator materials like expanded polystyrene (EPS) and extruded polystyrene (XPS) are around 0.03-0.06 [27]. Those values are, of course, greater than those of the rival. However, the material obtained in this work is totally bio-based.

Furthermore, the values found can be further improved with more extensive studies. After that, mixing ratios are further elaborated and more work is planned on the subject.

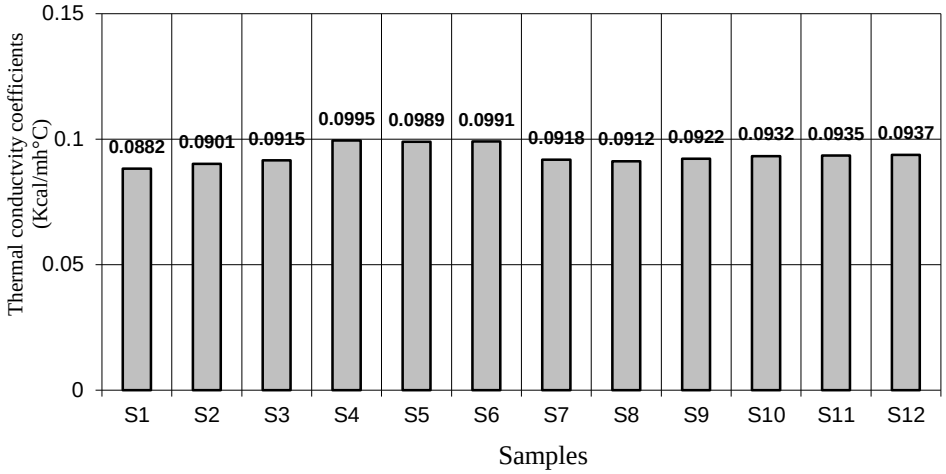
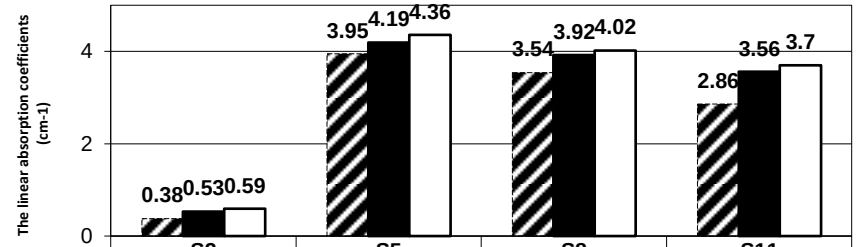


Fig. 8 Thermal conductivity coefficient results (Kcal/mh°C)

4.4. The linear absorption coefficients of the samples

The linear absorption coefficients of the samples are given in Fig. 9. Gypsum and perlite added samples have lower linear absorption coefficients than the other samples. The linear absorption coefficient of the sample S8 which had egg white, gypsum, perlite and fly ash was found to be the largest. The linear absorption coefficients of both egg white and fly ash added samples were found to be higher than the others. Sample S8 absorbed on the average four times more radiation than that of sample S2. Generally, as the radiation energy level increases, the percentage of absorption decreases. These results were similar to those obtained in some previous studies [21, 28].



	S2	S5	S8	S11
60keV	0.38	3.95	3.54	2.86
26keV	0.53	4.19	3.92	3.56
17,7keV	0.59	4.36	4.02	3.7

Fig. 9 The linear absorption coefficients (cm^{-1})

3.7. Compressive and flexural strengths

The compressive and flexural strengths of the samples are given in Figs. 10 and 11, respectively. The compressive strengths of the samples made with perlite additive is found low, due to its porous structure. Sample S4 had the highest compressive strength. This is due to the high degree of adhesion of the egg white after thermal processing. Egg whites provide high rigidity. Materials with low compressive strengths low thermal conductivity coefficients are expected to have low thermal conductivity coefficients, too. The compressive strength of each material with a high flexural strength is not expected to be high, also.

The flexural strength values of the samples are very close to each other. The obtained compressive strength values and bending strength values had a very similar trend. Compressive and flexural strength values of samples with egg white additive were found higher than the other samples. The compressive and flexural strengths decreased with the use of egg whites in the mortar. The higher compressive and flexural strengths of the egg white added samples improved the ability of the egg white to adhere after heat treatment. In addition, the strengths of these samples due to less voids in their structures.

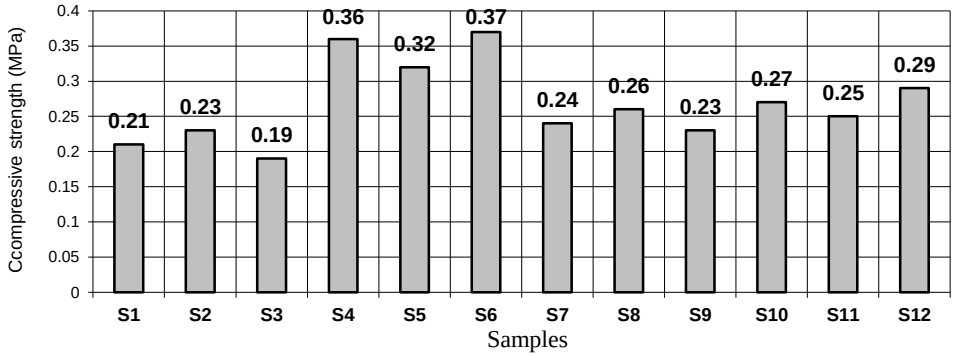


Fig. 10 Compressive strengths of the samples (MPa)

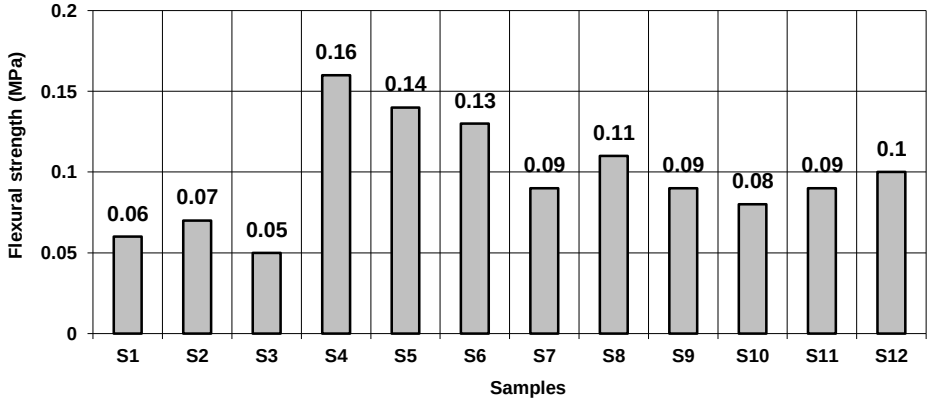


Fig. 11 Flexural strengths of the samples (MPa)

5. CONCLUSIONS

Based on the present study, the following conclusions can be drawn:

1. Radioactivity shielding performance of mortars is very important for radiotherapy rooms, nuclear reactors and similar buildings [20]. This research provides sufficient information for the use of egg whites as an additive to increase the radiation absorption property of mortars.
2. Unit weights of the samples whereas found to be dependent on their contents.
3. The compressive and flexural strengths decreased with the use of egg whites in mortar. So, egg white enhances the binding property of samples.
4. In most cases, some organic and/or inorganic additives are used as well, to improve the physical and mechanical properties of mortar, such as egg whites and others.

Finally, this study shows that it is possible to produce insulation material resistant to sound and against radiation by using egg white, perlite and fly ash. It is seen that samples incorporating egg white could be used at hospitals, military and industrial facilities and shelters which are under radiation hazard. Furthermore, this insulation material is going to be put into industrial production in Turkey after many experiments have been done in laboratories.

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UTICAJ DODATKA BELANCA IZ JAJETA, ELEKTROFILTERSKOG PEPELA, PERLITA I GIPSA NA EKOLOŠKE IZOLACIONE MATERIJALE

U ovoj studiji, istražuju se inženjerska svojstva izolacionih materijala proizvedenih sa dodatkom belanca iz jajeta, elektrofilterskog pepela, perlita i gipsa. Ispitivani su specifična težina, odnos upijanja vode, brzina prolaza ultrazvuka i koeficijenti toplotne provodljivosti. Dalje koeficijent linearne apsorpcije je meren putem zaćienja gama zracima sa energijama od 17.7, 26 i 60 keV. Koeficijenti toplotne provodljivosti proizvedenih kompozita se nalaze u rasponu 0.0908- 0.1112 Kcal/mh°C. Belance iz jajeta smanjuje koeficijente linearne apsorpcije. Jedinična težina uzoraka je zavisila od njihovog sadržaja. Kako se povećavao udeo gipsa, sa njim se povećavala jedinična težina. Kako se udeo perlita povećava, tako se povećava i koeficijent toplotne provodljivosti. Koeficijent linearne apsorpcije se smanjuje sa smanjenjem količine belanca iz jajeta.

Najvažnija korisna osobina ovih tipova materijala je njihova nepropustljivost i izuzetna kompatibilnost sa prirodnim okruženjem. Ovi laki materijali su bili kompatibilni u turskim uslovima i uslovma Srednjeg istoka. Belance iz jajeta je otporno na radijaciju. Stoga je i veoma ekološki

kompatibilno. Čvrstoće na pritisak i savijanje maltera u kojima je korišćeno belance iz jajeta su smanjene. Belance povećava vezivnu čvrstoću uzoraka. U nekim slučajevima, korišeni su i drugi organski i neorganski aditivi, da bi se poboljšale fizička i mehanička svojstva maltera, kao što su belanca i neki drugi. Konačno, ova studija pokazuje da je moguće proizvesti izolacioni materijal za izolociju od zvuka i radijacije korišćenjem belanca od jajet, perlita i elektrofilterskog pepela. Videlo se ad uzorci koji sadrže belance iz jajeta mogu biti korišćeni u bolnicama, vojnim i industrijskim objektima i skloništima za zaštitu od radijacije. Dalje, ovi izolacioni materijali će biti pušteni u industrijsku proizvodnju u Turskoj nakon ispitivanja u laboratoriji.

Ključne reči: *Belance iz jajeta, elektrofilterski pepeo, perlit i izolacija*

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SEISMIC DAMAGE MITIGATION OF THE GLAZED BUILDING FAÇADE

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Danijela Đurić-Mijović, Jelena Savić, Danijela Milanović, Aleksandra Cilić

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

Abstract. *Glass as a material in architecture and civil engineering represents a challenge, and it is often a material of choice for designers, used both for the building interior elements as well as for cladding of building. The paper has addressed specifically the glazed curtain wall façades and the earthquake-induced issues related to them. A review of the standing standards and practice in this field are provided. The paper presents some of contemporary solutions for damage mitigation of glazed building envelopes caused by earthquakes, such as: solutions with clearances between glass and its frame, earthquake-isolated curtain wall system, modified geometry of glass corners and friction damping connectors.*

Key words: *facade, architectural glass, curtain wall, earthquake, facade damage mitigation.*

1. INTRODUCTION

Exterior building walls have a structural, environmental and architectural role. The structural role comprises not only resisting gravity and wind loads and transferring them to a structural frame but also withstanding the movements caused by earthquakes. The environmental role reflects in the protection of the building from weather effects, moisture as well as the capacity to provide the thermal comfort. Since they represent the building face, and they may have a decisive impact on the impression the appearance of the building leaves on an observer, they are paid great attention. Apart from the traditionally used materials of building façades, the hi-tech materials can be encountered nowadays. It is noticeable that a large part of the building envelopes is constituted by the glazed areas, be them the commercial, cultural buildings, or the storefronts.

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Corresponding author: Danijela Đurić-Mijović
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: danijela.djuric.mijovic@gaf.ni.ac.rs

When natural disasters strike, whether they are earthquakes or strong winds, or man-made hazards, architectural glass as an integral part of the façade represents a sensitive component. Once the integrity of the building envelope is disrupted, rain, snow, wind but also debris can easily destroy the interior of the building. The price of envelope repair and lost time very often exceeds the repair cost of any of the structural elements. However, the greatest hazard is posed by the broken glass which can injure both passers-by or building residents.

Considering the previous statements, it is clear that architectural glazing and glazing components must be designed as structural components (Behr & Minor, 2006). The standards in this area are not numerous, and in designing, practical experience is used very often. Building envelope designers currently do not have comprehensive regulations concerning architectural glazing.

2. ARCHITECTURAL GLASS TYPES USED FOR FACADES

Glass production technology has advanced considerably, and nowadays there is a wide spectrum of glasses meeting the most diverse requirements regarding resistance capacity, blast protection, filtering of certain bands of Sun spectrum, etc. The following types of glass are used within each of the glazed exterior wall system: annealed, heat-strengthened, fully tempered, laminated glass and sealed insulating glass units (FEMA 356, 2000).

These different types of architectural glass (Savić et al., 2013) also belong to different strength categories. One of the most frequently used types of glass in architecture is *annealed glass*. This glass is not heat-treated, has good surface flatness and its downside is that when shattered, it would fall apart to numerous sharp shards. The glass characteristics are considerably improved if it is heat-treated. This procedure especially increases resistance to breakage. *Heat-strengthened glass* and *fully-tempered glass* belong to these glasses. Although *heat-strengthened glass* is no less than 2 times stronger than the ordinary annealed glass, after breakage, large, sharp shards are also formed, which represent a hazard for the building residents and passers-by. *Fully-tempered glass* is no less than 4 times stronger than annealed glass, so in terms of breakage resistance it is considered superior to the previously mentioned types of glass. Another favorable characteristic is that when broken, it would fall apart into numerous small pieces, so in some cases it can be used as a safety glass. *Laminated glass* consists of several layers of glass with a plastic interlayer in between. This glass is often used as a safety glass because plastic interlayer prevents pieces of glass from falling out. *Insulating glass units* (IG units) as well as laminated glass consist of two or more lites, but they are mutually connected with continuous spaces whose role is to enclose a sealed air space. IG units are in thermal and acoustic terms superior to the previously mentioned glasses, so the curtain walls and skylights are mostly made exactly of this type of glass (Vigener & Brown, 2009).

3. CURTAIN WALL PROBLEMS CAUSED BY STRUCTURAL FORCES AND MOVEMENTS

Curtain walls belong to a group of lightweight façade systems, and they are a sublimation of all protective functions of a building into a lightweight, thin membrane which is permeable only to light. The curtain wall structure consists of a bearing structure, which is most often built of metal, and of the infill panels which, in addition to glass, can also be metal, stone, plastics, etc. Most of the problems of curtain walls arise from the wind action, however,

earthquakes can also have destructive effects on them. The most curtain wall problems are caused by construction imperfections, inappropriate design and incompatibility with the primary building frame (Newman, 2001). Wind and earthquake action can cause considerable displacements of the primary bearing system of a building. This displacement must be entirely followed by a glazed curtain wall. During these displacements huge racking forces occur, which in addition to disintegration of sealants can lead to compromising the integrity of connections of the façade and the bearing building structure, but also to destruction of entire walls (Fig. 1). For these reasons, during designing curtain walls, a special attention must be paid to adequate connection design between the façade structure and main bearing system of the building.

3.1. Damage examples

After the San Fernando earthquake in California in 1971, the cost of damaged glass and of its replacement was higher than the cost of any other individual element damaged in the earthquake. Twenty three years later, as much as 60% of glazed shop-windows were damaged during the Northridge earthquake in Los Angeles in 1994 (Fig. 1b).

a)

b)

Fig. 1 Damages caused by Christchurch 2011 (a) and Northridge earthquake 1994 (b)

Figure 2 shows façade damages after Mexico earthquake in 1985. The deformations of metal curtain wall elements can be easily noticed (Fig. 2a) while glass panes are not damaged as it should be expected. Figure 2b shows a badly damaged curtain wall where the majority of glass areas are totally damaged but also deformations of metal mullions are visible. The meeting areas of different planes, such as corners, are particularly susceptible to displacements due to impact of seismic forces. The effects depend on the direction of movement and significant damage can be caused. There is also the risk of glass shards falling off of the structure.

a) b)

Fig. 2 Damages caused by Mexico earthquake, 1985

4. STANDING STANDARDS

Protection of the glazing from seismic displacements in current practice varies from country to country and depends on numerous factors, primarily on the seismic zone and standing standards, but also the size of the building and importance of the structure, etc.

European standards, referring to earthquakes Eurocode 8 (EN 1998-1:2004) contain only general recommendations about non-structural elements including the curtain walls and their behavior during earthquakes. Glazed curtain walls or any glazing are not included in particular in this standard, but are generally considered with other non-structural elements. The standard EN 1998-1:2004 clearly emphasizes that curtain walls in case of failure may cause risk to persons or affect the main structure of building and that they should be verified to resist the design seismic action together with their connections and attachments or anchorages. A simplified procedure is also given, where seismic action may be determined by applying to the non-structural element a horizontal force F_a which is defined as follows:

$$F_a = (S_a W_a \gamma_a) / q_a \tag{1}$$

In equation (1) F_a is the horizontal seismic force, acting at the centre of mass of the non-structural element in the most unfavorable direction, S_a is the seismic coefficient applicable to non-structural elements, W_a weight of the element, γ_a importance factor of the element and for facade elements is assumed to be 1,0, and q_a is the behavior factor of the element which has the upper limit value 2,0 for the facade elements.

The practice in New Zealand considering architectural glazing is that during small earthquakes the glazing must remain protected and without damage. During the design-level earthquakes in the most flexible buildings, when the interstorey drift may reach as much as 90 mm, the glass panels must not fall out of their frames (Charleson, 2008).

The US code FEMA 450 stipulates that glass in glazed curtain walls, glazed storefronts and glazed partitions shall meet the relative displacement requirement shown by equation (2):

$$\Delta_{fallout} \geq 1{,}25\, ID_p \tag{2}$$

or 0,5 in. (13 mm), whichever is greater.

Δ_{fallout} represents relative seismic displacement causing glass fallout from the curtain wall, storefront or partition. It should be determined by an engineering analysis or in accordance with AAMA 501.6-2001 (AAMA, 2001). In equation (2) I is occupancy importance factor and D_p is the relative seismic displacement that the glazed curtain walls, glazed storefronts or glazed partitions component must be designed to accommodate and shall be determined over the height of the glass component under consideration (FEMA 450, 2003).

This standard also emphasizes three exceptions. The first relates to the glass with sufficient clearances from its frame which facilitates that there is no physical contact between the frame and the glass, even in the cases of design drift. This is presented by the equation (3) and should be exempted from the provision of equation (2):

$$D_{clear} \geq 1{,}25 D_p \tag{3}$$

$$D_{clear} = 2c_1\left(1+\frac{h_p c_2}{b_p c_1}\right) \tag{4}$$

In the previous equations D_{clear} designates a relative horizontal displacement between the upper and the lower edge of the glass panel. Height and width of the rectangular glass are marked with h_p and b_p while c_1 and c_2 represents the gap between the vertical and horizontal glass edges and the frame, respectively.

The second and the third exception relate to fully tempered monolithic glass in seismic groups I and II located maximum 3 meters above the ground and annealed or heat-strengthened laminated glass in single thickness which is mechanically captured in a wall system glazing pocket.

5. Seismic Damage Mitigation of Glazing Systems

On the glazed building facades, the glazed panels themselves are fitted into the metal frames which are fixed on the bearing structure of buildings. Glass, as a material, has considerable in-plane strength and out-of-plane flexibility. However, glass panels, in addition to the external loads, are also exposed to the impact of the forces which are transferred from the metal frame on its corners and edges, and in this way they can be partially or fully damaged (Fig. 3).

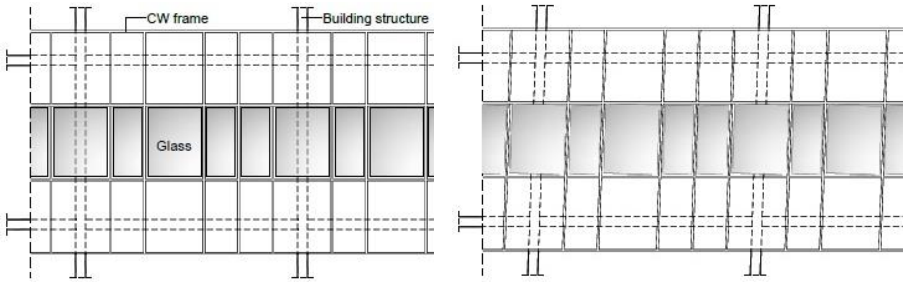


Fig. 3 Building structure and curtain wall frame before and after deformation

For stiff buildings, such as those with numerous shear walls, if the interstorey drift is very small (up to 2 mm) it is not necessary to design any special seismic separation details. However, interstorey drift for multi-storey buildings is much greater, e.g. ±20 mm is typical movement to accommodate during small earthquakes and even up to 90 mm for very flexible structures during strong earthquakes (Massey & Charleson, 2007). Such large displacements cannot be easily designed, regarding that a good design must keep out wind and water, allow thermal movement, meet acoustic requirements, be durable but also to meet high esthetic criteria. Further in the text is the review of the contemporary solutions allowing mitigation of seismic damage to glazing systems of building envelope.

5.1. Mitigation using clearance

In the cases, where due to the earthquake action, small displacements are expected, it is common to implement such solutions where clearances are provided on all 4 sides of the glass pane. Clearances (marked as c on Fig. 4) or gaps facilitate prevention of glass panel corner and edge damage as a result of rotations and displacements caused by earthquakes. Very often such solution is not sufficient, so in cases of larger interstorey drifts it is recommended to implement the so called seismic mullions (Fig. 5a). This element is built in the bearing elements of curtain wall, and it provides the isolation of the glass panels from the metal elements of the frame by allowing larger clearances.

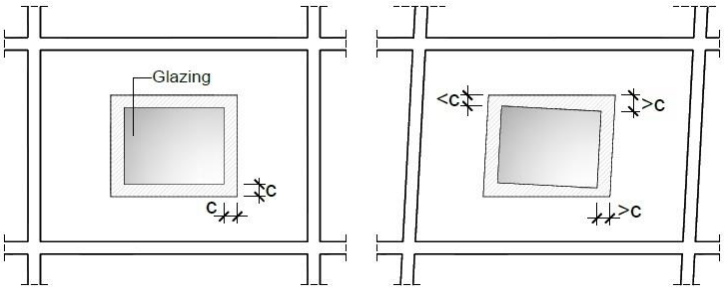


Fig. 4 A single façade unit before and after building movement

Some of the most frequent approaches for prevention of the damage of glass panes during earthquakes are presented on Fig. 5. A detail where besides the frame into which glass is

fitted, there is also an additional seismic frame (Fig. 5b) which is connected to the building frame and it moves in unison with it. If there are no additional frames, then the glass is fitted and sealed with a gasket into the frame, so that the glazing pockets are sufficiently deep to allow the designed glass displacements (Fig. 5c). This approach is most frequent in case of stick systems. In case of the unitized systems almost as a rule, individual units which interlock are used (Fig. 5d). This system became common for multi-storey building, because the displacement between (units) is facilitated both along the horizontal and vertical axes (Massey & Charleson, 2007).

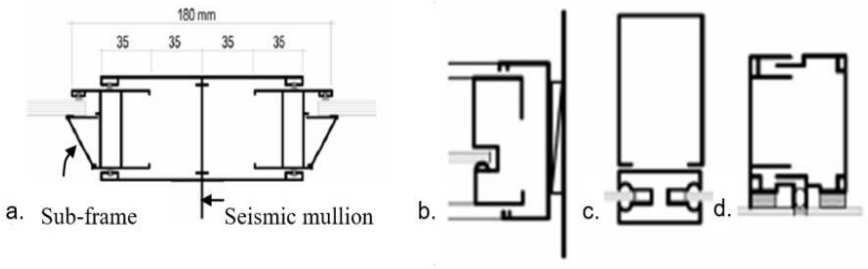
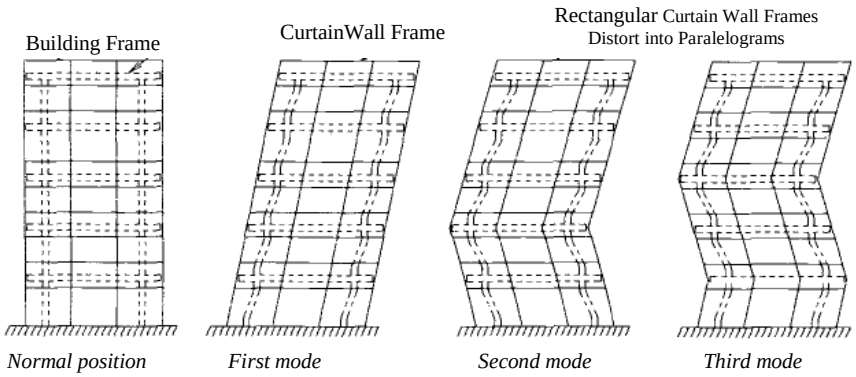


Fig. 5 Aluminium seismic mullion (*a*); Seismic frame (*b*); Glazing pocket (*c*); Unitized system (*d*)

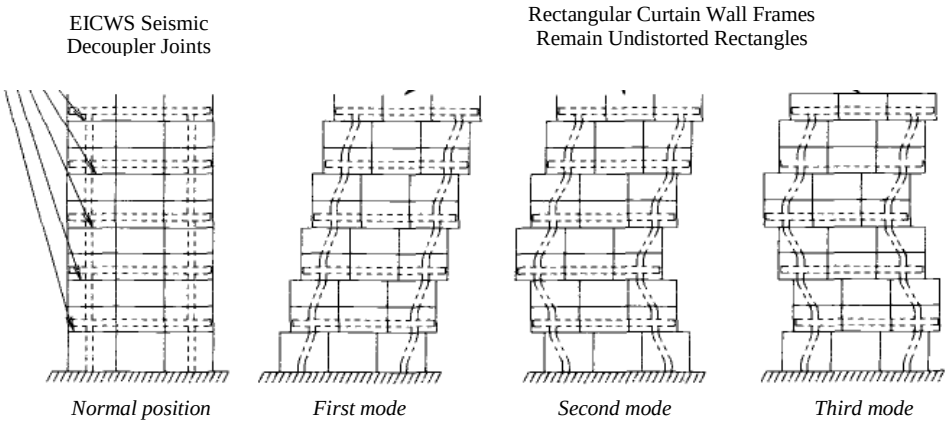
5.2. Earthquake – Isolated Curtain Wall System

A curtain wall system called Earthquake-Isolated Curtain Wall System (EICWS) (Behr & Wulfert, 2003; Brugemann, 2000) provides high resistance to earthquake-induced building motions. The essence of this system is that the curtain wall façade on the multi-storey building is constructed in such a way that each floor is decoupled, both from the façade on the upper floor, and from the one on the lower floor. In order to allow this EICWS system utilizes a specially developed „seismic decoupler joint“ whose fundamental role is to isolate vertical mullions at each floor from the mullions on the floor above and below. In order to accomplish this, a specialized structural support system is necessary. In this way, large interstorey displacements are allowed, both in horizontal, vertical and out-of-plane directions so no intensive forces can occur in curtain wall frame as a consequence of earthquake action. The difference in behavior of the classic curtain wall and EICWS system during earthquakes is presented in figure 6.

The basic difference of EICWS systems in comparison with the classic curtain wall systems available on the market is that the mullions have exclusively the height of one floor, while in case of classic curtain walls, they can have the height of 2 and 3 floors. For that reason precisely, due to the displacement of the main bearing system of the building, distortion of curtain wall frame occurs. By using the decoupling of vertical mullions, this is avoided. The seismic decoupler joint (Fig. 6c till 6f) which apart from its lore to facilitate and accommodate large interstorey displacements, must also provide water tightness. An advantage of this system is that it provides a great freedom of design, because it can be used irrespective of the floor plan.



(a) clad with a conventional curtain wall system



(b) clad with an Earthquake-Isolated Curtain Wall System

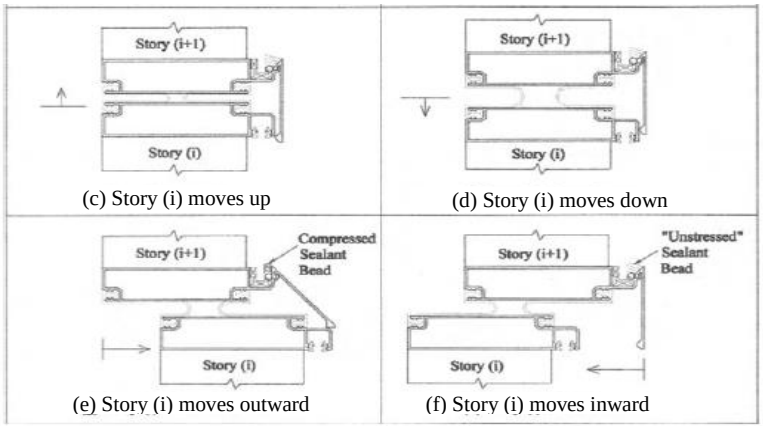


Fig. 6 Fundamental vibration modes of a typical building frame (a, b); joint behavior at various displacements (c, d, e, f) (Behr & Wulfert, 2003)

5.3. Modified glass corner geometry

The fact is that the majority of seismically isolated wall systems designed to resist earthquakes are not envisioned for building retrofit but primarily for application on new buildings, and that their cost is considerably higher than the cost of conventional systems which are not specifically designed for earthquake resistance. However, some of the existing solutions, aimed at achieving as favorable behavior of curtain walls in earthquakes as possible, effectively represent a limiting factor in terms of esthetic design of building facades. One of such examples is a wide mullion wall system which allows and increased clearance so as to avoid glass-to-frame contact during earthquake displacements.

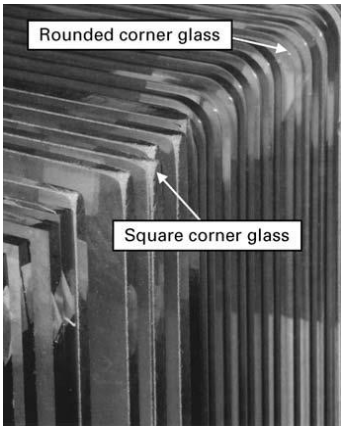


Fig. 7 A stock of squared corner glass and rounded corner glass panes (Memari & Schwartz, 2003)

The fact is that the damage and breakage of glass panels as façade elements firstly occur at their corners. Considering this Memari and Schwartz proposed a change of corner geometry in order to reduce the damage. The proposed design (Memari and Schwartz, 2006) comprises usage of rounded panel edges instead of regular straight angles (Fig. 7). In this way a grater rotation of glass panels in metal façade frames is allowed, and the most favorable effect is achieved using the corner rounding radius of 25 mm.

This research demonstrated that using this design increases both serviceability and ultimate drift limit, i.e., reduces glass cracking as well as fallout of glass panes. This design is simple, and its advantage is the potential for application both on the newly built structures and during retrofitting of the existing buildings.

5.4. Friction Damping (FD) connectors

As an alternative to the existing seismic solutions comprising clearance between the glass panel edges and the frame, the idea of isolating the façade from the main structure using advanced connectors has been proposed within Action COST 25. The use of advanced connectors was proposed by many researchers earlier especially for heavy cladding systems. The fixed elements of a cladding system are vulnerable to damage during an earthquake due to deformation occurring in the bearing structure. The advanced connectors provide isolation

between the light-weight cladding system and the bearing structure by dissipating energy. Energy dissipation systems can be used for lightweight façade systems to provide a degree of isolation which would ensure the least damage possible. Friction damping connectors are implemented as connecting devices between the glazed façade and the main bearing structure of the building. Friction behavior of those devices reflects in the friction coefficient between two sliding surfaces and force perpendicular to them (Afghanikhorasgani et al., 2011). Friction damping connectors are simple devices, both to produce and to install into curtain walls. Their advantage is also the possibility to transfer the set force intensity. When the force intensity is higher than the set one, the device no longer transfers the force but starts to displace in the force direction. Friction damping brackets are presented in Figure 8.

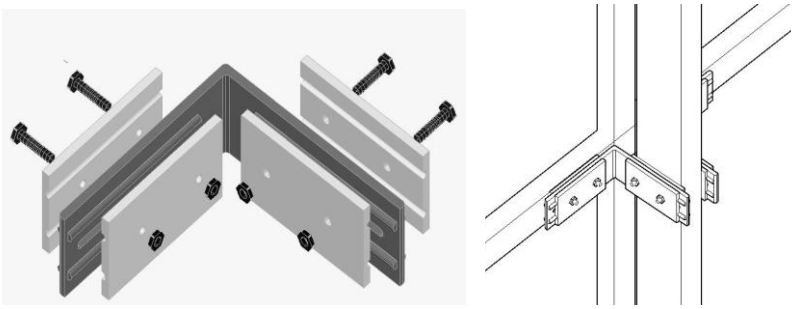


Fig. 8 Friction connector bracket (Afghanikhorasgani et al., 2011)

6. CONCLUSION

Glazed curtain wall facade system consists of large glass panes, long aluminium mullions and steel anchorages which connect curtain wall to structural building frame. All applied materials, elements and connections have to be designed in such a way to withstand all lateral movements. Any failure, such as falling glass or falling wall system components, presents potentially serious life safety hazard. From dual perspective of injury prevention and reducing economic loss, glazing and glazed facade systems are worth protecting. The paper presents some of the designs whose aim is the reduction of glass panel damage due to earthquakes, where glass panels are a part of glazed curtain wall facades. Each design has certain advantages, and some can be implemented both on the newly built structures and on the retrofitted building. Considering that the behavior of lightweight façade structures due to the earthquake action cannot be observed separately from the main bearing structure and other loads (dead loads and wind loads), only good knowledge of the systems for seismic damage mitigation can lead to the selection of adequate designs. Therefore, it is important that earthquake design criteria of facade systems are established at an early stage.

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REDUKCIJA ŠTETE NA STAKLENIM FASADAMA ZGRADA USLED ZEMLJOTRESA

Staklo kao građevinski materijal predstavlja stalan izazov za projektante i njihov je čest izbor kako za primenu unutar objekta tako i za njegovo oblaganje. Rad se bavi staklenim fasadama tipa zid zavesa i njihovim ponašanjem usled dejstva zemljotresa. Dat je pregled aktuelnih standarda kao i rešenja koja su našla primenu u praksi. Predstavljena su sledeća savremena rešenja za redukciju štete staklenih fasada izazvanih zemljotresima: rešenje sa međuprostorom između stakla i rama, EICWS sistem, modifikovanje geometrije uglova staklenih panela i FD konektori.

Ključne reči: *fasada, staklo, zid zavesa, zemljotres, redukcija štete.*

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THE IMPORTANCE OF ETHYLENE-TETRAFLUOROETHYLENE FOR BUILDING DAYLIGHTING

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691

Adrijana Pavlović, Snežana Đorić-Veljković, Jugoslav Karamarković

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

Abstract. *Nowadays, it is possible to implement and realize solutions that once seemed inconceivable. Namely, the development of novel technologies allows the implementation of creative ideas, as well as new approach to building design. The use of the state of the art technology offers the application of functional high-tech coatings and building claddings. Hence, a new generation of plastic - ethylene tetrafluoroethylene (ETFE) is increasingly used in buildings and architectural structures. The use of ETFE is increased due to its very low weight, high transparency potential and possibility to control the utilization of daylight in buildings, as well as due to self-sufficient performances and low environmental load. Therefore, it is necessary to overcome a lack of information on some advantages of this environmentally friendly material. In this paper, the properties and possibilities of applications of ETFE are presented. It increasingly replaces traditional glazing and enables the implementation of creative solutions due to its performance and possibility of advancing sustainable construction. This could contribute to sustainable development and to the prevention of the negative influence to climate change.*

Key words: *Daylighting, self-sufficient performances, environmentally friendly, novel materials, ETFE foil cushions, sustainable construction*

1. INTRODUCTION AND HISTORICAL DEVELOPMENT OF ETFE

Ethylene tetrafluoroethylene-ETFE ($C_4H_4F_4$) is a fluorocarbon based polymer, a new kind of plastic generation. It is important to mention that considerable research has been carried out through the world, providing a large volume of useful data and important findings on the possible application. Namely, investigation of fluoropolymers paved the way for the development of products such as ETFE. Although ETFE was first developed in 1938 at DuPont, the foils of this material were commercially applied by American chemical

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Corresponding author: Adrijana Pavlović
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: archadrijana@gmail.com

company DuPont and German chemical company Hoechst in the early 70's of the previous century [1, 2]. This novel material was recognized for architectural application due to good properties, such as low weight, excellent light transparency, high tensile strength, resistance to tearing and low flammability, but building cladding was not possible until the discovery of the drop bar welding technique that was capable of welding large sheets. This has enabled application of this new generation material for cladding of swimming pools, botanical gardens, zoological gardens, sport facilities and exhibitions.

Membrane structures with ETFE-foils have been used in building constructions in the last several decades and every year approximately 30 new famous ETFE-foils constructions are designed. It should be noted that the first structure clad by ETFE was done at Burgers Zoo in 1982, (Fig. 1) and that although it has been fully functional for 35 years and the applied material has not shown visible signs of deterioration.

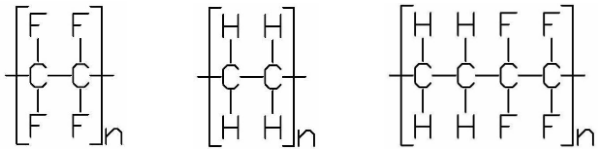
Fig. 1. The first structure clad by ETFE single layer at Burgers Zoo [3]

In this privately owned zoo, in the forest near Arnhem in Netherlands, exotic animals are housed in large enclosures that attempt to replicate their natural habitats. At the same time, by using ETFE, the animals are protected from the influence of weather conditions. Also, visitors can enjoy an outdoor feeling, because ETFE foils are highly transparent for visible light. Further that, this type of foils transmits ultraviolet UV-A radiation. Namely, a single layer used foil of 100 μm transmits more than 90% of light (ranging 380-780 nm) and 80% of UV-A rays, which is important because of so-called bactericidal effect [3].

2. MANUFACTURING AND CHEMISTRY

The raw materials for ETFE manufacturing are fluorspar CaF_2, sulphuric acid H_2SO_4 and trichloromethane $CHCl_3$, that make chlorodifluoromethane (CHF_2Cl) and then tetrafluoroethylene-TFE (C_2F_4). It should be noted that chlorodifluoromethane is a II class substance (according to the Montreal Protocol on ozone depleting substances) i.e. does not contribute to global warming [4]. Following process is pyrolysis which produces tetrafluoroethylene $CF_2 = CF_2$. In the manufacturing ETFE the by-products are calcium sulfate $CaSO_4$, hydrogen chloride HCl and hydrogen fluoride HF [1, 4]. The by-products $CaSO_4$ and HF are reused to make more fluorspar which can be used again as an input into the manufacturing process and the other waste products are incinerated.

In the manufacturing, the polymerization process is used to create long molecular chains, i.e. ETFE (25% ethylene and 75% TFE) [5]. Polymerization is a chemical reaction that constructs a long molecular chain using small basic molecules, so ethylene and tetrafluoroethylene monomers alternately form *n* identical units (Fig. 2). The process is carried out at approximately 125 ^{o}C. The result of the manufacturing process is an ETFE powder. The next step is the creation of ETFE granules in the process of granularization by heating up the powder. Further, granules can be formed into many different products including a sheet, rod, and film. Obtained ETFE material can be extruded into large thin sheets (foils or films) which can be used in single or multi-layer cladding applications. The thickness of films in production ranges from 50 mm to 300 mm, while wide ranges from 150-220 cm.



(a) (b) (c)

Fig. 2 (a) tetrafluoroethylen; (b) ethylen; (c) ethylen - tetrafluoroethylen [5]

ETFE is a semi-crystalline polymer (there are crystalline regions, which are impeded in the amorphous matrix) with a degree of crystallinity of about 33% [6, 7]. Amorphous properties increase the flex life of a material, as well as the number of fatigue cycles until failure, while crystalline properties decrease a material's resistance to fatigue. The presence of the hydrogen atom is also very important, because it increases the hardness and toughness of the produced material and reduces susceptibility to creep, but decreases its thermal stability.

Regarding the environmental impact, it is important that the whole process is water based and does not involve any solvents or additives (to enhance ETFE service performance). Also, they are environmentally friendly as they can be recycled by heating and require ten times less energy per square meter than glass for their production.

3. Properties of ETFE Material

3.1. Basic physical properties

It is important to note that ETFE has excellent chemical, thermal and electrical properties, as well as superior resistance to abrasion and cut-through. Another important advantage is its ductility and flexibility. Namely, the material is able to elongate between 250-650% and to maintain its tension and stability despite large deflections. A stress-strain curve for a typical uniaxial test of ETFE, which illustrates qualitatively how ETFE strains under loads [7] is presented in Fig. 3. It could be seen that the first substantial change in stiffness occurs at the point called Elastic Limit, although the elongation is negligible. At the next important point called Yield Point, the material momentarily loses all of its stiffness and becomes highly nonlinear (at elongation less than 20%). This point

is followed by the large plastic region, where the material is in a stage of strain hardening in which (before Break Point) it can elongate its own length almost 650%.

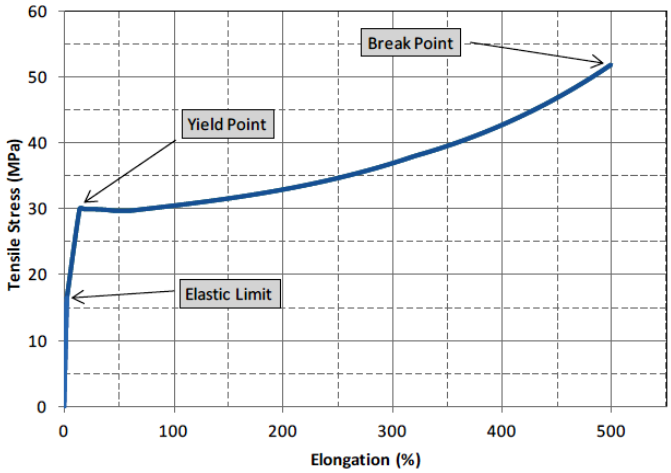


Fig. 3 Stress-Strain Curve for Uniaxial Tested ETFE Foil [7]

Besides significant ductility and flexibility, the most important advantage of ETFE is its light weight. Namely, one foil layer weights only 1% of the weight of glass. Even with the addition of the extra foil layers (to produce an inflated cushion), aluminum extruded flashings, and an inflation tubing system, the roof weight is significantly lower (10-50%) in comparison to glass roof [6]. The mass values of glass and ETFE foil are presented in Tab. 1. [8]

Table 1 Specific masses of glass and ETFE foil.

	ETFE			GLASS	
	single layer	double layer	triple layer	single layer	double layer
	200 μm	200 μm + A300 + 200 μm	200 μm + A300+200 μm + A300+200 μm	6mm	6 mm+A12+ 6 mm
Specific Mass (kg/m^2)	**0.35**	**0.7**	**1.05**	**15**	**30**

3.2. Thermal insulation properties

Originally, ETFE was developed as wire insulation for extreme temperature environments, so it is reasonable that it surpasses the insulation ability of glass. Values of overall heat transfer coefficient *U* (the measure of the heat transmission through a building part, such as a wall or window) for glass and ETFE foil are presented in Tab. 2 [8]. Lower *U*-value shows better insulating ability. Insulation ability is increased with the introduction of the air pocket (creating cushions) which acts similarly to double or triple pane glass. In addition, it is possible to adjust their insulation value by decreasing or

increasing the pressure in the cushions. The insulation characteristics of ETFE cushion system can be multiply improved by adding more layers of ETFE film. The additional (middle) layer of a typical ETFE film cushion is added just for insulation purposes. This film layer creates two divided air cavities, which vastly improves the thermal capacity of the ETFE pillow. The *U*-value is reported to vary from 2.94 to 1.18 W/(m^2 K) for 2–5 layers ETFE cushions [1, 6].

Table 2 Overall heat transfer coefficient *U* of glass and ETFE foil.

	ETFE			**GLASS**	
	single layer	double layer	triple layer	single layer	double layer
	200 μm	200 μm + A300 + 200 μm	200 μm + A300+200 μm+ A300+200 μm	6mm	6 mm+A12+ 6 mm
***U* (W/m^{2}K)**	**5.8**	**2.6**	**1.7**	**5.9**	**2.9**

Insulating properties of ETFE cushions could be improved by using coatings developed especially for fluoropolymers, so that low-energy coat applied onto the film increases insulating capacity.

3.3. Acoustic properties

Probably one of the most important disadvantages of ETFE is the acoustic transparency, because cushions made of ETFE transmit almost all sound from the outside and create additional noise from the impact on the surface such as in the case of raindrops. Also, the sound generated by building occupants passes through the ETFE foil and is not reflected back into the space below. A measure of acoustic insulation is the coefficient of fading or the R_w value, which measures a material's capacity of acoustic insulation. Even three-layer ETFE foil cushion has an R_w value of 8 dB, while R_w value of glass double glazing is 42 dB [9]. This drawback of the cushions made of ETFE material can be mitigated by including acoustic insulation.

Noise produced by rain can be easily minimized by installing a patented Texlon® RS rain suppression mesh, which is made from fluoropolymer monofilament fibers or fabrics with a weave diameter typically measuring 20 mm to 40 mm. The mesh is held under tension across the external surface of each panel and reduces both sound generation and transmission. This mesh decreases noise levels by 9.7 dB which equates to a 50% noise reduction to the human ear [10]. However, the use of the rain suppression mesh will result in a small reduction in light transmission by 5%-10%.

3.4. Light transmittance

One of the most important advantages of ETFE is the light transmittance. Namely, ETFE foils are more transparent than glass in every wavelength of visible light, and have a significantly higher level of transparency in the UV spectra, that can be seen in Fig. 4. This property makes ETFE foils attractive for atria and especially for greenhouses (as well as for already mentioned structures like Burgers Zoo) since plants use the entire spectrum of light for photosynthesis [11].

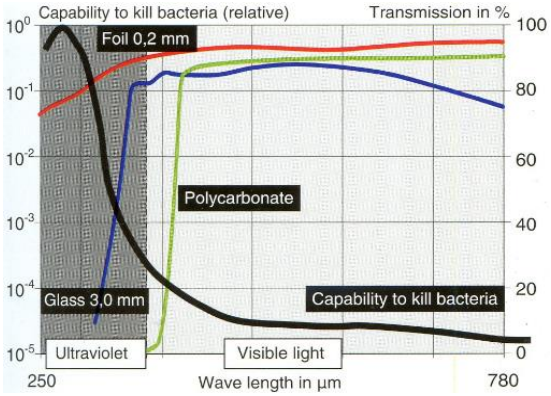


Fig. 4 Light Transmittance of ETFE and Other Glazing Materials [6]

Values of light transmittance for glass and ETFE foil are presented in Tab. 3 [8].

Table 3 Light transmittance of ETFE foil.

	ETFE			GLASS	
	single layer	double layer	triple layer	single layer	double layer
	200 µm	200 µm + A300 + 200 µm	200 µm + A300+200 µm+ A300+200 µm	6mm	6 mm+A12+ 6 mm
Visible (%)	**90.5**	**82.4**	**75.4**	**88.9**	**79.6**
UV (%)	**83.5**	**71.5**	**62.3**	**61.4**	**45.5**

Because ETFE transmit most ultraviolet light, it is resistant to UV degradation and discoloration, which is a common problem with other architectural glasses. On the other hand, high value of transmittance has adverse effects on solar heat gain in buildings. In order to reduce this effect, foils can be printed with an infinite variety of shading patterns that can block out light at varying amounts throughout the day.

3.5. Fire performance and chemical resistance

Another very important property of ETFE is self-extinguishing, as well as unique property of self-venting the products of combustion to the atmosphere [6]. Under fire conditions, the cushions self vent as the hot plume causes the foil to shrink back from the source of the fire (the film will shrink away from the flame), thus allowing the fire to vent to atmosphere. In the case of fire any hot gases impinging on the cushions at a temperature above 200°C will cause the foil to soften and lose strength. It is important that the quantity of material in the roof is insignificant in fire terms and molten drips of foil do not appear, so according international standards, ETFE is very good (see Table 4 [8,12]). In addition to its good fire performance, ETFE has excellent chemical resistance to acid, base and salt, what is presented in Table 5. In comparison to other commonly used polymeric materials, such as polyvinyl chloride, polyvinyl fluoride and polypropylene, ETFE has superior properties.

Table 4 Fire resistance of 250 μm ETFE foil according international standards.

Standards	Class
UL 94VTM	V -0
EN 13501-1	B-s1-d0
ASTM E84	A
ASTM E108	A
JIS A 1322	1
DIN 4102	B-1

Table 5 Chemical resistance of ETFE foil, PVC, PVF and PP material [13].

	ETFE	PVC	PVF	PP
Acid	excellent	good	low	good
Base	excellent	good	good	good
Salt	excellent	low	low	low

However, some chemicals are not compatible with ETFE, such as oleum, chlorosulfonic acid (HSO_3Cl), nitric acid (HNO_3), acid brine ($NaHCO_3$, $NaHPO_4$), potassium permanganate ($KMnO_4$), sodium permanganate ($NaMnO_4$) [14].

3.6. Recycling and embodied energy

It is anticipated that the life span (life time) of ETF film may be 50-100 years. At the end of life, the ETFE film can be recycled. For this recycling process an additive is not required, since it is necessary to have only ETFE material and heat. It is enough that an old, torn, misshapen cushion is simply removed from the structure, cleaned and heated to melting temperature. Melting should be done along with virgin ETFE granules, and such obtained material could be extruded again to create more ETFE film. Besides that, low melting temperature shown in Table 6 [15] (more than three times lower than melting temperature of glass) makes the process of recycling energy-efficient [9].

Table 6 Melting temperature of different polymer products.

	ETFE	PTFE	FEP	PFA
Melting point [^oC]	220-280	327	260	306

Table 7 Embodied energy of ETFE foil and 6 mm float glass [16].

		ETFE foil	6 mm float glass
EE	[GJ/t]	26.5	20
EE per m^2	[MJ/m^2]	27	300

Embodied energy is the measure of required energy to produce a certain material (including raw material extraction, manufacturing, and transportation). Embodied energy values of ETFE foil and 6 mm float glass [9] are presented in Tab. 7. It could be noticed that embodied energy for ETFE is an order of magnitude less than that of 6 mm glass due to the thinness of the material. The amount of material required to clad a building with ETFE cushions is extremely low (mass of a typical foil for the roof is 450 g/m^2).

4. TYPE OF ETFE FOR BUILDINGS OR CONSTRUCTIONS

The ETFE product that is predominantly used in buildings or constructions is ETFE film. This film could be utilized as a single layer stretched between two supports or in a form of many air-trapping layers to create a foil cushion (pillow). In both cases, the ETFE material requires a pre-tensioning process so the film transfers imposed loads through tension only without folding. In the case of the single layer ETFE film membranes it is important to perform the mechanical pre-stressing in order to transfer loads to the primary structure. On the other hand, in the case of the multi-layer ETFE cushions the air is used to pre-stress the film layers and to carry applied loads.

4.1. Single layer ETFE film panels

Single layer ETFE film panels are supported by a primary structure, stretched to the frame edges and fastened (Fig. 5a). The single layer ETFE membrane takes advantage of double counter curved surface increasing its capacity of load by using two way action of the material. The size of each membrane panel is limited by load capacity of the ETFE material (a factor of surface and thickness). Usually, the maximum size of mechanically inflated film panel is approximately 1.5 m and they could be used to cover small surfaces.

(a) (b)

Fig. 5 a) Cross section of single layer ETFE film panel; b) Gaislachkogl gondola [17];

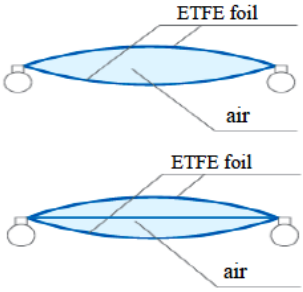
The mechanically pre-stressed panels are much smaller than pneumatically controlled ones because the ETFE supports the load with only its material strength. Besides that, due to lower insulating values than that of cushions single layer films could be used for objects which do not have to be heated.

While in the past high-altitude buildings could be made only as solid structures, all the roofs of the Gaislachkogl cable car stations have been built with sculpted foil -ETFE which is highly tear resistant (produced by 3M Dyneon®) [17]. The Gaislachkogl project is the first time that foil architecture has been used in high mountain locations where extreme conditions come with the territory. The cover of the mountain station is designed for wind loads of up to 300 km/h. The Gaislachkogl cable car is opened in 2010 year, in the Austrian municipality of Sölden.

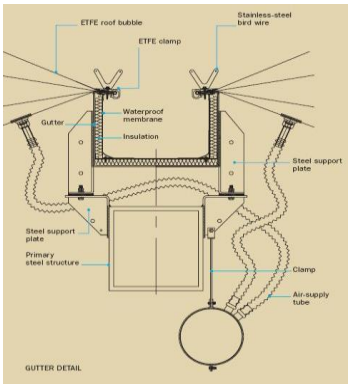
4.2. ETFE foil cushions

ETFE cushions are of the great interest for application in structural engineering and architecture. There are several different methods of creating the foil cushion. Generally, pillows are created by connecting two or more (3-5) layers of ETFE foil shaped together

around their perimeter (Fig. 6a). The cushion consists of layers of ETFE foil and pressurized air which stabilizes the pillow and pre-stresses the system to take the load. Such a pneumatic system achieves adequate thermal properties, structural stability and resist to external forces due to the difference between external and internal pressure. The pressure (provided by air supply) is usually between 200 Pa and 1000 Pa, which is enough to resist most external loads such as wind and snow. In the case of failure of air supply system, the pressure in cushions is maintained during the next 3-6 hours due to use of non-return valves [18].



(a)



(b)

Fig. 6 a) Cross section of two-layer and three-layer ETFE cushions; b) *detail* of the air supply for the formation of cushions [24]

Once the air hose is attached to the cushion it is inflated using a central air pump system (Fig. 6 b) that monitors the cushion's internal pressure, temperature, and humidity. By using cushion sensors the central air pump system also monitors external factors caused by weather such as snow loading, wind pressures and directions, temperature, humidity, and dew point. Using the control system and central pump the cushion's pressure can be adjusted to adapt to a number of external stimuli [18]. It should be mentioned that the pump system is meant to maintain pressure and not to produce airflow. A single inflation unit consists of two backward air foil blowers powered by electric motors and can pressurize about 1000 m^2 of ETFE cushions.

ETFE foil cushions systems are produced in various shapes and sizes. It is important to note that maximum glass panel spans from 2 m to 4 m, while ETFE can span much larger distances. Namely, hexagonal cushions as large as 11 m across (Eden Project, England [19]) and 17 m rhombuses (Allianz Arena, Germany [20]) have been constructed for buildings in Europe. The larger ETFE cushion spans reduce the length of flashing at the edges of cushion, which improves the insulation value of the entire roof and provides fewer points of entry for water leakage and outside air. Thermal insulation properties with the cushion-like system can be changed by employing a variety of film with a certain texture.

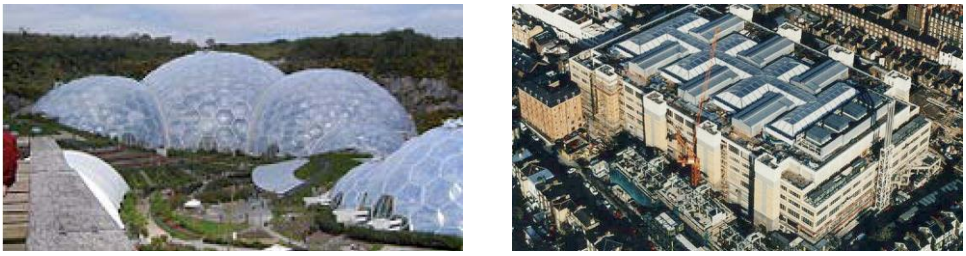
5. MAINTENANCE OF THE STRUCTURES

Maintaining an ETFE roof is less expensive than maintaining a glass roof. The foil cushions can be either prefabricated or assembled on site. The cushions could be easily replaced or mended and do not require access from inside of the structure. Maintenance can be performed from the outside of the structure by mending a cushion onsite or removing it from the frame and replacing it.

ETFE is resistant to weathering due to environmental causes (ultraviolet light and pollution) and when it is exposed to the elements, it experiences no chemical or physical degradation and also maintains its strength. These advantages, as well as light weight, have led the selection of this material for biome domes at the Eden Project in England (Fig. 7a). Inside the two biomes (that consist of hundreds of hexagonal and pentagonal cells supported by steel frames) [19] are plants that are collected from many diverse climates and environments.

The anti-adhesive nature of ETFE allows that self-cleaning properties could be pronounced. Dust or mineral deposits from snow or rainwater remain unattached to the very smooth surface of ETFE and are immediately washed off during the next rain. Furthermore, this non-stick property prevents the creation of algae or dirt collection on the cushion surface. Considering that ETFE is one of the smoothest known substances, the need for regular cleaning services is reduced. This leads to a reduction in the cost to the owner of the building. Also, this leads to a reduction in the use of detergents and water to maintain the building that is very important regarding the influence on the environment. On the other side, the inside face of the cushions could not be cleaned by occasional rain so the internal surface of the pillows may be cleaned (if necessary) every 5-10 years [9, 11].

It is interesting that according to a report provided by the Department of the Environment Transport and the Regions, Westminster Hospital (Fig. 7b) only £30500 was calculated to be spent for cleaning of their ETFE atrium during the 60 year lifespan of the building, as opposed to £104700 for a glass atrium [21].



(a) (b)

Fig. 7 a) Eden Project, Cornwall (England); b) Westminster Hospital, London

Although the ETFE could not be broken like glass, it can be punctured by a knife or by birds or other sharp objects. It is interesting that ETFE film cushions are vulnerable to direct penetration, however, the film has considerable tear propagation resistance. A puncture will penetrate the layer of foil but will not continue to its perimeter. For tears, less than 100 mm, a patch of ETFE tape can be heat welded into place. In this way, the need to replace entire panel if any cracks occur is not necessary, in contrary with a glass panel. However, if it is eventually necessary to replace the entire panel, the ETFE is so light weight that it can be easily replaced

without the need of scaffolding or lifting equipment. Also, servicing the roof with workers is not problematic since the cushions could easily handle the weight of foot traffic.

6. Design and Solar Control

It is known that daylighting techniques can both reduce electric energy demand for lighting as well as minimize loads on the cooling equipment due to overheating. Consequently, daylighting design has to be carried out with great care. In order to obtain diverse visual effects, ETFE Foil can be treated in a number of different ways. Namely, light transmission properties could be manipulated by printing, tinting, surface treatments, radiation and adding layers.

Printing (fritting) means that the surface of the foil is covered with a variety of patterns in order to reduce solar gain while retaining translucency. In this way, the energy transmission can be altered by varying the percentage of coverage and density of the ink. The foil can be over printed with a number of treatments to affect transmission. Tinted, coloured foils can be used alongside clear foil to incorporate branding and large scale imagery. Also, white ETFE foil can be used to reduce glare keeping the light transmission and insulation properties. Surface treatments undertaken during the manufacturing process can vary the properties of the foil and allow light transmission manipulation. These treatments render the foil matt in appearance and therefore provide a good projection surface for light shows and images. The foil could be conditioned with a range of radiation treatments which can reduce the levels of infrared and ultraviolet rays transmitting through the membrane skin. Insertion of additional ETFE foil layers to a cushion also allows light transmission and solar gain to be controlled.

Solar gain (solar heat gain or passive solar gain) refers to the increase in temperature (heat gain) in object or structure that results from solar radiation. The amount of solar gain increases with the strength of the sunlight, and with the ability of the material to transmit or resist the radiation. To measure the solar energy transmittance of glass a g-value is commonly used (a Solar Factor). The g-value of an installation represents the fraction of solar energy transmittance through glazing. This factor is usually expressed as a percentage (0% - 100%) or a value ranging 0 to 1, where 1.0 or 100% represents the maximum amount of solar energy passing through the surface. It could be observed that on some window literature value is very often 0.53 (standard glass is approx 0.88 whereas some specially treated glass may be as low as 0.46). On the other hand, the g-value of an ETFE roof can be reduced to 0.48 for a 2 layer system with a fritted top surface and to approximately 0.35 by using a 3 layer system. It has to be noted that the g-value of any ETFE installation is very dependent on aspect and location and should be estimated taking project elements into account.

An additional design aspect is that companies can have their logos printed onto the ETFE building brand equity along with controlling the light and heat transmission.

Depending on application and design of the structure, various types of ETFE foil could be chosen. In Fig. 8 common used foils are presented **Error! Reference source not found.**. The corresponding transmittances are shown in Tab. 8.

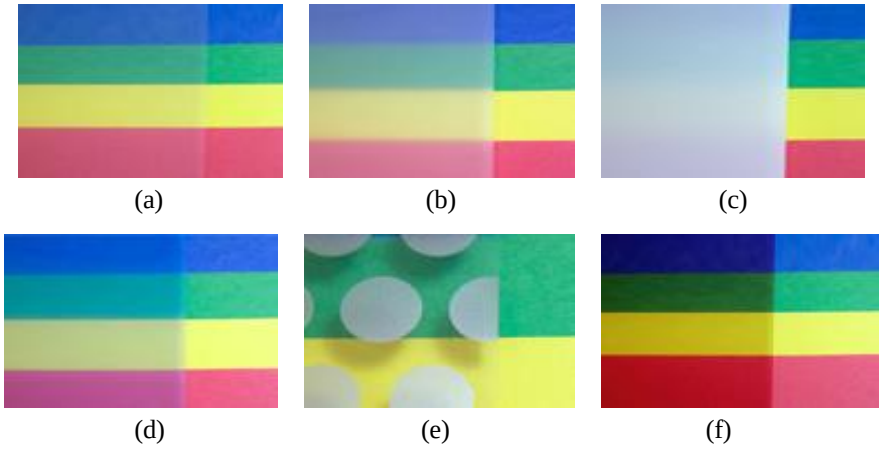


Fig. 8 Types of ETFE film: (a) Transparent (NJ), (b) Matte (HJ), (c) White (WT), (d) Blue (TB), (e) Print (PT), (f) UVC

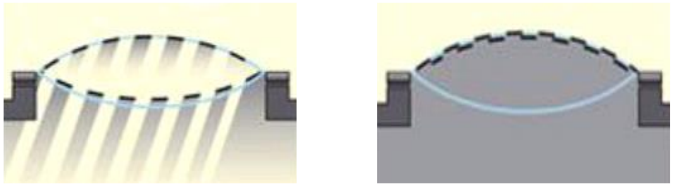
The Transparent (Fig. 8a) transmits over 90% of sunlight; the Matte (Fig. 8b) diffuses light giving it a natural glow and has a privacy aspect as because it cannot be seen through it with clarity; the White (Fig. 8c) diffuses the light letting up to 40% through to light up the area, reducing the need for electric lighting (provides a great shaded area as well with less than 1% UV filtering through); the blue (Fig. 8d) was chosen as the coloured ETFE film pioneer to be developed as needed; the Print (Fig. 8e) has silver patterns (dots or squares) printed with special ink (to reduce fading), specially designed to control light and heat transmission; specially developed film UV reflection cut (Fig. 8f) allows for high light transmission yet reduces the UV transmission to the inside.

Table 8 The values of transmittance (in different parts of spectrum) for presented types of ETFE film (200 μm thickness) [8].

Type of foil		NJ	HJ	PT	WT	BT	UVC
Visible light (380-780 nm)	%	90.5	91.7	63.2	40.5	80.3	87.3
Ultraviolet (300-380 nm)	%	83.5	88.2	58.2	1.0	75.4	36.9
Sunlight (300-2100 nm)	%	91.9	90.4	63.7	50.1	86.9	88.9

Combining the different types of film, UV protection and/or light control to the inside could be created. For example, by combining one translucent and two printed ETFE films into a three layer design and moving the middle layer up and down, the amount of light that is transmitted to the inside can be controlled.

Multi-layer cushions could be constructed to incorporate movable layers and intelligent (offset) printing. By alternatively pressurizing individual chambers within the cushion, maximum shading or reduced shading could be achieved as and when it is required. Practically, this means that it is possible to create a building skin which is reactive to the environment through changes in climate.



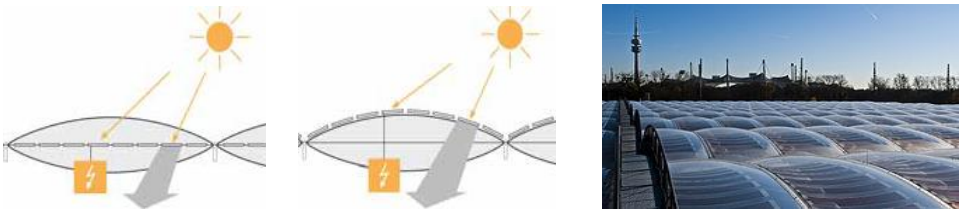
(a) (b)

Fig. 9 Lighting control system of cushions by using two printed foils and one transparent ETFE film: (a) middle layer (supplementary print) down and (b) middle layer up **Error! Reference source not found.**

It should be emphasized that principles of sustainable development criteria and the preservation of environmental quality in the function of preventing the negative consequences of climate change could be achieved by integration of photovoltaic cells into the membrane structures. In addition, it is important that using flexible solar cells could contribute to solar control [23].

In general, integration of photovoltaics (PV) in buildings offers a lot of potential in future. Namely, in an appropriate application in transparent or translucent parts of surface it might also provide necessary shading which reduces the solar heat gains in the building (or structures) and thereby helps to minimize cooling loads and energy demand in summer. Practically, this synergy effect is of great importance because it principally helps to reduce the balance of system cost for the PV application. From an aesthetic point of view (which is very important especially for building design in urban areas), an integrated solution offers significantly more potential than any other application. Such, extremely flexible, amorphous thin-film solar cells embedded in ETFE cushions can follow the most complicated form of the roof construction. In this way, architecture has received a completely new dimension [24]. Also, the PV does not require an additional substructure as it is an integrated part of the building envelope.

The PV can be integrated into pneumatic constructions such as ETFE foil cushions as presented in Fig. 10. When PV is applied in the middle layer (Fig. 10a) it will be protected, but the power output will be limited due to refraction effects (of the top layer foil) and also due to the heating of the absorptive middle layer which will not be reduced by convection effects of the outside air. Consequently, the integration on the outer top layer of the cushion (Fig. 10b) will be more efficient [23].



(a) (b) (c)

Fig. 10 ETFE cushions roof with integrated photovoltaic cells a) on the middle layer [23]; b) on the top layer [23]; and c) Munich's municipal waste management department **Error! Reference source not found.**

In Fig. 10 c the new roof of the Munich's municipal waste management department with its integrated photovoltaic cells is presented. This roof constructed in 2011 fulfils all the requirements which can rightfully be expected of a functionally and ecologically advanced structure [25].

Another attractive possibility is an application of various lighting effects that can be achieved through LED lighting or image projection used at night for the best results. During the last decade in many attractive buildings ETFE foil was combined with LED lighting.

7. THE MOST FAMOUS ETFE PROJECTS

Advantages of using ETFE enabled application of this material for many famous structures which are located all over the world. The use of ETFE allowed completely new approach to the architecture. Especially, light sources incorporation and final visual performance make this novel material useful for creation of advanced structures. Each of these structures are modern and innovative. Several examples of ETFE application are presented below.

Donau Shopping Center [26] is the biggest shopping mall in Vienna and second largest shopping centre in Austria (Fig. 11). The impressive air-cushion facade of this mall is made of partially transparent and partially printed ETFE foil. LED lights are arranged in a polygon behind the air cushions, while the outer foil is printed in white using screen printing.

Fig. 11 Donau Shopping Center

The facade made of air-cushions (printed ETFE foil) gives the centre its unique visual charm. Such facade enables that, during the day, the light passes directly through the cushion and provides a bright feel-good atmosphere, while, when night falls, the LED lights draw attention to the spectacular facade.

Baku National Stadium [27] in Azerbaijan is the six-story, 65.7 m structure near the Boyukshor Lake (Fig. 12). Construction of the 225.000 m^2 stadium on a 650,000 m^2 site

was completed in 2015. This multi-function stadium is set on land fill site of petroleum production. During the construction, it was difficult to determine the height of the appropriate ground level because the groundwater was high due to the adjacent lake. To maximize design flexibility, the structure was designed using piled raft foundations, a system more typical of high-rise buildings than stadiums. During the building process, an advanced modelling approach was applied. An automated design routine to check beam and column reinforcement was developed. Precast reinforced concrete, main and secondary steel structures were all modelled using Tekla Structures 19.0 and full fabrication drawings were delivered to the contractor's fabrication facility. In addition, the ETFE facade and roof systems were applied.

Fig. 12 Baku National Stadium

The stadium is equipped with an innovative lighting solution, including an HDTV-compliant floodlighting system. The outstanding lighting could create different visual effects.

Water Cube National Swimming Centre [28] in Beijing, China is a multifunctional aquatic centre, which required extensive use of digital technology, energy-reduction and water-saving methods, as well as the incorporation of new construction materials (Fig. 13).

The unique design of this 31 m high centre played on the geometry of water bubbles within a square form. The structure's shape was specifically designed to work in harmony with water games and functional requirements.

There are two parts to the structural framework – internal and external. The external structure forms the actual roof, ceiling and walls and comprises a flat web of rectangular boxed sections. These sections are clad with the transparent ETFE. More than 22.000 stainless steel members create the sides of the bubbles, which are welded at the joints to more than 12.000 spherical steel nodes. The advantage of using this frame design, as well as resembling water bubbles, is ideally suited to the seismic conditions found in Beijing.

This swimming centre is built in 2008 (for the Beijing Olympics), and its envelope surface is covered by 100 000 m² of ETFE (4000 cushions), making it the largest ETFE structure in the world. One of the challenges encountered by the designers was to convince the authorities about the advantage of ETFE and that the design allows 140 000 t of recycled water to be saved a year. The ETFE cladding lets in solar heat, reducing energy costs by up to 30%. A stringent temperature and humidity control system, and a recycled hot water system were incorporated into the design, helping to air-condition the public area and the swimming pool. These indoor and outdoor air recycling systems, solar energy systems and

deck ventilation systems maintain a comfortable climate and humidity of 50%-60% in the venue. Also, the designers had to prevent dewdrop from the ceiling, which could affect the swimmers in the pool or divers on the springboard. The ETFE and air conditioning systems have partially helped in preventing of dew dropping. Moreover, the building's air supply, return inlets and exhaust outlets improve the ventilation in the upper spaces of the building.

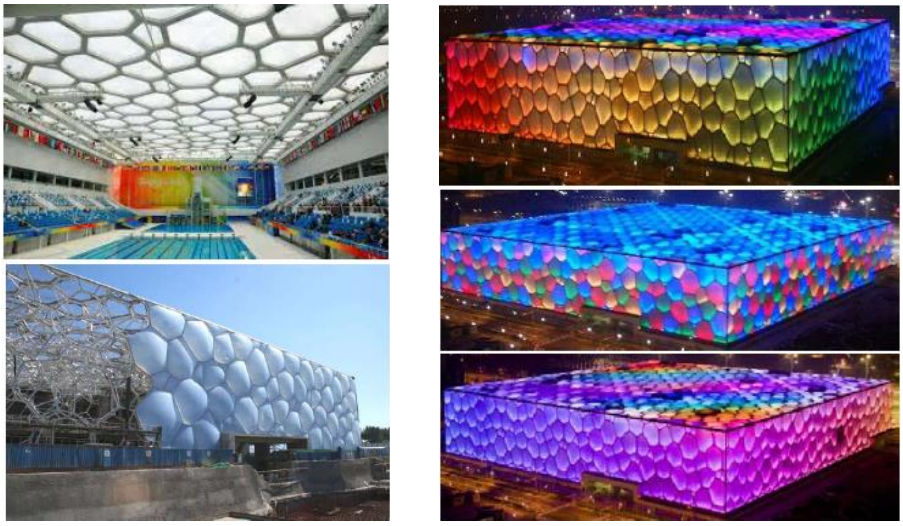


Fig. 13 Water Cube - National Aquatic Centre in Beijing, China

The Water Cube is lighted by LED light sources, which are produced by novel technology. It is possible to use the cube's lighting to simulate an extremely low-resolution screen. Dynamic lighting allows incredible lighting effects. More than 450 000 LEDs are embedded throughout the structure. LED lighting fixtures illuminate the bubble designs from inside the structure's translucent walls, allowing the entire building to glow with extraordinary colour changing LED light. In addition, spectacular lighting effects are enabled by using remarkable, world-renowned lighting installation. Also, it is important that it is possible to create dramatic effects while consuming as little energy as possible.

The bubble like "skin" of the massive five-story building is illuminated each night with a light display that is designed to reflect traditional and contemporary aspects of Chinese life. The colours and movement patterns are based on the ancient Chinese philosophical system, and on the daily mood of the Chinese people as expressed through social media. The resulting display of light, colour and movement is visible every evening from dusk to 10 p.m. on the surfaces of the building.

Khan Shatyr Entertainment Center [29] in Astana, the new capital of Kazakhstan was built in 2010. Although the city lies in an austere eastern landscape with an inhospitable climate that can generate temperatures of -35 ^{o}C in winter and +35 ^{o}C in summer, Center is designed to provide a comfortable microclimate all year round, whatever the weather. The building's tented structure has great resonance in Kazakh history as the tent is a traditional nomadic building form, and Khan Shatyr means the Tent of the Khan.

Fig. 14 Khan Shatyr Entertainment Center, Astana **Error! Reference source not found.**

The structure soars 150 m from a 200 m x 195 m elliptical base to form one of the highest peaks on the Astana skyline. Enclosing an area in excess of 100 000 m^2 it comprises an urban-scaled park, with a wide variety of shopping and leisure facilities. The tubular-steel tripod structure supports a suspended net of steel, which is clad with a three-layer ETFE envelope, formed as 3.5 x 30 m cushions. Specific areas are air conditioned, but the open circulation areas are environmentally tempered, with target temperatures of +14 ^oC in winter and +29 ^oC in summer. Preventing ice forming on the inside of the envelope is achieved by a combination of temperature control and directing warm air currents up the inner fabric surface, a strategy that also prevents downdraughts.

The new Unilever headquarter building [30] for Germany, Austria and Switzerland is located in Hamburg near the river Elbe (Fig. 15). It was built in 2009 and marks the end of the route out of the town centre to the cruise ship terminal and the promenade on Strandkai. The central element is the generous atrium, flooded by daylight, which gives passersby the opportunity to get to know the company better while browsing in the shop stocked with Unilever products, sitting in the cafe or relaxing in the spa. Also, the atrium is the central place for people to meet and communicate.

The building follows the principles of sustainable architecture. Although technologies that help the saving of resources are implemented, the energy concept adheres to the principle of avoiding technical solutions wherever possible. A single-layer ETFE film, placed in front of the building insulation glazing, protects the daylight optimized blinds from strong wind and other weather influences.

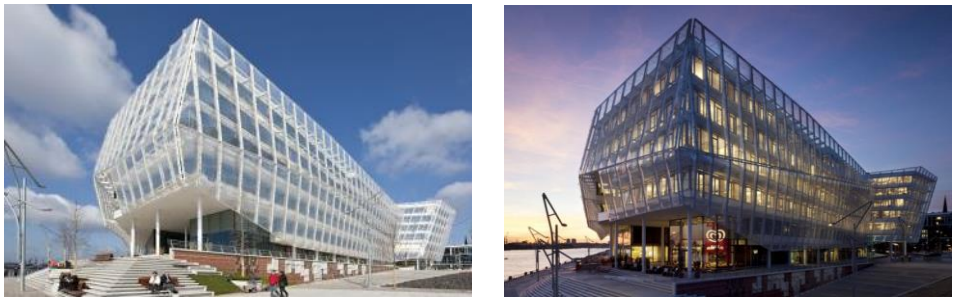


Fig. 15 Unilever headquarter building

A newly developed SMD-LED system has been applied for the building's general lighting and for workplace lighting. It is very important that this system is up to 70% more efficient than conventional halogen or metal halide lighting. This building received the newly established HafenCity EcoLabel in gold.

Allianz Arena [20], a football stadium located in Munich, in Germany is widely known for its exterior of inflated ETFE panels (Fig. 16). It is the first stadium in the world with a full colour changing the exterior, officially opened on May 30, 2005. Total steel used during stadium construction is 22 000 t, while for the parking garage was used another 14 000 t. The roof of the stadium has built-in roller blinds, which may be drawn back and forth during games to provide protection from the sun.

Fig. 16 Allianz Arena stadium

The arena facade is constructed of 2 874 rhomb designed ETFE foil cushions (air panels) that are kept inflated with dry air to a differential pressure of 3.5 Pa and can be effectively illuminated from the inside.

Each panel could be independently lit with red, blue or white light. Usually, the panels are lit for each game with the colours of the respective home team (red for Bayern, blue for TSV and white for the national team). Other colours or multicolour or interchanging lighting schemes are theoretically possible, but police insist on uni-colour only due to several car accidents on the nearby road when drivers have been distracted by the changing lights. It is

interesting that in clear nights the stadium can easily be spotted even from Austrian mountain tops, e.g. from a distance of 80 km.

Innovative stadium-facade lighting concept of Allianz Arena has been subsequently adopted in other newly built venues.

8. CONCLUSION

Physical properties and possibilities of ETFE application have been presented, considering that it could contribute to sustainable construction in our region also. Firstly, the production of this recyclable material requires significantly less energy per square meter than glass. In addition, superior characteristics of this kind of plastic allow a huge range of potential applications and enable creativity, practically without boundaries.

A single layer ETFE foils can be transparent, translucent, coloured or printed with a graphical design. Also, between two and five layers of foil could be used to form air pressure stabilized cladding panels. The number of layers depends on project specific requirements for structural and thermal performance, so that wide range and combination of visual transparency, solar control and thermal resistance could be achieved. Each layer of cladding panel is made up of smaller elements cut from the foil rolls to a predetermined design by a computer controlled plotting machine and welded together to form sheet, which is usually supported by steel frames. In addition, incorporating light sources into the envelope and possibility that building or construction could be lighted "from the inside" significantly contribute to achieving the visual performance and appearance, while the application of amorphous thin-film solar cells embedded in ETFE cushions could contribute to providing energy and to controlling solar gains.

It is obvious that applications of this environmentally friendly, lightweight material (which offers a wide range of attractive options) could further contribute to the development of architectural design and new dimension of architecture.

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ZNAČAJ PRIMENE ETILEN-TETRAFLUOROETILENA ZA UVOĐENJE DNEVNE SVETLOSTI U GRAĐEVINSKO - ARHITEKTONSKE OBJEKTE

Razvoj visokih tehnologija materijala omogućava realizaciju kreativnih rešenja i ideja. Savremene tehnologije i materijali, uz sasvim nov pristup načinu projektovanja, pružaju realizaciju nečega što je nekada izgledalo nezamislivo da se može izvesti. Jedan od takvih materijala, novije generacije jeste etilen – tetrafluoroetilen (ETFE). Ovaj materijal koji se sve više koristi u građevinsko-arhitektonskim objektima, stekao je svoju popularnost zbog izrazito male težine, velike mogućnosti propuštanja i kontrole uvođenja dnevne svetlosti u objekte. Inovativni materijal - ETFE se kod prekrivanja objekata koristi u vidu folija koje se u cilju postizanja toplotne izolacije povezuju na ivicama i pune vazduhom uz pomoć kompresora formirajući oblogu koja podseća na naduvane jastuke. U ovom radu prikazane su osobine i mogućnosti primene ETFE koji zbog svojih performansi održive gradnje sve više zamenjuje tradicionalno stakleno oblaganje i omogućava realizaciju kreativnih rešenja

Ključne reči: *dnevna svetlost, inovativni materijali, ETFE folije, ETFE jastuci, održiva gradnja*

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A REVIEW OF EMPIRICAL RESEARCH ON CONTEMPORARY NEEDS AND CONDITIONS IN HOUSING IN THE CONTEXT OF FLEXIBILITY

UDC 728.2

Milica Živković

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

Abstract. *This paper presents the results of a previous empirical research on users' needs and living conditions in multi-family housing units in the city of Niš, based on a German study of flexible housing named "Flexible Wohnungen". The research involved the interviewing of tenants about different aspects of living in multifamily housing, with particular reference to the flexible housing programme and its implementation in practice. By systematising and comparing the achieved results with the results of foreign research, certain conclusions can be drawn on the universal housing needs and current living conditions in the city of Niš.*

Key words: *flexibility, sustainability, tenants survey, multi-family housing*

1. INTRODUCTION

The physical environment should be stimulating and supportive to the psycho-physical and social development of individual, family and other social groups, in accordance with the individual affinities and ideological choices, as well as the established general goals of the society. In this regard, it is necessary to create a living space characterised by the qualities of development and flexibility, because the continuous satisfaction of the users' needs ensures a longer service life of a residential environment and builds a healthy social community. The realization of housing programmes whose variability in use covers the needs of social diversity represents a sustainable and socially responsible action.

Examining the situation and needs of housing is a necessary precondition for extending the period of effective exploitation of the building. Multidisciplinarity of housing issues conditions a continuous implementation of a strategically designed research, which would among other things include permanent monitoring of housing correspondence at all stages of exploitation. Such studies would involve surveying and interviewing tenants, tracking statistical data, with

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Corresponding author: Milica Živković
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: milica.zivkovic@gaf.ni.ac.rs

the involvement of professionals of various profiles (architects, civil and mechanical engineers, economists, ecologists, sociologists, psychologists, etc.) and an appropriate institutional support.

Serbia, which is nowadays on the path towards European integration, is facing a task of reorganising the entire state system, which also includes the reforms in the domain of the housing sector. Harmonization with European norms and standards, especially in the segment of sustainable development, requires the improvement of conditions and quality of housing, with the implementation of an appropriate advanced planning and construction policy.

The quality of the implemented housing programme is in the particular case examined in the conditions of the local urban community of the Republic of Serbia. Further work presents the empirical research of user satisfaction and living conditions in multi-family housing in the city of Niš, which is part of a more extensive study on the subject of flexibility. The aim of the research is to determine the extent to which the issues of housing sustainability are considered and, in this context, the extent to which the flexibility programme is implemented in local architectural practice.

2. METHODOLOGICAL BASIS OF THE RESEARCH

In order to perceive the real housing needs and living conditions in a specific social and urban environment, a survey on tenants of multi-family residential buildings located on the territory of the city of Niš was conducted (June-September 2015). The collected data on the tenants' opinion refer to the quality and disadvantages of the belonging living space, priorities of housing exploitation, individual needs and aspirations of household members and the general needs of the family group.

The interview form is, in an adapted form, taken from the study entitled "Flexible Wohnungen" [1], which, within the research on the topic of flexibility, also deals with the issue of user satisfaction with residential space in the built settlement of flexible housing. The motive for using this survey model is the author’s intention to compare the degree of correspondence between housing priorities within the local community and the developed countries of Western Europe.

Data collection was carried out through a technique of direct interviewing of respondents in their households, at various locations of multi-family housing in the area of the city of Niš. The survey research included different aspects of living in a local residential area, with particular reference to the flexible housing programme and its implementation in practice. In further research, samples and types of collected data are described and the final results interpreted through the numerical indicators are presented. Eventually, the obtained results are compared with the results achieved within the research "Flexible Wohnungen” in order to make general conclusions about the universal needs and problems in housing.

3. DESCRIPTION OF THE SAMPLE

The survey was conducted on a representative sample of 500 male and female respondents living in multi-family residential buildings located on the territory of the city of Niš. The lower age limit of the respondents was 19, and the upper limit was not set.

During the research, the attempts were made to include the households with different structures and modalities of housing. Table 1 shows the age structure of the respondents.

Table 1 Structure of respondents by age

Age	Number	Total
19-30	78	
31-40	125	
41-50	163	**500**
51-60	90	
> 61	44	

4. Research Instrument and Variables

A questionnaire taken from the German study of flexible housing named "Flexible Wohnungen" was used as a research instrument. This study was aimed at gathering information on user satisfaction and living conditions in realised buildings of flexible housing by interviewing tenants in this kind of settlement. The study, which was carried out with the support of the Ministry of Regional Planning, Construction and Urbanism, included the analysis of 70 flexible units within two buildings of social housing, built in the 1970s at the location of Viblingen, Ulm (Germany). The residents, who had the opportunity to arrange their own apartments before and after they moved in were examined about the types, modalities and frequency of changes made within the apartments. Based on the achieved results, the degree of user satisfaction with the residential environment was identified.

The original questionnaire consists of 40 questions. The questionnaire is part of a more comprehensive study on the topic of housing, so only 25 questions were used for the specific research.

The variables in the research refer to the following items:

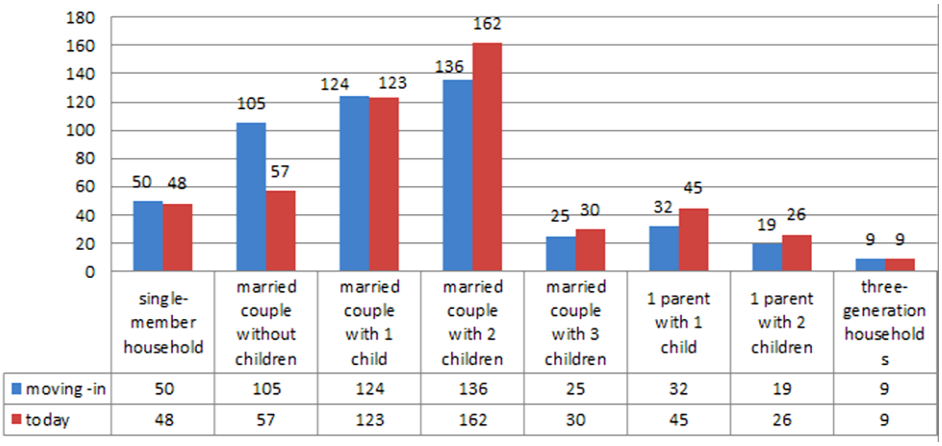
1. socio-demographic variables: age of parents, gender and age of children, level of education;
2. household structure at the time of moving in and making the interview;
3. data on the history of housing exploitation;
4. priorities of housing exploitation;
5. expected quality of housing;
6. perception of housing comfort;
7. assessment of the quality of the associated living space;
8. level of awareness of the respondents about the possibilities of flexible organization of space.

5. Analysis and Interpretation of Research Results

The results of the survey were interpreted through textual explanations, charts and diagrams.

Diagram 1 shows the number of individual household structures in a representative sample at the time of moving in and interviewing. At the time of the survey, the

representation of the categories is as follows: married couples with two children (32.4%), followed by married couples with one child (24.6%), married couples without children (11.4%), single-member households (9.6%), parents with a child (9%), a parent with two children (5.2%) and three-generation households (1.8%). Comparing the redistribution of households at the time of moving in and at the time of interviewing, it can be concluded that there is a pronounced tendency of increasing family structure with children.



	single-member household	married couple without children	married couple with 1 child	married couple with 2 children	married couple with 3 children	1 parent with 1 child	1 parent with 2 children	three-generation households
moving -in	50	105	124	136	25	32	19	9
today	48	57	123	162	30	45	26	9

Diagram 1 The structure of households at the time of moving in and interviewing (today)

Within the representative sample, the share of households that have chosen the flat layout as a complete solution (62%) is greater than those that had the opportunity to participate in the conceptualization of the plan or to choose among the offered solutions.

Within the sample of households which previously lived in another apartment (29% in the sample), 67% went from a smaller to a larger apartment, with the apartment structure on average increased by one to two rooms. The most common reason for relocation is the extension of the family, which is in accordance with the observed increase in family structures with children in the total household share.

The largest number of respondents indicated the size of the apartment and the location of the building as a crucial criterion for selecting an apartment. Flexibility as a choice is represented by 13%. Analysed according to household structures, most respondents who have indicated flexibility as a key criterion in choosing an apartment are in a group of married couples with children (Diagram 2).

When asked what was crucial in choosing a spatial solution of the apartment, with the possibility of multiple answers, 54% answered that it was the number of bedrooms and 50% the size of the living room, while the other characteristics were less represented (Diagram 3).

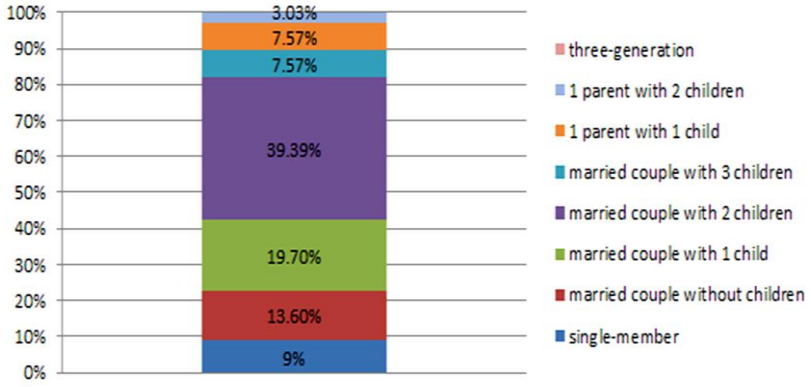


Diagram 2 Flexibility as a key criterion for selecting an apartment

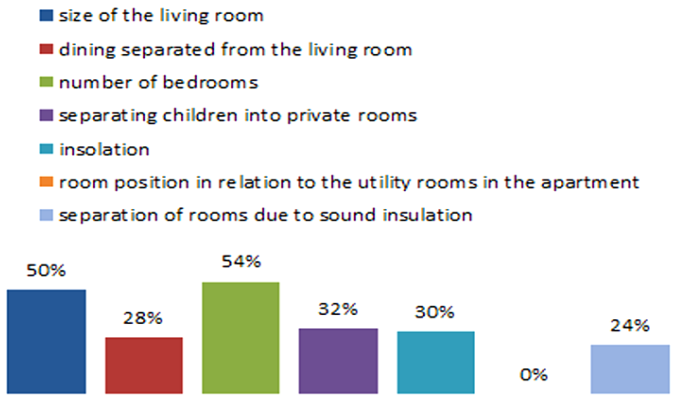


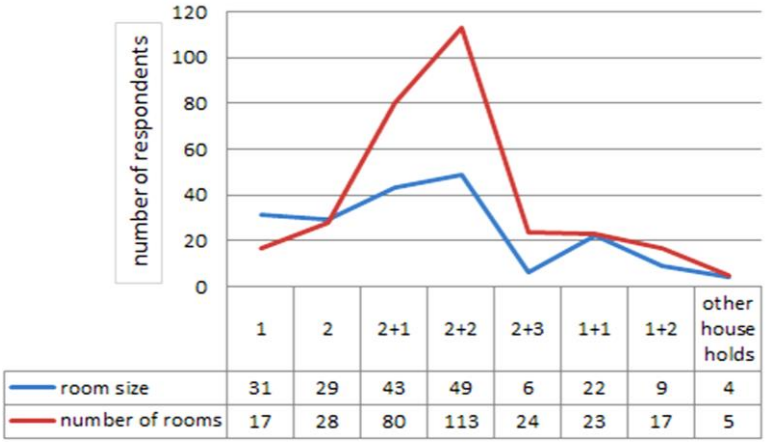
Diagram 3 The crucial criterion for choosing a spatial solution

By linking the answer to the question of whether the family is more important, the size or the number of rooms, the nuclear family structure, expected, gives priority to the number of rooms, while in the case of other households, both responses are equally represented (diagram 4).

The possibility of later changes in room arrangement is a preferable option among respondents in relation to the possibility of choosing from the offered plan variants or independent organizing of the plan before moving into an apartment. These data point to the fact that the users themselves are aware that at different stages of family development, different housing priorities are emphasised, which is very difficult to fully anticipate and perceive in the initial phase of moving in. It is therefore necessary to provide users higher level of freedom at the exploitation stage.

Although the majority of the respondents are satisfied with the size of the rooms within the apartment (75%), those who have this kind of objections especially emphasise the size of the bedrooms.

An additional space that the family needs in the apartment is a pantry, work space, an additional bedroom and the possibility of its subsequent division. According to the obtained results, the majority of respondents recognise the living room as space with potentials of multipurpose use, which could receive the sleep function during the night. This is supported by the fact that a certain number of respondents use the living room as a sleeping area (22%).



	1	2	2+1	2+2	2+3	1+1	1+2	other house holds
room size	31	29	43	49	6	22	9	4
number of rooms	17	28	80	113	24	23	17	5

Diagram 4 Representation of the response "size of rooms" ie "number of rooms"

Comparing the flat structure with the household structure, it can be concluded that a large number of households live in inadequate overcrowded living space (Diagram 5). Often, some members do not have their own bedroom (usually parents) or adult children share a common room.

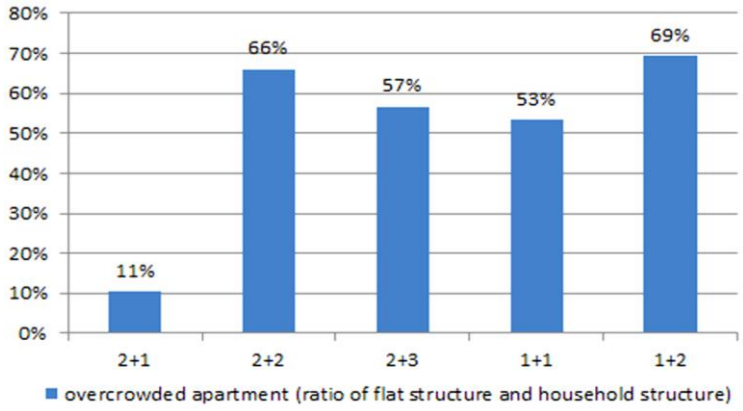


Diagram 5 Overcrowding according to the ratio of flat and household structure (%)

Of particular importance for the research is the ratio of the useful flat area and the number of household members, as one of the indicators of the quality of housing, but also the measure of the adaptability of the living space to the future needs of the user (diagram 6). Considering the ratio of the flat area and the structure of the household it belongs to, it can be concluded that a large number of households with three children live in undersized apartments.

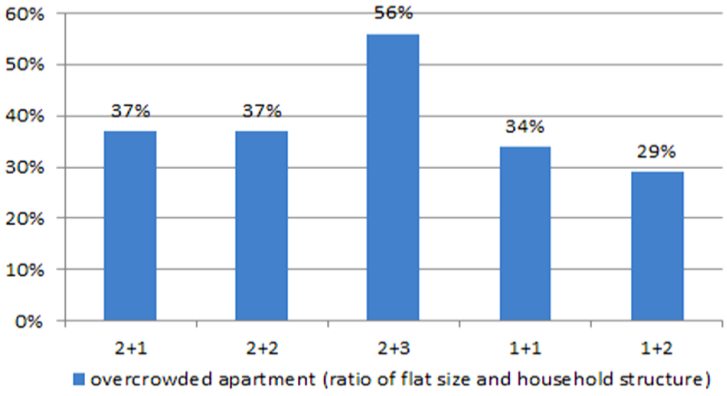


Diagram 6 Overcrowding according to the ratio of flat size and household structure (%)

After comparing the results from Diagram 5 and 6, it can be concluded that in the case of four-member households, the problem of disparity between the flat structure and the household structure is more pronounced than the problem of the sub-dimension of the space. This result is a consequence of poor representation of apartments with larger structures on the housing market.

In most households (89%), no changes were made in the apartment after moving in. Interventions that were realised in the rest of the surveyed households mainly involved painting, changing the furniture position, rearranging the bedroom, closing the terrace area, rearranging and changing the dining room to get space for bedroom, enlarging the bedroom to the account of the living room, etc.

When asked "Would you change the layout of the apartment or change the apartment with a change of household needs?", 62% of respondents replied that they would change the apartment, while 38% answered that they would change the layout of the apartment. The reason for such a result is probably the fact that in practice very often flats are so inflexible that users are forced to look for a new living environment in case of changing needs. The reason may also be the insufficient education and awareness of tenants about the possibilities of flexible housing exploitation.

The diagram 7 shows the ratio of representation of the response in which flexibility is recognized as a crucial criterion for selecting the apartment and the level of education of the respondents. It can be concluded from the enclosed that the increase in the level of education (awareness) increases the interest of users for flexibility.

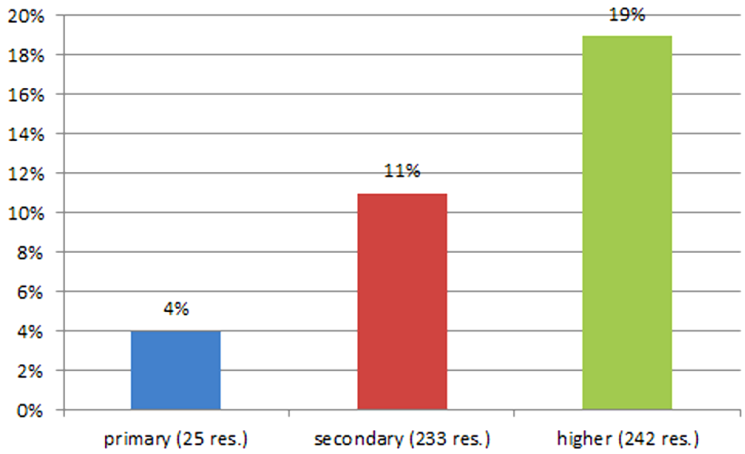


Diagram 7 Connection of the education level of the respondents and representation of flexibility in responses

The key question: "What kind of apartment would you choose if you moved into the apartment again?", the largest number of respondents said that they would choose an apartment that could be organised by themselves, with the possibility of moving partition walls (53.2%). Diagram 8 shows the representation of individual responses within the defined age categories of the respondents. The preferred option of a conventional solution is, as expected, smaller among the younger population.

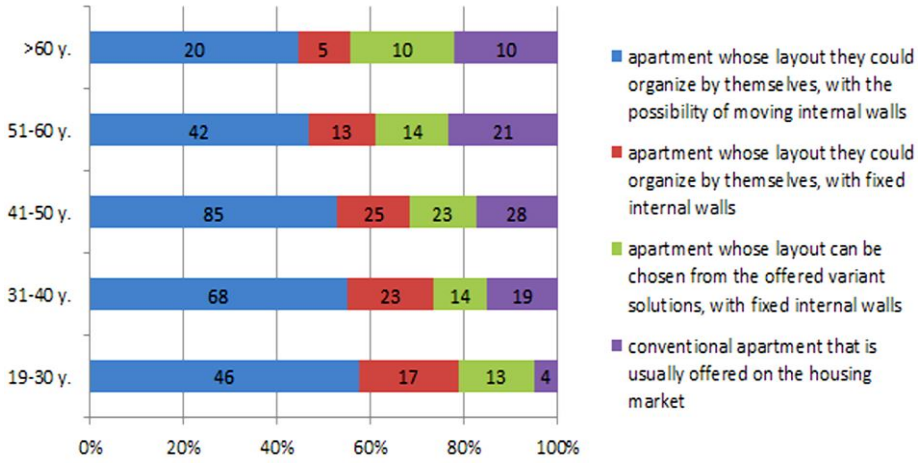


Diagram 8 Connection of the age category of the respondents and the answer to the question about the choice of the apartment

6. Comparison of the Obtained Results with the Results of the Study "Flexbile Wohnungen"

For countries in transition, such as Serbia, it is extremely important that measures of improving the quality of housing are strictly and rigorously defined and supported by adequate institutional and programme solutions. In this regard, the experience of the developed Western countries, both in terms of objectives and in terms of strategic measures for their implementation, are of great benefit.

By comparing the results of the survey of the tenants in multi-family housing units in Niš with the results of the survey of the tenants in social housing in Ulm (Germany), presented in the study "Flexbile Wohnungen", the following specificities and analogies are noted:

1. Within both surveys, a nuclear family is the most common category of households (with the largest share of married couples with two children and married couples with one child). There is also a noticeable increase in this type of households from the period of moving in to the moment of the interview. This data is of particular importance for the validity and reliability of the comparison and generalisation of the following results;

2. When asked which criteria were crucial in selecting an apartment, in both cases, the most frequent response was the size of the apartment, while only a small number of respondents indicated flexibility as the decisive factor in selection of the apartment, with the most common share of this response in nuclear family structures;

3. It is also interesting to note that in both cases, the choice of flexibility among answers is growing together with the level of education of the respondents. Based on this, it can be concluded that the concept of flexibility is unknown to a large number of users, as a result of insufficient awareness and knowledge of tenants about the potentials of housing exploitation and possible programme measures of sustainability;

4. In both cases, half of the respondents consider that the size of the living room and the number of rooms are an important criterion for choosing the apartment, wherein the representation of these responses proportionally increases with the increase in the household structure, which is a logical result;

5. In both surveys, smaller households give priority to the size of the rooms, while households with a larger number of members, as expected, the number of rooms is more important;

6. Although most of the respondents are satisfied with the size of the rooms in the apartment, those who have objections especially emphasize the size of the bedrooms, the need for separate bedrooms for adult children and the lack of storage for the needs of the household;

7. The possibility of a later change in the layout of rooms (extensive flexibility) is in both cases more preferable option than the possibility of choosing and changing before moving into the apartment (offered flexibility). This result points to the fact that the identification of users with housing space is better achieved by establishing of continuous communication between man and his immediate surroundings.

From all of the above it can be concluded that, regardless of spatial and temporal distance, cultural and social differences, the establishment of an active dialogue between human and the environment in which he lives represents the essential need for the self-sustainment of each individual in the narrower and wider community.

7. DISCUSSION

In the previous local architectural practice, apartments were mostly designed for an unknown user, where the characteristics of the plan leaving no space for tenants to express their own individuality through design. The static space of a typified expression in its exclusivity has become a place of use rather than a place of residence. Housing cannot be reduced to use only for practical purposes [2]. Minimum potentials for incorporating identities into the physical environment further intensify the sense of helplessness and frustration of users in conditions of greatly degraded living and social environment.

The possibility of choosing before moving into an apartment, which is occasionally realised in the domestic practice, is a positive step in methodological thinking, but not a sufficient prerequisite for the quality of life in the residential environment. Forecasting programme movements in the development cycle of exploitation is only approximate, as it depends on individual preferences and numerous other circumstances that can occur in the space-user relationship. Therefore, the solution chosen by the users in the initial phase of exploitation represents only a partial and temporary measure of meeting the needs of the household. The problem is further complicated by the possible changes in the structure and typology of tenants that bring their own criteria, needs and habits. Human needs in residential environments are an ongoing process, which is why it is necessary to allow users a choice at all stages of exploitation.

The conducted analyses have shown that the most frequent cause of the relocation of the household to a new apartment is the need for larger housing space due to the expansion of the family. On the other hand, the decision to change the place of residence depends to a large extent on the economic power of the household, which is why the purchase of a new apartment can be characterized as a privilege of higher social strata [3]. For households that are for financial reasons forced to stay in an area that does not correspond to the developmental needs of the group, living in a residential area can be a serious frustration and the "necessary evil" of economic weakness of its members. For this reason, in less developed societies, flexibility can be considered as an essential means of rationalized and socially responsible construction.

The results of the survey showed that the structural deficit is most pronounced in households with a larger number of members (families with three and more children and three-generation households) as larger apartments are poorly represented on the market, as indicated by statistical data [4]. Another problem is the fact that apartments are often sold on the market in a structure that does not actually correspond to the defined structural standards. Also, there is the case that the room where the accommodation of two users is planned actually corresponds in the size and dimensions to a slightly larger half-room (room for one user). In this way, the elementary health, hygienic and functional criteria of living are being destroyed and it creates an inadequate framework for the proper development of psycho-social and bio-physiological functions in the apartment [5].

Survey studies have shown that in apartments where family households live, the living room often assumes the sleeping function, which can be considered as an inappropriate and forced solution. In the context of a permanent housing crisis, families are consciously opting for an apartment where initially or over time some incompatible housing functions are performed within the same area, sacrificing in this way the overall quality of life in the apartment. The living room where sleeping is planned cannot be considered as a common

room for gathering family members, nor an individual room where, in accordance with psycho-physiological needs, it is possible to periodically allocate members from the group. Such practices can lead to serious problems in the family's development cycle, even to its breakdown [6]. Multipurpose use of space in terms of day-night regime superfluously divides the housing functions on day and night, although human needs in the apartment are much more complex and diverse.

Flexibility as a crucial criterion for selecting an apartment has been recognised, to a large extent, in the group of nuclear family structures, as well as among respondents of higher education. The need for space flexibility is, therefore, the most prominent in micro social environments in which the complexity and unpredictability of housing needs causes prolonged decision-making. The absence of an adequate policy to propagate and affirm different modalities of tenants' participation in decision making is one of the reasons why the flexibility potentials are exclusively recognized by information through education [7].

And in cases where the flexible potentials of improvement of the housing environment are recognized by tenants, the desired interventions are realized in a small number in practice. The reasons may be financial but also psychological, as a consequence of the inertia and apathy of the users in the domain of self-expression. A sense of resignation and unwillingness for changes is often conditioned by a culture of housing in a particular community, but also with a general social climate that can act as a disincentive to an individual [8].

8. CONCLUSION

The uncertainty of future needs and the way of building exploitation requires a continuous assessment of the conditions and quality of life in a particular environment. Forecasting the programme movements is merely an orientation measure of sustainability, whereby the negative effects of changes can be mitigated by a flexible physical platform. Interviewing tenants can give very useful information about the spatial and functional characteristics of the space, user satisfaction and "visibility" of flexible potentials within the residential area.

The dynamics of housing needs and potential modalities of space use cannot be fully anticipated at the design stage and the stage of moving into the apartment. Therefore, it is essential that the appropriate design solutions, with the technical and professional guidance leave the space to the users to adapt the apartment to their own needs during the exploitation.

Correspondence between the physical and social component in the temporal continuum categorizes the living space as a renewable resource, which undoubtedly contributes to the preservation of the environment in conditions of population and urban overcrowding, recorded at the local and global level. Raising awareness, informing and educating users and professionals about the criteria of socially responsible and ecologically conscious activities within the community creates a healthy housing policy, which can contribute to resolving global problem issues by local influence.

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PRIKAZ EMPIRIJSKOG ISTRAŽIVANJA SAVREMENIH POTREBA I USLOVA STANOVANJA U KONTEKSTU FLEKSIBILNOSTI

U ovom radu su prikazani rezultati prethodnog empirijskog istraživanja potreba korisnika i uslova života u jedinicama višeporodičnog stanovanja u Nišu, zasnovanog na nemačkoj studiji fleksibilnog stanovanja pod nazivom "Flexible Vohnungen". Istraživanje je uključivalo intervjuisanje stanara o različitim aspektima života u višeporodičnom stanovanju, s posebnim osvrtom na fleksibilan program stanovanja i njegovu primenu u praksi. Sistematizovanjem i upoređivanjem ostvarenih rezultata sa rezultatima inostranog istraživanja, mogu se doneti određeni zaključci o univerzalnim potrebama stanovanja i trenutnim uslovima života u gradu Nišu.

Ključne reči: *fleksibilnost, održivost, anketiranje stanara, višeporodičnno stanovanje*

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ARCHITECTURE AND CERAMIC MATERIALS, DEVELOPMENT THROUGH TIME: ADOBE AND BRICK

UDC 72:691.4

Ana Momčilović-Petronijević, Gordana Topličić-Ćurčić, Aleksandra Ćurčić

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

Abstract. *The fired earth products are from the dawn of time very readily used as a building material in architecture. Regardless of the geographical area, or era, both adobe and bricks have been often used because they are easy and cheap to manufacture.*
The paper provides the review of adobe and brick use, from the earliest times until nowadays. The evolution of their production, forms, physical properties and ways of their usage on the structures are presented.
The goal of the paper is an analysis of development of use of these products which will certainly remain in use for many years to come.

Key words: *ceramic materials, adobe, fired bricks, historical development.*

1. INTRODUCTION

The ceramics in a broader sense comprises the products created by firing clay which is previously treated in a specific way. The ceramic materials industry includes creation of a variety of products which can have different applications in everyday life. From clay and similar raw materials, an entire range of products is obtained depending on the processing method, raw material composition, temperature and number of firing cycles; the obtained products range from the coarsest pieces, such as bricks used in civil engineering, over the pottery which surrounds us in our lives to the finest porcelain.

Clay in its natural conditions, with water added, becomes soft and workable. There are several types of clay, which are mutually different depending on the share of kaolin in the sample, and on other ingredients. Porcelain clay, pottery clay, argil, loam, clay soil, marly clay, as well as brick clay are only some of the varieties. Firing of clay makes the obtained product strong and durable.

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Corresponding author: Ana J. Momčilović-Petronijević
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: ana.momcilovic.petronijevic@gaf.ni.ac.rs

According to their appearance and purpose, ceramic products can be classified as:

- coarse ceramics (intended for industrial usage in construction engineering – roof tiles, masonry blocks, covering panels, floor panels, insulating layers…). Industry of ceramic materials comprises production of most diverse products with a broad spectrum of possible applications in civil engineering;
- fine ceramics (pottery, decorations, object for everyday use, for electric material, for health care use, etc.).

According to a technological production procedure and processing technique, the ceramic products can be classified as: terracotta, majolica, faience, porcelain…

In this part of the paper is presented the historical development of the so called coarse ceramics, i.e. of the ceramic materials used in civil engineering. The paper discusses emergence and historical development of the production technology using adobe, as a precursor to the fired brick, and then fired bricks as one of the most widely used construction materials.

2. BACKGROUND OF THE CERAMIC PRODUCTS USE

History of production and usage of ceramic products goes back to a long time ago, to the paleolith [1]. Making and production of ceramics can be considered one of the oldest industries in the world. When people discovered that clay mixed with water can be easily shaped into a desired form, and that the clay objects become tough after firing, this "industry" was born. It is stands to reason to assume that it was a serendipitous discovery that earth changes after firing. In order to prevent grains from falling out of wicker baskets, people plastered them in mud. When left close to a fire, the clay hardened and turned into a "petrified" mass [2]. This pottery craft was improved in time. Not all societies developed this useful artisanal ceramics. The tribes which had a nomadic way of life did not engage in production of pottery. Life on the move could not satisfy the technical requirements for production of ceramics, and vice-versa, fragile ceramics was not suitable for the nomadic way of life. Most communities in which pottery use was detected are related to the neolith and stationary way of life. Of course, there are exceptions. As early as in the period around 24000 BC were made and then fired first human and animal figurines [3]. For example, on the site of Dolni Vestonice (Czechia) the animal and Venus figurines were dated of having been made in 25000 BC. About ten thousand years later, when the first communities were founded, the first ceramic tiles were created in India and Mesopotamia [3]. It is considered that the pottery products were for the first time functionally used for keeping food and drinks around 10000 – 9000 BC. Agriculture was first developed in the region of Near East. On the Catal Huyuk site in Turkey were found pottery fragments dated back to 6500 BC [4]. Except for the objects for everyday use, fired earth was used as a building material on a massive scale since the ancient times. Earth as a building material is used in several different building techniques, in several kinds of building semi-products and products. The simplest form of earth usage comprises using rammed earth, or grass turfs [5]. It is then followed with adobe and fired brick.

Ceramic products were from the ancient times used as a building material. Usage of these materials for construction purposes is related to the very distant past. They were used all around the globe. A large number of magnificent structures from the ancient past

which are preserved even today prove that the ceramics is a tough, durable and gladly used material. Their production was historically improved with the technological advancement. A large number of significant buildings are even nowadays built of ceramic materials, primarily of bricks. The reason for this is in its numerous positive physic-mechanical properties, simple way of production, low cost.

3. ADOBE

Regarding that in the concept of ceramics are comprised clay product which are fired, i.e. after forming exposed to high temperatures, one of the first building materials, adobe, could not be completely classified within this group of materials. Adobe comprises a formed and dried, but unfired brick. The clay mixture, as a form of micro-reinforcement, was added straw, animal hair or some other available material in order to prevent onset of cracks during drying.

In the history of architecture it became famous very early. Adobe survived in Jericho, in the territory of present day Israel, and it is dated in the 9th millennium BC. It was shaped as a loaf of bread, because it was made without moulds, in the same way bread was kneaded [5]. In Mesopotamia, around 2800-2300 BC was used a rough form of adobe, with a flat base and a rounded top [5]. Rectangular, regularly shaped adobe appeared at a later date, because for making it, it was necessary to make moulds, which required a considerable degree of carpentry skills. The tool used for making adobe was, therefore, the mould, which represents the first technical innovation in the brick production industry.

The oldest images attesting usage of the mold in production were discovered in the tomb of Rekh mi Re in Thebes, in ancient Egypt [6]. In the mentioned picture, one can see the entire production procedure: the workers are taking the water out of the pool, mixing the water with earth and straw and then placing it in the moulds arranged on the ground. After that, a piece of wood is being used to remove excess mass from the mould, the mould is being taken out and placed on the ground so that the procedure can be repeated. In this way, it was possible for one craftsman to make several hundred regular adobe bricks. Fresh adobe bricks formed in this way were left to dry on the hot Egyptian sun. (Fig 1).

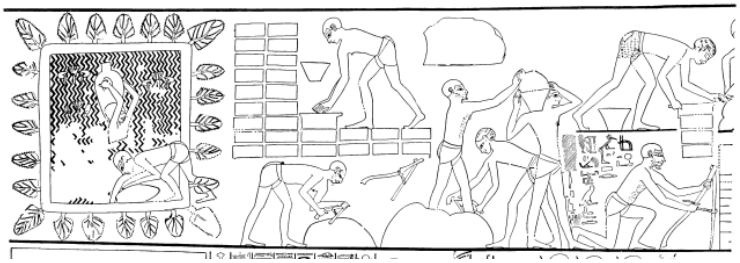

Fig. 1 Adobe mould and the picture from the tomb of Rekh mi Re in Thebes where the procedure of adobe making can be seen [7].

According to some authors, the daily norm of the workers making adobe was at first 1000 pieces, and after a period of practice, it would reach in time as much as 1800 pieces [8]. Adobe was used in Egypt for construction of housing buildings, but also for construction of religious edifices of lower importance. Mud mortar was used as binder during adobe bricklaying [9], but woven straw was installed in the walls, and it had the function of a bedding course. Adobe was used for making terraces on which buildings were built, but also the auxiliary ramps for lifting of loads to higher elevations. Different dimensions of adobe were used for various buildings in Egypt. Starting from the period of the Middle Empire, the adobe used for the temple walls had the pharaoh seals imprinted in them, which is most welcome when determining construction time of the buildings.

It is assumed that it was not the Egyptians who used these wooden moulds for adobe production, but that rather they adopted them from Mesopotamia, where they had been used as early as in the Ubaid period (5900-5300), long before people started using metal. [10]. In Catal Huyuk, in the south of Turkey earthen slabs formed using moulds and dated back to 5700 BC were found; they were so large it took two men to lift them [5].

In the area of Mesopotamia, the most frequently used building materials were adobe and fired brick of various dimensions and formats. Often used was the insufficiently dried adobe, which in the wall under the own weight compressed into a mass resembling rammed earth [11]. For that reason, the Mesopotamian building technique is based on the massive load bearing walls. As soon as around 3000 BC, quadrilateral – parallelepiped adobe made in moulds was widespread across the entire Near East. In Mesopotamia, this material was abundantly used, in almost all types of structures, starting from the plateau terraces on which buildings were erected to the fortification walls… Adobe was used for construction in Mesopotamia using mud mortar, often with courses of reed at specific intervals. The ziggurat cores were built using adobe, and the external cladding was constructed using fired bricks and bituminous binder. This method improved waterproofing of structures to a great extent.

In Persia, several types of materials were used, including adobe. Walls were constructed using adobe, and then they were clad using fired bricks, glazed bricks, stone and sometimes adorned using metal elements. Adobe was used for building structures on Crete and Mycenae, mostly for housing architecture. Even the walls of royal palaces were built of adobe, whereby for the palaces the stone in very large blocks was also used.

In construction of buildings in the ancient Greece, different kinds of material were used. Adobe was also used, in the earliest phases of development of Greek architecture, both for housing buildings and for city walls.

During other, later phases and historical epoch, in other civilizations, adobe was likewise used. Adobe was used in construction of the following large structures: Great Mosque of Djenné (Fig 2), famous building made from banco, a type of adobe, San Miguel Mission in Santa Fe, New Mexico, Poeh Museum tower, the tallest adobe structure in New Mexico, USA, Church at San Pedro de Atacama, Chile, Cliff dwellings of poured or puddled adobe (cob) at Cuarenta Casas in Mexico. The world's largest adobe structure is probably Bam citadel, or the Arg-é Bam, in Kerman Province, Iran, dating to at least 500 BC.

Fig. 2 Great Mosque of Djenné, source [12]

In the Near East countries, then Africa, the Danube river delta in Europe, even nowadays this material is often used. It is used for structures of vernacular architecture in almost all the world where clay is readily available material. Portugal, for instance, has a large number of buildings made of this material [13] [14], followed by Cyprus [15], Chile, Iran, New Mexico, Spain, France, Romania, Serbia... In Serbia, vernacular architecture structures were, until a several tens of years ago built using adobe (Fig 3). In the area of Vojvodina, the dominant type of popular houses are those made of rammed earth and adobe.

Lately, construction using ecological materials is insisted upon, so adobe is often encountered as well.

Fig. 3 Adobe on the buildings of vernacular architecture in Serbia.
Photo A. Momčilović Petronijević.

4. FIRED BRICK

The fired brick is one of the dominant construction materials. It has the same origin as adobe, it is made of the same raw material, so it appears in the same area where there adobe emerged prior to it, in the areas of Mesopotamia, Egypt [16], China... It is probable that the fired brick was created when people found out that after the fires that broke out, the buildings made of adobe became hardened, while all wooden elements were burnt. Fired bricks developed in China in the similar fashion, where it has been existing since 16^{th} century BC.[5].

The earliest data on the fired ceramic date back to the period 7000-6000 BC. The idea that the same technique, firing, can be used for building materials was for the first time put into practice in old Mesopotamia, around 5000-4500 BC, in Madhur, for construction of drainage [10]. Yet, usage of fired bricks remained rare to around 3000 BC. Usage of adobe was simple and cheap, and no qualified labor was needed to use it. The fired brick was different. In order for the clay to obtain the proper strength, it has to be fired at the temperature of 950-1150 degrees. Lower temperature results in brittle bricks, and higher would melt the clay. It is also necessary to select the proper clay, since experimenting is expensive, regarding that the fuel – wood for brick firing is scarce. Firing made the bricks thirty times more expensive [10]. Even in the time of Babylon, when the industry of firing bricks was already well advanced, fired bricks were still two to five times more expensive than the unfired ones. Regarding the shortage of wood required for brick firing, it was used scarcely, in combination with adobe, by using the fired bricks for external or decorated surfaces and on places where loading is higher and there where damp was prone to create problems [5].

There were different forms and dimensions of the bricks. It was possible to see the bricks on the construction plans surviving on the clay tablets. From them, one can conclude that bricks played a significant role in the building engineering of the period, and it was a unit of measure in all construction works [10].

Glazed bricks constitute a major discovery in the production of fired bricks. Parts of the palace in Babylon were artistically decorated using the glazed bricks. Bricks were shaped, and as still fresh, they were dried and then baked and glazed. Small elements were used to compose large desired images, in order to avoid fracturing due to shrinkage of large parts. The dye glazing was applied on them as an emulsion prior to baking, so it became glazed after baking. Unfortunately, there are no surviving detailed data of their technology (Fig 4). The Sumerians plastered, painted their buildings and used mosaics of clay cones inserted in the wall surface to improve durability and esthetics of their buildings [17]. In the Column temple in Uruk, there surviving cones made of terra cotta mosaics, arrange across a plastered area to form a specific pattern.

Glazed bricks were used in Susa, in a similar way as in Babylon [18] (Fig 4). Here, the bricks are tapered towards their back side, so that pointing joints on the wall face would be minimized. Each brick was marked, showing its position in the wall. The brick was laid prior to baking for trial, and in the kilns were produced the elements of a giant puzzle which had to be laid in a certain order [10].

On Crete, there is evidence about using the fired bricks for construction, while it was almost not used at all in Mycenae. In almost all ancient civilizations, fired brick became a very important building material. Yet, the greatest leap in producing and using fired

bricks occurred in the period of the Roman Empire. Roman legions took the brick firing technique into all corners of the empire.

Fig. 4 Glazed bricks on the Ishtar Gate, Babylon.
Source [19], photo by Jan van der Crabben

The fired brick was profusely used in Rome, and until 2nd century AD, it became sophisticated and industrial. Digging up clay, its processing and placing in moulds was performed by slaves in the Roman empire. In the surrounding areas, it was the Roman military that was charged for the production of fired bricks. The earliest fired bricks made in Rome were of poor quality. Only later, in order to avoid the negative effects of clay shrinking during drying and baking, sand was added to mitigate this problem. Fired brick became the most used building material in 3rd and 4th centuries AD.

In Rome, the dimensions of bricks were standardized, but rarely uniform. Bricks were modeled by inserting the prepared mixture of clay into the open moulds. Usually, the roman brick had a square form, even though there could be other shapes (rectangular, triangular if needed, or any other shape for special purposes). Vitruvius [20] tells about three types of adobe, „Lydian", *pentadoron* and *tetradoron*. The latter two types of brick have Greek origins. The standard Roman brick has a side of one foot[1], and thickness of around 4,5 centimeters. There were bricks of larger dimensions, square, having sides of 1,5 foot and larger having 2 feet which were rarely used. Rectangular bricks were rare. During production, some bricks had a seal imprinted on the top sides. In the earlier period, the seal was simple, and had nothing but the initials. Later, the data in the seal were extended, including the name of the land owner, manager of the brick baking facility, datum. These data are contained within circular or rectangular frames.

Bricks were used for bricklaying of walls, for lining of walls, for construction of arches and vaults, for floor tiling (Fig 5).

Walls could be constructed of brick only, which was a rare case, or they were concrete, with a cast core, lined with bricks, as a more common variant. The thickness of the joints could be different, and varied from only 0,5 millimeters, up to several centimeters, when it suited the thickness of the brick. There are multiple versions of bonds, depending on the way the brickwork was laid. The Romans called the building techniques – the opuses. This term survived to this day, and refers to the construction method in the ancient Rome, regarding

[1] The Roman foot is long 29,57 cm

building walls, floors or other types of building works [21]. Wall lining with bricks was elevated to a higher level, with formation of different ornamental styles. Therefore, bricklaying styles featured *Opus latericium*, *Opus testaceum* or *opus doliare, Opus spicatum, Opus mixtum...*

Fig. 5 Usage of bricks for floor tiles and wall construction at an early Byzantine site, Iustiniana Prima (6th century) in Serbia. Photo A.Momčilović Petronijević and Č. Vasić

Bricks were used for bedding courses of the cast walls. Bricks were used for construction of arches [22]. In addition to the arches, vaults were massively built, used for spanning large areas, as well as domes.

Lining of internal walls of thermae was performed using special elements made of fired clay, a kind of tiles with flanges, which were pressed into the wall in a way that there is a spacing between the wall surface and the tile, where hot air would flow. Also, for this purpose were used hollow rectangular cross-section bricks. Bricks were used for construction of aqueducts, and fired clay was used for water distribution pipes, water cisterns… the waste water drainage system was once built from bricks, as well as hypocausts… glazed bricks were used in the eastern parts of Empire.

The best example for brick usage can be seen in the remains of the Trajan's market (Fig 6), and in Ostia, where almost every structure was built of brick.

Fig. 6 Remains of Trajan's market, Rome. Source A. Momčilović-Petronijević

The Romans spread the technology of production and bricklaying across entire empire. Thus usage of bricks took root in almost all parts of Europe. After the decline of the Roman Empire, bricks lose some of their popularity, but come back into mass usage during the medieval period. During 12th century, the production technique of fired bricks was transferred from the north of Italy into the north of Germany, where a particular gothic style was established, based on bricklaying construction, the Backstein gothic. Gothic buildings of this kind are found in the area of Denmark, Germany, Poland... [1] In England in the first half of the 16th century, the brick baking is at its heyday during the reign of Henry VIII. Large parts of his Hampton court (near London, 1520.god) were built from fired bricks [5].

In the period of Renaissance and Baroque, fired bricks could be rarely seen on the facades, it was most often covered with plaster. In 18th century bricks continued to be rarely used on the facades in northern Europe. At the beginning of 19th century, some Georgian architects used bricks for construction of family houses. The brick is back in style by the mid 19th century during the Neogothic period. In the long history of its existence, bricks alternately came in and out of architectonic style.

In the 19th century, with industrial revolution, bricks became more available and its transport cheaper. The form and quality of new, machine produced bricks became more regular, and its usage more cost effective. In 19th century, the fired brick was especially extensively used in England, but also in its colonies in South Africa, Australia, New Zealand… [5]

With the increase of labor cost, in 20th century, more and more only the wall faces were clad in bricks, to reduce the cost, without losing the esthetics of these buildings. Bricks proved to be not the right choice of materials, concerning construction of multi-storey buildings which saw expansion by the end of 19th century in the USA, because of the considerable thickness of the walls necessary for resisting the loads of the upper floors. Apart from the technical problems, it was the emergence of modernism by the turn of the 20th century which gradually reduced usage of bricks in construction, basing it on concrete, steel, glass… Yet, some of the architect of early 20th century did not completely abandon bricks: Walter Gropius, Adolf Mayer, Mies van der Rohe, Le Corbusier have in their creative opus some structures made of brick. Brick was often used by Frank Lloyd Wright, who used it on almost every building he designed. The Finnish architect Alvar Aalto played an important role in reintroduction of brick into contemporary architectonic buildings. The Aalto's modernism with regional characteristics inspired by the tradition of the brick architecture of northern Europe is what makes this architect stand apart from the international style (Fig 7). Willem Dudok is a Dutch architect who also very readily employed bricks in his designs.

In the period after the WW2, many great names at the architectonic stage recurrently used bricks – Philip Johnson, Robert Venturi, Aldo Rossi, Mario Botta...

In addition to Europe and America, which were mentioned, the brick is considerably used in the Islamic world, Sin which on the occasion of construction of building it is combined with glazed tiles, producing impressive results [23]. The Near East Architecture reached may its highest level in the Iranian city of Isfahan in which almost all buildings are made of the brick. Two large mosques, Royal or Imam's or somewhat smaller sheik Lotfollah's mosque are true pearls of Islamic sacral architecture. It is assumed that in the Royal mosque, more than 18.000.000 bricks were installed; the height of the portals

supporting the minarets is 48m, and the height of the central cupola is 52m [5]. This mosque represents a very important creation made of bricks, built in 17th century. Yet, the visual effect was not achieved with bricks but with glazed tiles, covering the mosque both on the outside and on the inside.

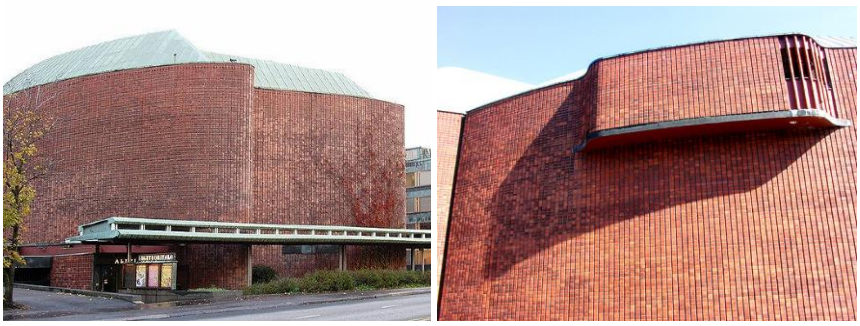

Fig. 7 Alvar Aalto. House of Culture.
Source [24]

4.1. Production of bricks

Prior to 19th century, bricks were made manually, by compacting the clay first in wooden and later in metal moulds, after which it was baked.

The brick firing procedure can vary, and it evolved in time. The simplest way of baking is the following: raw bricks are stacked, with the fire burning in the middle. There are kilns with two chambers, where the firing chamber is in the bottom part, while the bricks are on the top. The deficiency of these kilns is that those bricks which are in the lower rows, closer to the fire chamber, are exposed to higher temperatures and get over-baked, and clinker bricks are produced, while those bricks further away from the fire remain under-baked and brittle [5].

The Roman kilns could have been different in form, but they all worked using the same principle. The lower level accommodated the fire chamber where fire was fed through the side opening (Fig 8). The most common fuel was wood, while there are examples that the baking temperature was achieved using coal. Above the fire chamber was a perforated ceiling, which was the floor of an upper level, on which bricks and roof tiles were stacked. Hot air reached the upper level through perforations, and in this way fired the stuff. The walls around this space were thick, to prevent cooling. The layouts of these kilns were rectangular or circular [10]. The making and baking technique of firing bricks was so perfected, that it could not be surpassed in quality even by the makers of many later epochs.

The other type of dual chamber kilns, which emerged later comprises an elongated kiln design, so the fire burns at one end of the kiln, and chimney is on the other. In this way, the hot air does not flow directly upwards, but flows around the bricks, providing a more constant temperature and contributing to the more regular quality of bricks.

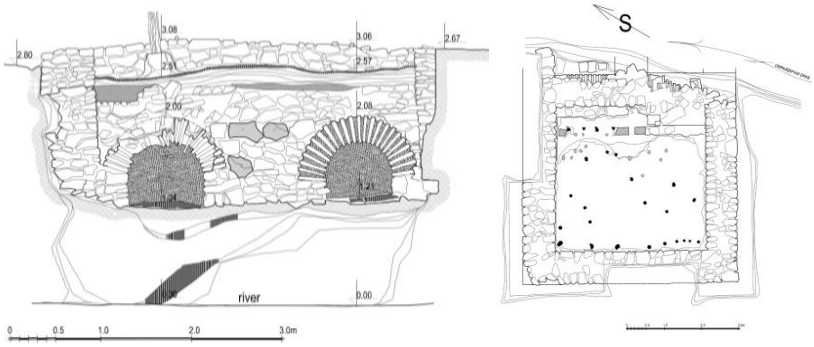

Fig. 8 Brick kiln, Caričin Grad.
Drawing A. Momčilović Petronijević according to the documents of the Institute for protection of cultural monuments of Niš [25]

A traditional kilns type are so-called Scove kilns. Those are temporary structures. Scove kiln is a kiln in which green bricks are stacked, enclosed with burned bricks that are then daubed with clay to reduce the loss of heat, and burned. A brick clamp is a traditional method of baking bricks, done by stacking the unbaked bricks with fuel under or among them and then setting the fuel on fire. The clamp is considered a type of kiln. If the clamp is insulated by packing earth or mud around it, it becomes a scove kiln. [26]

The permanent kilns are called continuous permanent kilns. The bricks from these kilns are of good quality, but the initial investment is slightly higher. The Hoffmann kiln and the bulls trench belong to this group of kilns.

In 1857 an Austrian inventor, F.E. Hoffmann invented a brick kiln for continuous baking consisting of an arched tunnel around a central chimney, so that the heat passes by the chambers filled with bricks, by heating up the chambers, one by one, so that the fire never needs to be extinguished [5] [27] (Fig 9)

Bull's Trench is the brick firing kiln conceived in England in 1876. The fire burns in a trench dug in the ground, which takes considerably less investment for kiln construction, while the number of produced bricks is large. It has usually a rectangular, circular or elongated layout. Such kiln type is used nowadays in India, Pakistan, Bangladesh... [5] In 1927 was designed (by a German, Habla) a highly automatized tunnel brick kiln. It facilitated serious savings of human labor, and it was very popular in Germany, England and USA before WW2. Simultaneously with the industrial production of bricks, it was still made manually, particularly those bricks of specific format and shape, and decorations of fired clay – terra cotta which were used for the facades of buildings in 19th century in addition to various brickwork bond combinations. [5].

Production of hollow bricks began in France, in 1843, and the following year, 1844 in England, too [5]. This was an important milestone in its construction. A lighter bricks were made, for whose production was used less material, and which has better thermal characteristics. It could also have various forms, from parallelepiped, to square, cylindrical, hexagonal, triangular and other specific forms.

Fig. 9. Hoffmann ring oven in Mildenberg museum.
Source [28]

Nowadays, the brick production process is advanced, and it mostly consists of the following phases: the initial step in production of the brick is crushing and grinding of raw material in a separator and a jaw crusher. Next, the blend of ingredients desired for each particular batch is selected and filtered before being sent on to one of three brick shaping processes - extrusion, molding, or pressing, the first of which is the most adaptable and thus the most common. Once the bricks are formed and any subsequent procedures performed, they are dried to remove excess moisture that might otherwise cause cracking during the ensuing firing process. Next, they are fired in ovens and then cooled. (Fig 10) Finally, they are dehacked - automatically stacked, wrapped with steel bands, and padded with plastic corner protectors [29].

Fig. 10 Bricks production – some phases.
Source [30].

5. CONCLUSION

Adobe at first, and then the brick was used for construction of a large number of most diverse types of buildings. Be it housing architecture, fortification system architecture or magnificent sacred structures, the brick was very often and readily used in almost all historical epochs. In some epochs, it was more popular, in some less, but it was never abandoned. It was used as a building material, as a cladding or in combination with other materials. Most different types of bricks in terms of forms, physical and mechanical characteristics… A number of good characteristics as a building material made the brick

and its varieties almost omnipresent in all types of buildings since the beginning of architectonic creation until today.

The brick as a building material is very durable. It has a number of good characteristics it is very user and maintenance friendly, creating energy efficient buildings, but also performing various functions [31]. The brick advantages are numerous – it has high strength to compression, frost, it is not flammable, it can be reused and recycled, it is available in many shapes, colors and textures…

Some other reasons for using readily the brick are as follows: for its making is used raw material, the production processes are environmentally acceptable, life cycle of structures are long, without intensive maintenance, durability, recyclability and esthetics [31], cost [32].…

The brick and brick products will undoubtedly, for a long time be an integral part of the architectonic trade.

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ARHITEKTURA I KERAMIČKI MATERIJALI, RAZVOJ KROZ VREME: ĆERPIČ I OPEKA

Proizvodi od pečene zemlje se od najdavnijih vremena veoma rado koriste kao građevinski materijal u arhitekturi. Bez obzira na geografski prostor, ili epohu, ćerpič i opeka, su jako često u upotrebi zbog pogodnog načina proizvodje i pristupačne cene.

U radu je dat pregled upotrebe ćerpiča i opeke, počev od najdavnijih vremena pa do danas. Prikazana je evolucija njihove proizvodnje, oblika, fizičkih osobina i načina primene na objektima.

Cilj rada je sagledavanje razvoja upotrebe ovih proizvoda, koji će zasigurno još dugi niz godina biti u primeni.

Ključne reči: *keramički materijali, ćerpič, opeka, istorijski razvoj*

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GENTRIFICATION, CREATIVE CLASS AND PROBLEMS OF CONFLICT OF INTEREST IN CONTEMPORARY URBAN DEVELOPMENT

UDC 711:316.334.56
711:338.2
711.316.33

Vladimir Kostić[1], Aleksandar Kostić[1], Milena Dinić Branković[2]

[1]University of Pristina, Faculty of Economics, Kosovska Mitrovica, Serbia
[2]Univesity of Niš, Faculty of Civil Engineering and Architecture, Niš, Serbia

Abstract. *This paper considers modern city territories and analyzes neoliberal spatial city planning which is, among other things, mostly realized through gentrification. While explaining the modern transformation tendencies of cities the authors seek to find the link between the gentrification phenomenon and the rise of city inequality. In this context, marginality is not the result of economic underdevelopment but economic progress. The paper explores the reasons why contemporary urban politics leads to class segregation. The authors investigate a genetic connection of the capital and urbanization confirming Harvey's paradigm that „capitalism is forced to urbanize in order to renew itself". Furthermore, the paper investigates the relationship between creative class-creative city and to what extent it is reality and to what "a utopia for the chosen ones."*

Key words: *urban renewal, neoliberalism, post city, inequality, commercialization*

1. INTRODUCTION

Social sciences, economy and sociology in the first place, have recognized a challenge in the possibility of exploring city gentrification as an instrument of neoliberal urban politics. Therefore the sociologist Lefebvre (1970) came to the conclusion that capitalism could only survive with the aid of the production of space and was the first to use the term "city substance". Harvey who applied Lefebvre's idea on urbanism as a social and engineering discipline in the 1980's (1985) was on the same track. Both authors realized that gentrification itself would solve the problem of excess financial capital. They saw the growth of cities as an important factor of economic stabilization of capitalism on a global

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Corresponding author: Vladimir Kostić
University of Priština, Faculty of Economics, Kolašinska 156, 38220 Kosovska Mitrovica, Serbia
E-mail: vladakostic1985@gmail.com

scale. The definition of the term gentrification is complex. The term gentrification was first introduced in sociology by Ruth Glass with the intention of describing the invasion of middle-class into residential districts of London that were at the time used by the working class people. Tiesdell et al. (1996: 128-129) talk about gentrification as a phenomenon according to which residents of lower income and less profitable entertainment are replaced by wealthier tenants and more profitable uses. The law on Spatial Planning of the Republic of Serbia 2010-2020 defines gentrification as the improvement of economic standards of a certain district, often by well-planned urban renewal after the megaprojects related to great sport or cultural events. What all of the existing definitions of gentrification have in common is that they define it as the construction of residential areas intended for wealthy people, or in other words, for the population homogenous according to the symbolic and economic status. Capitalism is forced to urbanize in order to renew itself. A great urban structure transformation with a dramatic change of socio-economic picture occurred at the end of the 19th century in Paris and was led by Baron Haussmann. Thanks to the ideology and governmental support of the public official Robert Moses, in the period 1940-1970 a significant reorganization of New York took place. Its aim was to lead the market out of the crisis through construction and attraction of excess capital. "Spatio–temporal fix" occurred (Harvey, 2005a), and the production of "city substance" acquired greater dimensions and the capital started creating its own reality.

Gentrification of cities with all its vagueness of meaning to this day attracts the attention of researchers. The importance of cities in modern world is constantly growing and their network is building up. Therefore, „in the countries with low income rate economic activity makes up 55% of GDP, in moderately developed countries 73%, and in developed countries up to 85%, which implies that modern economy is not 'tied to' territories but rather cities and their networks. (Vendina, 2012: 812). This indicates that markets have "swollen" the excess capital. Sociologists begin to renew a critical approach towards space. It becomes the "expanding of city substance" (Rex extensa) as a paradigm of given and simple. However, the involvement of social sciences makes the whole process more complex. In fact, "the labyrinth of complications" is created (Harvey, 2005b: 93). The neoliberalization of urban space or in other words urban practice has put the rebellion, that is to say, the understanding of "the right to the city" in the foreground (Harvey, 2008: 88). In this sense, there is no division between the spatial structure and economic paradigm of competitiveness and conjuncture. Consequently, space becomes contradictory - because, apart from being the category of power transition, in the language of Marxism, it is being compressed and at the same time it is a substance of expansion, dynamic, its acceleration becomes faster day by day. Cities become a paradigm of speed at which things happen in urban politics. Consequently, discussions on the construction chaos and corruption become modern urban topics.

The purpose of this research is to investigate the "creative city" as a wide-spread concealment of enormous social costs and neoliberal agenda. The "creative city" concept focuses on the dynamic sources of change, incorporating the youth cohort and popular culture shaped by the digitally literate and entrepreneurial consumer (Hartley et al., 2012), and is driven by the "creative class" (Florida, 2002). Florida's view on economic growth and development of cities and regions is based on the idea of a distinct group of people working in so-called "creative" professions, whose creativity represents a great potential for innovation and urban growth. The "creative city" should not necessarily be considered as an absolute discrepancy of creative urban development and gentrification of urban area. Therefore, the aim of this paper is to investigate the following: (1) the gentrification

phenomenon in all its complexity, which includes both positive and negative discourse, and (2) to what extent a neoliberal city represents the fertile ground for entrepreneurs on the one hand and a problem for the majority of citizens on the other hand, as well as, whether a "creative class=creative city" represents a realistic developmental perspective or rather a utopia for the chosen ones.

2. GENTRIFICATION AS A MODERN URBAN PHENOMENON

In the last fifty years great deindustrialization of cities has happened. Namely, there is the case of relocation of industrial facilities outside of the city which leads to the changes reflected in the areas ready for the construction of residential and commercial property. Urban renewal of these areas means better housing quality and better communal infrastructure in ruined urban area potentially interesting for investors. This may result in gentrification and leads to socio-economic stratification. This phenomenon is especially associated with cities in Great Britain, South America and Australia (Butler, 1995: 190).

The term gentrification literally denotes refinement, ennoblement, and prestige, making a particular space more attractive for living or renting. This may refer to individual buildings or the whole districts that earned such reputation for objective socio-economic processes such as: lowered standard of living, depopulation, deindustrialization, etc. In European and American cities this process started in the middle of the 20th century and implied mass migrations of residents from districts that became prestigious all of a sudden. These marginal groups usually moved to the suburbs or even farther (Glass, 2010: 7). Gentrification affected long forgotten and deserted industrial buildings. Researchers in such cases talk about the changed purpose of a parcel of land, city regeneration, urban renewal or reconstruction (Tallon, 2013: 42-66; Helms, 2003: 474-477; Smith, 2010: 93-94, Vaništa-Lazarević, 2003). *The first stage* of gentrification involved depopulation of whole districts which were characterized by the low standard of living and high crime rate (so called ghettos). These were devastated and neglected locations where compact, racial and national minorities used to live, usually in ruined apartment buildings that belonged to factories. This stage is linked to 1960s. The second stage began in 1970s with the emergence of the so called squatters (English verb squat – overtake, conquer cities) and lofters (English loft – a flat in the attic, inaccessible place). The nature of this phenomenon is in the occupation or cheap lease of for various reason empty flats, houses or whole districts. These districts were usually inhabited by bohemians, actors and artists who turned the space into art galleries, art studios, night clubs, etc. These places were characterized by a special "aura" and image which contributed to the rise of prices in the near neighborhoods. Having realized this, the owners changed the terms of the lease and the rent went up or the institutionalization of space was carried out by granting it the official status. These processes happened in Chicago, Amsterdam, New York, Berlin, and Paris. The third stage is connected to the period after the beginning of 1990s. Gentrification started flourishing with the aid of accumulated capital and the support of public sector.

Gentrification does not only represent an important capital investment it also represents the realization of non-economic goals that would contribute to the overall success. Actually, that is a symbolic capitalization of space that enhances some segments of post industrialization. Such developmental strategy is connected to the establishment of national and global market of consumers prepared to pay a lot for the service they get. Similar

strategy is impossible in the cities where there is no good transportation infrastructure, as well as in the cases of undeveloped inner demand, the lack of initial capital, and often the lack of stable institutions. Space as a socio-economic, political and cultural phenomenon poses a number of dilemmas for a term that was considered unambiguous. It was the domination of the given condition of space that long excluded the role of social sciences because it was considered that space was far simpler than society. Things became more complex with the involvement of social sciences.

Therefore, gentrification as a new phenomenon in urban development represents higher standards of living for some people, and for the others, the struggle for survival and migration. It included class dimensions which took place in social geography of working class districts. Those who supported this process used more sophisticated terms: „recycling of districts", „improvement", „renaissance", etc. This was an attempt to blur class, and racial connotations of gentrification (Beauregard, 1993), which indicates that gentrification is a controversial process with the class character. That is the reason why the opposition to gentrification is often seen as the opposition to advancement. It is obvious that disputes related to gentrification do not only represent a struggle for urban space, but also for symbolic political power to determine the future of a city (Smith, 2012: 46). Gentrification is a process which lasts and provokes debates.

2.1. Neoliberal city, gentrification and the problem of conflicts

Starting with the 80s the production of "city substance" becomes unlimited and it is not only focused on cities, which was common in the past. Neoliberal logic turns everything into resources, whether it is the case of brands, processes, ruins or people. Since the only true measure of neoliberalism is efficiency, everything comes down to interchangeable monetary resources, from oil to spiritual values. The question arises as to whether or not the neoliberal cities are a prey of entrepreneurs or truly at the service of citizens? It is obvious that a large financial surplus is absorbed by space and in return increased through urbanization, in other words strategies for faster city development at all costs. In this sense the existing, but insufficiently efficient city substance, is restructured through gentrification. Therefore it is forced by the capital, or better say, a new possibility for the rent income through realty arises (Rent-gap theory). In other words, gentrification represents the struggle of opposing poles which takes place within neoliberal cities (Smith, 1996). So called chaotic concepts which are the result of the low quality criterion represent negative implications of gentrification. It often happens that "Districts populated by middle and upper class strive to achieve exclusiveness, namely to impose various measures of restricted trespass for nonresidents, such as placing some physical barriers or inhumane security systems, or discouraging passersby to find themselves in such areas by some symbolic means. In both cases boundaries are set, although of different level of restriction between the private and public space, which has great political implications" (Krstic, 2015: 88). It is obvious that residents of gentrified city areas are not interested in social life and interaction with their neighbors. Such people are only mobile within their own groups, especially when residential and spatial mobility is concerned, which only explains self-sufficiency of new middle class people and their lack of desire to keep in touch or develop any kind of a relationship with the neighbors. (Goodlad and Meegan, 2005: 198).

Gentrification is an ongoing process and it does not imply that the neighborhood dimensions are not susceptible to change. The atmosphere is created through interaction. If

there is a "shell" in "gentrified" neighborhood, social life becomes impossible. The best example of this is Belleville, a district in eastern Paris where besides autochthonous French people lives a great number of immigrants. However, its location and traffic infrastructure was noticed by middle and high class people, so they started inhabiting Belleville in 1980s. In that part of the city residents formed two groups. The first autochthonous group does not look upon social and ethnic diversity with hostility, whereas the second group is reserved because the type of life led in the neighborhood does not suit it, it keeps itself at a distance from the local residents and does not interact with the first group. The immigrant group does everything to make native residents leave the neighborhood. It is obvious that gentrification of Bellville brought to a conflict, and given the economic and social power of new residents it is inevitable that the old residents who nourish community spirit and solidarity cannot survive in the district, in other words they will start moving out (Simon, 2005: 218-228). In that sense, the space itself is formed as a network of mutually "blind" places that negate each other (Замятин, 2013). However, gentrification does not necessarily has to bring troubles because the middle class sometimes develops social relationships which include different spheres such as work, church, various associations, which enable it to transfer social capital from one discourse to another (Coleman, 1988: 109). Even though the relationships are developed between different social strata, and different social groups intertwine, there is a potential for making contacts that would help the social capital bridge the divide and create the setting for the improvement of the social status of marginalized groups.

Gentrification has an element of reurbanisation and revitalization in itself which comes from disputable necessity, even though everything rests on urbanism as the product of neoliberal ideology. It is precisely the conjunction of ideology and the market characterized by the urbanistic strategies that enables "the real estate market to mediate space in the same way in which financial market mediates time" (Sheppard, 2006: 125). Gentrification is always in the sphere of social relations and class power because without excess capital there is no urbanization. It sometimes has devastating consequences since the whole families have to move out. Sometimes integrated communities characterized by solidarity and companionship are scattered on the periphery of the city, which consequently makes them lose their sense of rebellion. These people think that the right to the city has been taken from them. This only illustrates the power of capital in the process of urbanization - "a fundamental and radical aspect of neoliberal gentrification" (Harvey, 2013: 27).

It is obvious that „liberal urbanism leaves citizens in a vicious circle of poverty without finding other solution for them but make them move somewhere else" (Đorđević, 2016: 261). Marginalized groups have neither strength nor power to resist such processes. After leaving gentrified areas the state sees them as an additional cost, and they find themselves in more hopeless situation. It is in government's interest to, for example, make profit out of construction not realizing that the problem becomes bigger because of the growing number of aggravated city inhabitants (Levine, 2004: 89). A way out of this situation lies in the fact that the complexity of gentrification must be realized. Namely, in the process of urbanization, urbanistic aspects, architectural solutions, ecological, social and legal norms must be taken into consideration. It is a fact that in the process of gentrification different interests are intertwined and the power struggle is usually at the expense of citizens. The first negative result is socio-spatial stratification and the rise of inequality. The decision making should be transparent and citizens and community should participate in the creation of politics.

3. Creative City and Immaterial Factors of Development of Urban Space

National and global market as well as globally integrated organizations cannot function properly without central places in which globalization finds its embodiment. Such places are cities, since innovation, science and international trade are concentrated there. Creative class is described as the most active subject in the construction of urban space because it possesses human and social capital. Creative man has the knowledge that dominates the society which is also called the intellectual capital (Gorz, 2010: 209). The description that the Frankfurt school gave in order to explain the transformation of culture into business and deceit, or in other words the birth of chimera whose name is "creative city" is in fact the attempt to use the mask of culture as a camouflage of real estate speculations. The creative city bares the template of the ideological construct (Pasquinelli, 2012: 141-142). That is how Florida (2002) promotes the concept of creative city as the construction of an appealing urban identity and symbolic branding of small territories. According to the above mentioned, one can notice the tendency of the agenda and social expenses concealment. On the other hand, Pasquinelli approaches this problem from an alternative perspective "the creativity of a city is simply a biomorphic extension of its social composition and competence" (Pasquinelli, 2012: 142).

The complexity of "the creative city" lies in the fact that it does not succumb to the canons of classics, nor the measures of high culture. That is the reason why it is hard to select a consistent and comprehensive definition of "the creative city". From the standpoint of this research the closest definition is the one that says that it is "a biopolitical machinery which integrates all the aspects of life that are included in the process of work, in which new lifestyles become goods, in which culture is considered to be material movement as any other and specific, in which collective image production is recaptured in order to increase private profit – 'creative city' appears as a closed circle" (Pasquinelli, 2012: 143). From the sociological standpoint, creative identity of views is typical of small creative groups and in that sense their particular interests are not visible enough. Creative urban environment should function as a catalyst for creative activities of the citizens. However, such activity can appear only where the basic traditional components of the open city economy exist. Even when the global cities fulfil the requirements of labor the creative industries employ 3-5% of people (Лэндри, 2011: 33). Even though according to the conception of Florida (2002) creative class is characterized by multiculturalism, tolerance and diversity, in reality creative city space often provokes quite the opposite – a decrease in ethnic diversity and an increase in the economic threshold access to central gentrified areas (Мартьянов, 2016: 43). Gentrification is a popular neoliberal cure for the places where devastated city areas and deserted factories with apartments are renewed. However, this happens under the pressure of the growing creative class. It helps in breathing a new life into the cities which survived deindustrialization and were deserted by a great number of workers and experts, and were populated by the members of marginalized groups who usually subsist on grey economy. In such circumstances a true motive for gentrification is the capitalization of urban city space. The interest of city community is offered as a sacrifice to the neoliberal city politics which inevitably leads to the segregation of city space where private profit is in the foreground. Even Florida (2013) admits that the growing creative class does not create a multiplier effect which would empower a wide range of social groups. Creative city by the nature of things has its postmodern dimension which implies urban changes that have not happened beforehand. That is how postmodern

urbanism generates the picture in which there is no place for the working class anymore. This is the case of "one special opportunistic vision of postmodernism, and not the so called cultural turnover per se" (Smith, 2012: 52).

Smit has not anticipated the problem of collective imagination in the process of gentrification even though he stresses out that dealing with culture and capital is vital (Smith, 1979; 1982). Unlike the traditional form of gentrification, the one that promotes artificial cultural capital and marketing of the "creative city" is becoming more and more popular. The process started in New York on Lower East Side at the end of the 20th century when the owners who could not rent their houses at a commercial price, rented them to the artists for the next five years at a lower price. However, when the process of gentrification in the neighborhood started the owners raised the prices enormously. The artists "built" their art into gentrification, however they were relocated. Nevertheless, the artistic production model turned into immaterial factories across Europe, and Berlin and Barcelona are typical examples of this. The real estate market established a depraved coalition with the world of art and cultural tradition in the majority of European cities which are produced by counterculture.

There is an interesting relationship between the local culture and gentrification where each of the cities has developed its unique style. Thus, the futuristic museum of modern art MACBA in Barcelona was built in the center of old part of the city in Raval quarter (Fig. 1). The gentrification effect of MACBA was successful, especially thanks to the cultural surroundings of the museum which consisted of a globalized middle class in Catalonia. Certainly, the gentrification of Raval had its controversy and obscurity such as the allegations against local residents for spreading homosexual orientation and concealment of various unethical interests related to real estate trading (Ribalta, 2004).

Fig. 1 MACBA Museum of Contemporary Art Barcelona in El Raval quarter.
Source: http://www.rafaelvargas.com/project/aerial-shooting-barcelona

Gentrification did not skip Russia. The best example for this is the neoliberal reconstruction of the capital city Anadyr (Fig. 2). In 2000 the team of Roman Abramovic brought a group of artists and architects from Moscow to design a series of unusual

buildings. A lot of people looked at them as Anadyr wonder. The buildings were built in the spirit of postmodernism. The gentrified city could boast about picturesque brands such as: Artica (new monumental art), amusement center Baklan, the radio Purga. Big Large parking lots for bicycles appeared on the streets, the Soviet panel houses were painted in bright colors, and the Moscow Center of Contemporary Culture Garage became the venue for artistic events. According to neoliberal logic anything goes; the most important thing is to be successful and efficient (Смирнов, 2016: 79-80). However, gentrification always happens in the same way, at least when the esthetic supervision is concerned. Newly arrived rich residents redecorate the whole districts, or better say renovate, taking care not to undermine the historical value of the building they are moving into. This is good since the architectural ambient stays the same. On the other hand, some care more for the luxury and location and the individual taste prevails there (Bridge, 2007: 41-43).

Fig. 2 Anadir, Russia panoramic view.
Source: https://www.pinterest.com/pin/279786195574099527/

There is an interesting urban enterprise in Serbia called Belgrade Waterfront on the location known as Savamala (Fig. 3). Following the example of respected cities in Western Europe and Northern America, the realization of the project according to which 6200 luxuries apartments, average size of 140m² intended for rich citizens and transnational elite has already started on the right bank of the river Sava (Крстић, 2015: 97). So far the workers of Serbian Railways have lived there, the majority of them has lost their jobs, and therefore the obvious intention of the project is to relocate the poor citizens. It will certainly be a challenge for the artists who transpose artistic content and who see gentrification as a collaboration between them and the investors in order to bring gain for the city. Gentrification of this part of Belgrade has aroused controversy and provoked intensive debates which never stop. „Commercialization of the right to have public debates and bringing the whole spectrum of aspects (social, cultural, political) down to arguments of short-term financial gain reveals that Belgrade Waterfront is primarily in the realm of financial market, and secondly in the tridimensional reality of the citizens of Belgrade (Крстић, 2015: 99).

Fig. 3 View of Belgrade Waterfront project from the bridge "Gazela" (photo montage). Source: http://www.politika.rs/old/uploads/editor/1(30).jpg

The autonomy of creative class is another problem. The question arises as to what extent it is able to support uneconomic factors of the city space development. Everything indicates that sooner or later it will succumb to the logic of the market, in other words, creative industry as one of the branches of capitalistic economy. The realization of creative concepts is determined by economic concept to a large extent (Крстић, 2015: 99). The concept of creative city subordinates the strategy of its development to interests and prospects of a small social group instead of trying to always find the balance and compromise of different collective interests (Мартьянов, 2016: 45). The creative concept of urban development implies the global context no matter how paradoxical it may seem. Namely, the concept of creative city, creative class and creative industry tend to promote the popularity of activities focused on the effects of local growth. Creative city makes the brand out of gentrification itself. That is precisely the reason why the corporate capital is becoming more and more interested in monopolizing creative industry on a global scale and in this way takes the central position in strategic planning of urban development.

3.1. Conflicts of interest which determine the concept of creative class and creative city

The question arises as to whether or not the creative class and creative city are able to create and support non-economic factors of urban space development. It is more likely that sooner or later it would come to terms with the logic of the market, or creative industry that represents one of the branches of capitalist economy. In fact, creative concepts and their realization are determined by the economic concept. The processes that have taken place in the past ten years confirm the thesis on segmentation, localization and commodification of creative utopias in the global space of creative cities (Мартьянов, 2016: 45). In megalopolises we can talk about topological unity, but we can also talk about the fact that they represent heterogeneous space in which different social groups try to protect their contradictory interests. It is precisely the power of the most influential group that determines the concept of creative city.

The creative class is a specific social group. It flourishes only when the social connections are not that strong, and the relations are established through the market with no strings

attached. It is composed of people without families and non-market mechanisms of support who find pleasure in constant work and individualistic competitiveness. It has been observed that such creative class is being reproduced by the external influence, affirmation of sexual minorities and those young people who are not in a hurry to create a family. As it cannot reproduce by its own power, the creative class is transformed into the desired subculture. Regardless of the creative class significance the question arises as to whether or not these groups can be considered within the context of an informative model which presupposes wide social regularities and a healthy society.

Recently, the nominal boundaries of megalopolis do not coincide with life boundaries. Namely, it does not make much sense to "reveal" resources of city development within itself. Postindustrial cities presuppose the existence of a greater material base which is situated outside the nominal boundaries of megalopolis, and even regions. There are a lot of factors which determine this sequence of events. First of all, there are people, or the personnel, capital technology, transport infrastructure, etc. There are also demographic problems that cannot be solved within the cities. Essentially, megalopolises as economic centers of creative industries cannot survive without external markets in modern conditions. However, this does not mean that global cities are available for the whole humanity. Such an idea shows the signs of utopia, even today. Immobile urban population will increasingly depend on deceptive plans of city administration for the attraction of the creative class of modern nomads. Lonely urban life, fear of commitment, the escape from a marriage, an apologia of an individual, body, independence, will make the ego/self an absolute value (Atali, 2010: 110). The creative class as any other speculative resource, in case there is a problem leaves the city without the means spent on suspicious creative investments, which easily leads to a problem. Unrealistic plans are often the consequence of neoliberal greed.

In a sense the creative concept of urban development all of a sudden becomes a sign of weakness of the global context. On the other hand, creativity which depends on the investors makes the architecture of large cities look alike. It is not an accident that some say that Belgrade Waterfall will resemble Dubai. Evidently, there are a lot of examples of unjustified attempts of certain cities, and with them certain states, to monopolize creative industry on a global scale. Obviously, the polarization of city space is, among other things, a product of aspirations for domination and profit. In such circumstances, creativity acquires a frivolous dimension.

4. CONCLUSION

In the developed world the problem of excess capital often appears, and gentrification is one of the best ways to absorb it. Therefore, in big cities, residential areas are built for middle class people who are representatives of the population homogenous according to the symbolic and economic status.

Not only urbanists, architects and economists deal with space but also sociologists who develop a critical approach to it. Namely, from the very moment the social sciences got involved in the problem of space the "labyrinth of complications" was created. The expansion of city substance is an efficient mechanism with which capitalism solves the problem of excess financial capital. This does not mean that gentrification is not followed by chaos, polarization of interests and ambivalent coexistence of different areas. The existing but insufficiently efficient city substance is being restructured with the aid of

capital, however, chaotic concepts appear during the process as a result of poor criteria. Consequently, the middle and upper class people who move to those areas do not want to have any contact with the neighbors who already live there, so they introduce some measures of denied access and create a hostile environment by some other safety measures. However, gentrification can sometimes have positive implications if it enables the social capital to expand beyond the boundaries of a limited social group.

One of the most severe consequences of gentrification and the creation of the so called post city is the displacement of entire families. Marginalized groups consider the displacement as the deprivation of the right to the city. That is the kind of attack of neoliberalism on the family through urbanization and gentrification. Neoliberal urban practice of gentrification directly creates geography of renewed class power. In that sense, creative city, creative class and a mantra of immaterial gentrification are at the service of making the middle class homogenous. This is a cover for enormous expenses and the lack of empathy for the marginalized groups and their destiny. The euphemism „concentration of immaterial" is basically the transformation of the spiritual into the discourse of market. Thus the syntagmatic terms "creative class" and "creative city" become a utopia for the chosen ones. In everyday life, gentrification is fundamentally between the inconsistent neoliberal theory and variable neoliberal practice. Such a process involves a variable introduction of theoretical concepts of classical neoliberalism, or intensifying the strictness of processes in practice. This would not only create the conditions for a renewal of class power but also for the future class conflicts in the cities. In such neoliberal commonplace of the city, gentrification represents a strategic, urban-economic practice. A way-out of this situation is to include the citizens in the process of decision making, in other words make the process transparent.

Big cities are the focus point where the effects of gentrification are most evident. The creative class is the most active participant in the construction of urban space, and cultural economics reveals its affinity towards the concrete. Essentially, the creative class and creative city are the templates of the ideological construct. The promotion of the "creative city" concept as the construction of the appealing city identity and branding of theories is nothing but the desire for the concealment of neoliberal agenda of social costs.

Postmodern urbanism creates a picture in which there is no place for the working class. In cities such as Barcelona and Anadyr, businesses have established an alliance with the world of art, but in a questionable manner. The creative concept of urban development, or the creative city, has its global context: corporate capital is interested in monopolizing gentrified cities and creative industries, which is only a confirmation of profitable neoliberal resource logic of the space perception.

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GENTRIFIKACIJA, KREATIVNA KLASA I PROBLEMI SUKOBA INTERESA U SAVREMENOM URBANOM RAZVOJU

Ovaj rad razmatra procese savremene gradske teritorije i analizira neoliberalnu prostornu strategiju grada koja se, između ostalog, najviše ispoljava preko gentrifikacije. Objašnjavajući savremene tendencije transformacije gradova autori traže vezu između fenomena gentrifikacije i rasta gradske nejednakosti. Marginalnost u tom kontekstu nije rezultat ekonomske zaostalosti, već ekonomskog progresa. Rad istražuje zašto današnja urbana politika dovodi do klasne segregacije. Autori ispituju genetsku vezu kapitala i urbanizacije potvrđujući Harvijevu paradigmu da je „kapitalizam prinuđen da urbanizuje kako bi se obnovio“. Takođe, u radu se istražuje odnos kreativna klasa-kreativan grad i koliko je to realnost a koliko „utopija za izabrane“.

Ključne reči: *urbana obnova, neoliberalizam, postgrad, nejednakost, komercijalizacija*

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CONSTRUCTIVE SYSTEM OF RECIPROCAL FRAMES IN TERMS OF CONTEMPORARY ARCHITECTURE

UDC 624.072.33
72.01

Zlata Tošić, Sonja Krasić, Dragoslav Stojić

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

Abstract. *In this paper, the reciprocal frame constructions are analyzed, starting from their definition, historical survey, to static and geometric characteristics, types and forms. Although very familiar for their shape, their earlier usage in contemporary architecture was not the same as at present. An overview of some of the more recent examples of conceptual solutions and derived pavilions has been established. These structures represent good example for temporary structures in a form of pavilions. Goal in this paper is to design a sample of a closed permanent building combining classical structural systems and RFs. The chosen geometry was predefined as regular in order to use its properties to determine if there is a possibility to form equal units. Finally, based on defined entities, the pavilion's conceptual design was made using a parametric design in plug-in Grasshopper and Rhinoceros software.*

Key words: *reciprocal frame constructions, design complexity, architecture design forms, Grasshopper, Rhinoceros*

1. DEFINITION AND CHARACTERISTICS OF RECIPROCAL FRAME CONSTRUCTIONS

Increasing number of designers and architects are aware of the fact that knowledge of form is a very important aspect of design of structures and perceptual process of observers [1][2]. Light constructions in architecture are a common trend that stems from the need for effective constructive systems and improvement of visual architecture qualities. There are many types of lightweight constructive systems in engineering [3], but this time subject of the work are *reciprocal frame constructions (RF).*

What does the word "reciprocal" mean when it comes to structure and what kind of quality does it stand for, if there is any? The Reciprocal Frame (RF) is a 3D structure composed of three or more pieces of sticks. Generally speaking, the rods are placed together

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Corresponding author: Zlata Tošić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: zlata10@live.com

to form a closed circuit called an RF unit, while multiple RF units can be further assembled to form large RF structures [4]. Although the structures are made of simple elements, no central support is required for its static maintenance [5]. Thus, these constructions make a perfect system for big continuous surface area such as ones with non-standard geometry. When it comes to combining elements, RF structures have been used for different types of modules and compound shapes which are made of several interlaced and single units (see Fig. 1) [6][7]. Their definition gives us possibility and freedom in making custom shapes by only assembling basic elements into proper structure.

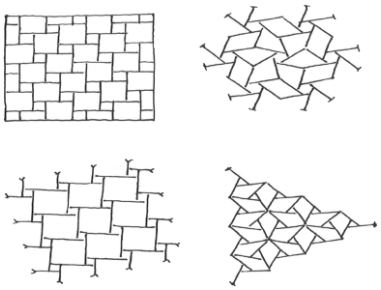


Fig. 1 Examples of the RF module assembling [7]
(Source: O. Popović Larsen 2014)

RF structures need a precise spatial definition when free or irregular forms are used. Understanding the geometry of the structure and parameters (see Fig. 3) that defines it is important to enable the design and construction of a reciprocal frame (RF). Parameters defining RF units with regular polygonal and circular geometry are the following [4]:

- Number of rods (n)
- Radius of the outer circle of rods (ro)
- Radius of the circle through the cross section points of rods (ri)
- Vertical distance from the outer rods to the beam cross-section (H)
- Vertical distance of the beam axis at their cross-section (h2)
- Thickness of the beam (L).

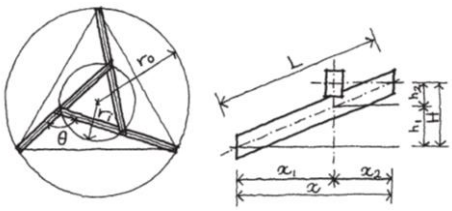


Fig. 3 Geometric parameters for RF constructions [4]
(Source: O. Popović 1996)

In practice, all this means that a set of well-chosen relationships between RF parameters should be determined in order to form a three-dimensional RF structure. These should help to select the initial parameters, and then we get guidelines for defining others.

Depending on the intention of the designers and constraints, the initial parameters will be selected and the others determined. It is important to note, however, that RF is a complex structure and that all factors should be taken into account at the same time. Considering any geometric parameter, separately of others, it would not bring optimal results [4].

When it comes to structural advantages of RF it is important to mention that because of their ability to find alternative load transfer paths, they have an excellent level of static uncertainty, which we know is important for local breaks. This property varies most from the type of RF structure. On the other hand the type of connections of structure make them partially work in bending which is perhaps one of the few faults that the RF structure has [4].

2. HISTORY OF RF STRUCTURES

Systems consisting of beams that support one another are known for centuries and there are numerous illustrations of such structural systems. For example, during the Middle Ages, French architect Villard de Honnecourt [4] gave a solution based on a mutually supportive framework for the problem of covering shrubs with shorter shrubs.

Leonardo da Vinci was also interested in this concept, made sketches for arrangements with a bundle similar to Villard de Honnecourt [8]. Another architect of the Renaissance period, Sebastiano Serlio, proposed similar drawings for short-beam spaces [9]. The historical record of the reciprocal frames and the overview of the constructed examples can be found in the work of Popović Larsen [10]. The RF is also used as term "nexorade" [11, 12, 13], which describes the spatial generalization of straight beams. This generalization relies on the fact that the eccentricity between the elements at the points of connection is dictated by the final form. This characteristic represents a special geometrical problem which is conducted out of spatial placement of the elements in order to match certain shape. The RF lamellas were, also, later used by Pier Luigi Nervi for hangar planes in Orvieto, destroyed in the Second World War (see Fig. 2).

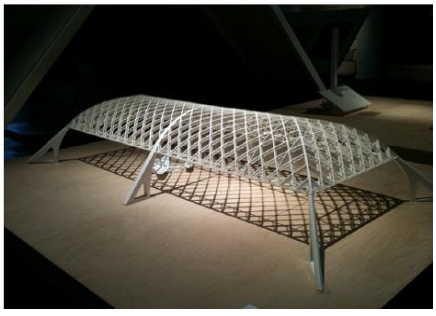


Fig. 2 Model of structure Orvieto hangar from Pier Luigi Nervia [7]
(Source: O. Popović Larsen 2014)

3. CONTEMPORARY CONSTRUCTIONS OF THE RF SYSTEM

In the past few years, RF structures have become a popular constructive medium. The Mount Rokko-Shidare Observatory, designed by architect Hiroshi Sambuichi and Ove Arupa and Partner in Japan, was completed in 2010 (Figure 4) [14].

Fig. 4 Observatory Mount Rokko-Šidare [7]
(Source: O. Popović Larsen 2014)

Although it is irregular, the shape is constructed of the straight rods. The main construction is made of 50 mm welded steel pipes 1-2 m long, arranged according to a specific RF scheme. The problem becomes complex geometrically with the introduction of a cross-section of elements because this parameter affects the overall geometry. According to Olga P.L., this was extremely important because precision was not of sufficient quality - it would be impossible to construct RF and connect RF members [7] [15].

Another interesting RF structure shown in Figure 5 is the Pavilion Kreod, which was developed by the Pavilion architecture, and was designed by the research and development team Rambøll London. The idea was to develop a cheap, easily feasible, assembly and disassembly structure, easily dismantled and then set up at new locations.

Fig. 5 Pavilion "Kreod" [7]
(Source: O. Popović Larsen 2014)

The Italians Francesco Gherardini and Francesco Leali suggested the exploration of some temporary architectural pavilions from the aesthetic and parametric point of view. The basic modules consist of four bamboo planks that rely on the circle (clockwise). Each basic module shares a board with each of the adjacent four units (the unit represents four elements bound in a circle) [6].

a) b)

Fig. 6 Pavilion of the Forest Park: the whole structure [6]
(Source: Gherardini et al. 2017)

There is a connection of 44 tiles (see the shadow in Figure 6 b). The shell structure is a double curved geometry with a transition from the concave and convex surface. These curve changes arise from the various final disposition of the elements in each unit and, furthermore, by using uneven distances when connecting with the elements themselves, as in [16]. The five bundled steel pillars support the structure (Figure 6a) [6].

4. NON-STANDARD GEOMETRY RF DESIGN WITH HEXAGONAL MODULES

After analysis of RF constructions, examples of built structures as well as suggestions for future works, final goal was to demonstrate an example of a designed RF construction in non-standard geometry shape. Recognizing the mentioned problems in assembling elements, this solution was designed to apply the system on a permanent closed building. Moreover, the aim was to start from the chosen geometry and try to create modules with identical elements, if possible.

This object is designed using RF structures with hexagonal units (Fig. 7). The tessellation is made by shearing wooden modules for half side of the unit. The main geometry used for shell is a hyperbolic paraboloid intersected with an elliptical cylinder [17] (Fig. 8).

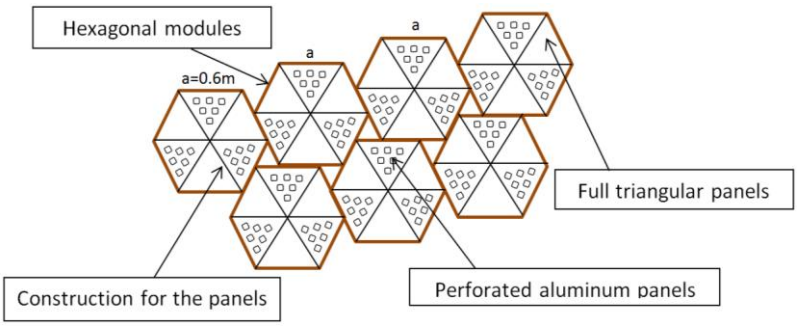


Fig. 7 Scheme of the selected RF structure with its main elements

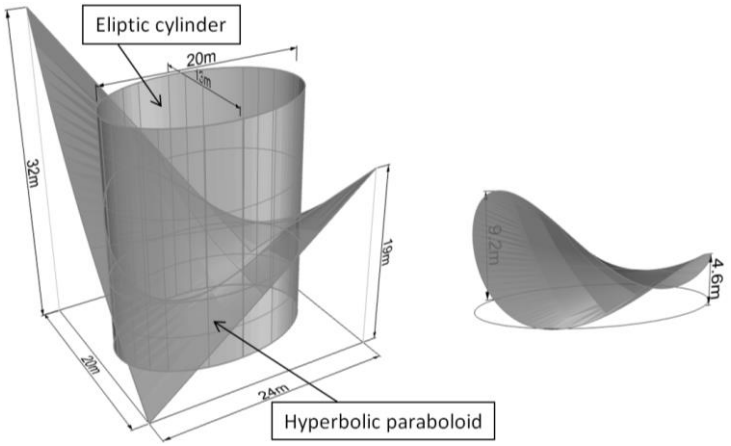
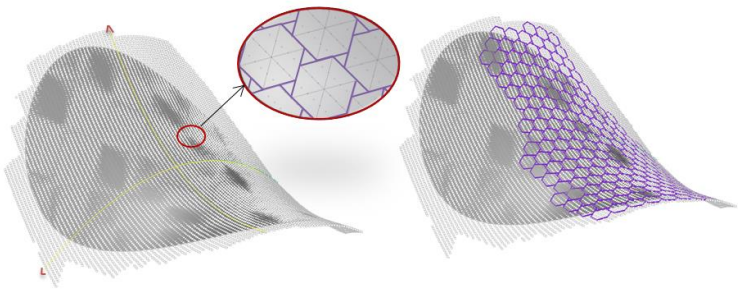


Fig. 8 Schematic breakthroughs done in Rhinoceros of two geometries from which the surface of RF was formed

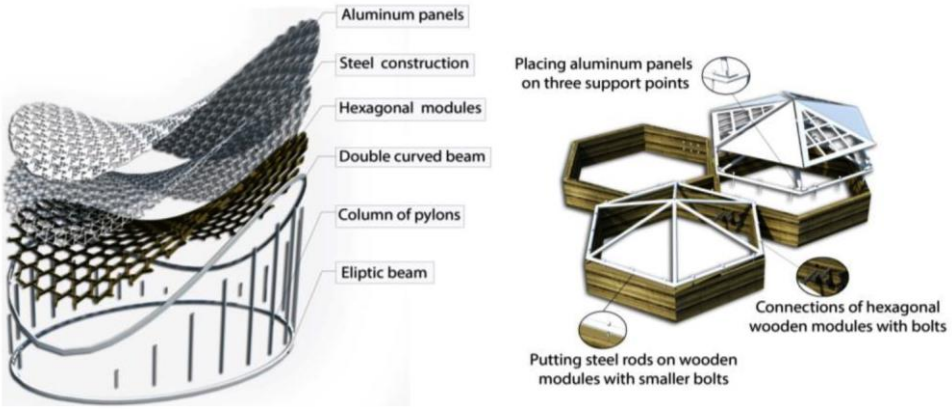
The next phase would be to set up modules on a given surface. In order to try to achieve equal elements we assembled succor points in the form of triangles on the equal x, y distance (Fig. 9 a). The element's length in basic directions x, y are a=0.60m. On the other hand because of a double curved surface and difference in diagonal point's distance the elements there vary a = 0.55m – 0.65m. When it comes to spatial structures, such as this one, we can encounter the problem while giving thickness to modules. In this case the direction of thickness represents the normal vector for the tangent plane in the characteristic points of the module (Fig. 9 b).



a) b)

Fig. 9 Rhinoceros drawing of the distribution of points for the setup of equal modules

These structures usually lack a cover layer. The solution was to cover modules with triangular panels. Half of them are perforated for the daylight illumination and all are connected to the inside part of the units, so modules could be visible outside (Fig. 10 a). Connections for modules are made with bolts, but steel sheets and welding are used for panels and the steel sub-construction (Fig. 10 b). The structural system is transferring loads from modules to the large double curved elliptic beam trough columns to the foundation.



a) b)

Fig. 10 Scheme of elements of the RF structure and the "T" connection between the rods

In these pictures we can see a finished model of the permanent closed building which is represents combination of a classical system of beams and pylons and RF structure. In the case of predefined geometry we were able to optimize elements, but in order for all of them to be equal, a change in geometry could be more visible. The purpose of the building can be various: exhibition hall, closed amphitheater, greenhouse (Fig. 11).

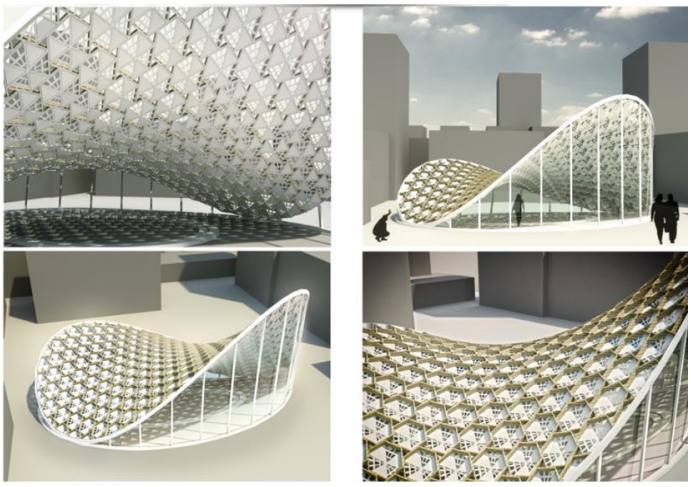


Fig. 11 3D reprezentation of final model of the object

5. Conclusion and Closing Remarks

Examples and built-in and conceptual solutions show that RFs offer great potential for creating innovative shapes. However, the RF structure is interesting not only because of the potential to achieve curved complex geometric shapes, but also because it offers the possibility of quick construction using elements of equal straight length.

Future RF research should focus on their application in constructions of temporary character which are necessary for quick construction, simple connections and their reuse [7]. It is also necessary to explore ways to use them as permanent buildings, where a combination of classical systems with RF would be used (as in this paper). There is a lot of research about geometrical aspect of assembling elements of RF but there are, also, challenges mentioned here that are worth exploring when we use predefined geometry. In this research we were able to design permanent structure of a closed building with optimized elements and solve problem of coverage of these constructions without an extensive modification of the building's shape.

Considering their contribution to connect simple constructions with complex geometry, it is very important that we study various aspects of RF structures. As a result, more interesting, imaginative and efficient RF structures can be designed.

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KONSTRUKTIVNI SISTEMI RECIPROČNIH RAMOVA U KONTEKSTU SAVREMENE ARHITEKTURE

U ovom radu analizirane su konstrukcije recipročnih ramova, počevši od njihove definicije, istorije, do statičkih i geometrijskih karakteristika, tipova i forme. Iako su vrlo dobro poznati njihovi oblici, njihova upotreba ranije nije bila ista kao u savremenoj arhitekturi. Analizirani su neki od savremenih primera konceptualnih rešenja i izvedenih paviljona. Ove strukture predstavljaju dobar primer za privremene objekte. Međutim, cilj ovog rada je definisanje zatvorenog stalnog objekta ovih struktura kombinacijom standardnih konstruktivnih sistema sa RF sistemom. Izabrana geometrija je definisana kao regularna, da bi se mogla koristiti njena svojstva i utvrdilo da li je moguće formirati jednake elemente modula. Na osnovu definisanih parametara, koncept dizajna paviljona određen je parametrijski korišćenjem plug-in Grasshopper i Rhinoceros programa.

Ključne reči: *recipročne konstrukcije ramova, kompleksan dizajn, dizajn u arhitekturi, Grasshopper, Rhinoceros*

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PHOTOCATALYTIC SELF-CLEANING FACADES IN ACHITECTURAL DESIGN

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544.526.5

Aleksandra A. Ćurčić

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

Abstract. *Sustainable and affordable technologies are an important aspect of environment and energy efficiency. Environmental pollution in urban areas is one of the causes for poor air quality. Gaseous emissions from daily traffic are continuously increasing often exceeding the allowable concentration in the atmosphere. The development of self cleaning materials- photocatalytic building materials- particularly when applied to facades, can contribute to providing the clean the air and to improvement of sustainability levels. They represents one of the most promising solutions for reducing air pollutant concentrations in urban areas, proving to be really effective and showing a real eco-sustainable value. The paper explains the mechanism of self-cleaning of façades, their types in architectural design and the importance of their application.*

Key words: *facades, self-cleaning, titanium dioxide, photocatalysis, glass, concrete, ceramics, architectural design*

1. INTRODUCTION

The air in the cities is polluted by nitrogen dioxide of vehicular exhaust and industrial emission. They cause respiratory problems and damage buildings. These problems cannot be handled even if car-free zones are created and environmental protection strategies introduced [1]. Normally, facades are cleaned twice a year using traditional methods. These methods provide a temporary solution and the building surfaces progressively become unsightly again. Soon, re-cleaning is necessary, and eventually refinishing due to the deteriorating effects of ultraviolet rays [2].

The use of environmental and sustainable green technologies is not simply a trend, but a necessity, which is increasingly important because of irresponsible attitudes of the past .

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Corresponding author: Aleksandra A. Ćurčić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: ajkiro94@gmail.com

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The goal should be set of not only saving the environment through a responsible use of natural resources, but also through the consequent use of green technologies, thus preserving the resources for future generations [3]. For the above reasons, architects and environmental scientists have been teaming up to address an interesting question: is it possible and economically feasible to design and construct buildings that can passively clean smoggy urban air? [4].

As a solution to the above problem, the ever important concepts, are depollution and photocatalysis [4, 5]. They are rapidly entering the vocabulary of designers and builders around the world. A major international research consortium – the Photocatalytic Innovative Coverings Applications for Depollution Assessment (PICADA) – is documenting the performance of photocatalysts [2,6].

Depollution is the opposite of pollution and means removal of contaminants and impurities from the environment. The newest tool for achieving depollution is a photocatalyst, a material that uses solar energy to accelerate chemical reactions without being consumed or depleted in the process [7]. Photocatalyst accelerates the oxidation process in the atmosphere and decomposes any air borne toxic organic matter. Titanium dioxide, a photocatalyst, also known as titania, is the naturally occurring oxide of titanium, whose chemical formula is TiO_2, figure 1 a). Titanium Dioxide is considered a safe substance and harmless to humans. Using energy from light, Titanium Dioxide creates two oxidation reactants: hydroxyl radicals and a superoxide which decomposes toxic substance by oxidation [8].

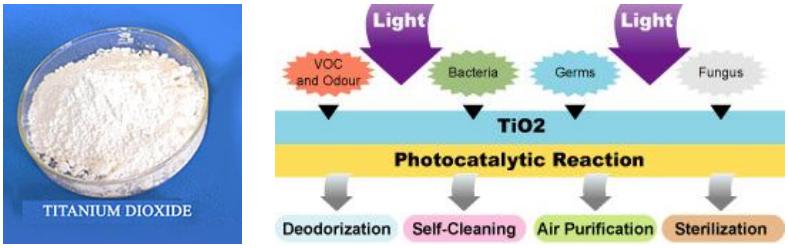

Fig. 1 a). Titanium dioxide [9] , b) Photocatalytic reaction[10]

Oxidative decomposition means that if titanium oxide is exposed to light, organic substances on its surface will be broken down by oxidation, eventually forming carbon dioxide and water. This has applications in fields such as deodorization, elimination of volatile organic compounds (VOCs), elimination of soiling, antibacterial action and sterilization [3], figure 1 b). Photocatalyst has the following advantages over any current air and water purification technologies: destruction of pollutants rather than a simple transfer on a substrate, degradation of pollutants at ambiental termohygrometric conditions and efficient energy consumption [11, 12].

2. PHOTOCATALYTIC SELF CLEANING FAÇADES

Photocatalyst treatment provides a long-term, cost-effective solution for facades maintenance while enhancing surface longevity. Once applied, it maintains the building's immaculate appearance with the self-cleaning cycle, figure 2. The treatment also protects

the surface of the building from mildew, dirt, oil residue and other pollutants. Photocatalyst architectural facades have the following properties:

1. Antistatic – Dust particles are no longer attracted to the surface.
2. Decomposition – Strong oxidizing effect to decompose hydrocarbon and any organic growth.
3. Hydrophilicity – Hydrophilic surface. Any dust or contaminant can be easily washed off by rainfall [10,13].

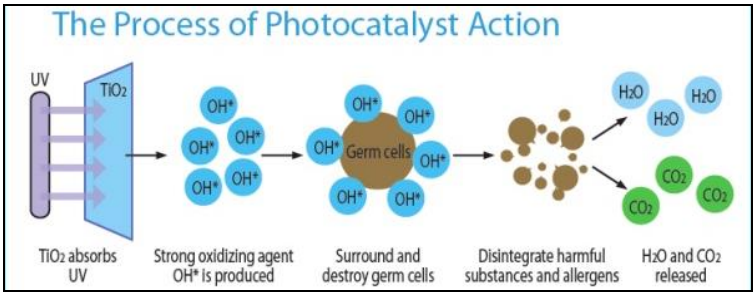

Fig. 2 Photocatalytic self-cleaning cycle [14]

The photocatalytic process of self-cleaning of facades progresses in the following manner: When a compound (either an organic soil or a pollutant) is present on the surface of a TiO_2 - containing covering, it can be degraded by redox reactions involving highly reactive transient species, thanks to the activation of TiO_2 in the presence of UV light in the appropriate region. Then, the degradation products are either stored in the covering or washed off the surface by rain water.

This offers a great interest as, when the redox reactions are complete, organics yield carbon dioxide and inorganics, nitrogen oxides are oxidized into nitrate ions, and ozone is decomposed into oxygen. Simultaneously, visible deposits due to soiling can become gradually transparent as a result of these photocatalytic transformations. Thus, these innovative coverings can contribute to keep urban constructions clean as well as to reduce atmospheric pollution generated by the road traffic and industrial activities [15].

2.1. Self-cleaning glass facades

Self-cleaning glass is a specific type of glass with a surface which keeps itself free of dirt and grime through photocatalytic decomposition. A nanometer-scale coating of titanium dioxide (10-25 nm) on the outer surface of the glass introduces two mechanisms which give it the self-cleaning property. Harsh chemicals that are used to clean normal glass are usually washed off into the soil and contaminate it, figure 3 a). The use of self cleaning glass eliminates this environmental hazard.

Self cleaning glass cleans itself in two stages. The first stage is called photo-catalysis, figure 3 b), which is the action of light on the surface of the glass to basically chomp away or eat the dirt on the surface. The next is a process known as hydrophilicity, figure 3 c). This ensures that any water that falls on the surface forms sheets and washes away dirt uniformly. The glass spreads the water evenly over its surface, without forming droplets. Only a small amount of sunlight is required to activate the coating, which ensures that

self-cleaning property will function even on cloudy days. A simple rinse with water during dry spells will help keep the surface clean [16].

The performance of self-cleaning glass can vary depending on the environment and the location of the glass. Optimum performance is obtained when the glass is installed in a vertical position, and receives maximum exposure to direct sunshine and rain. The other factors in play are: the type of dirt, the amount of dirt, total exposure to light and rain and the inclination of the installation.

Self-cleaning glass has numerous advantages in comparison with normal glass. It requires less frequent cleaning; in addition a façade stays cleaner for longer periods of time. Cleaning itself is easier and costs are reduced. Due to hydrophilic coat, the vision is always clear through the façade with neutrality and transparency the same as that of normal glass.

One of the most famous manufacturers of this type of glass is the Saint Gobain company of France, which developed its line of BIOCLEAN glass. This glass has a self-cleaning property, however, there is an improved variant which offers an option of prevention of space overheating and glare reduction. This line of products is called SGG BIOCLEAN Cool-Lite [17].

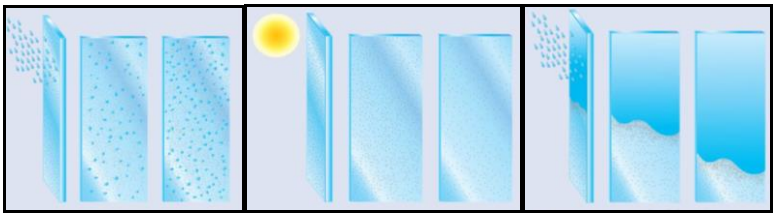

Fig. 3 a) Normal Glass- Dirty water marks and grime gather on the window. [17]
b) Step 1: Photocatalysis [17] c) Step 2: Hydrophilic Action [17]

2.2. Examples - Buildings with self-cleaning glass

The Infoscore office building, designed by architect Herbert Basler is located in Baden-Baden, Germany, figure 4 a). The most impressive part of the building is 200 m^2 glass façade made of SGG BIOCLEAN glass. The façade is composed of the 2x4 m panels, figure 4 b). SGG BIOCLEAN glass was chosen for its self-cleaning effect due to the high level of soil pollution [18].

Fig 4. a) Infoscore office building, Baden-Baden, Germany [18]
b) Infoscore office building, glass façade detail [19]

The five-storey extension of Infoscore offers office space for 400 employees. Cleaning of the associated glass facade would be difficult because it is not easily accessible and due to the high pollution load. The glass part of the façade is located on the rain-impact side and is mounted absolutely vertically. Due to its position, after heavy rainfall, soiling is washed away and the façade is clean again. Self-cleaning does not mean they do not absolutely require cleaning. Even glasses like SGG BIOCLEAN have to be cleaned from time to time, but considerably less often than conventional glass. The length of the cleaning intervals depends strongly on the angle of inclination of the glass surface. The steeper the angle, the longer the intervals.

Brive-la-Gaillarde hospital in France represents a very interesting example of façade reconstruction with an aim of improving its quality. The building was built in 1976, while the renovation process started in November 2012., figure 5 a). It was designed by the architectonic studio EMaa in cooperation with Manière & Mas and Technal design company. The concept was based on construction of a double ventilating façade using the most contemporary materials. The glass used for the external part of the façade was SGG BIOCLEAN Cool-Lite, figure 5 b).

Fig. 5 a) Hospital Brive-la-Gaillarde after renovation [20]
b) SGG Bioclean Coll-Lite used for the outer glass [21]

This building, which occupies the main artery of the Hospital Center, has its south-east and south-west façades modified by the addition of a double skin. This project was realized without interrupting the hospital operation. Renovation of these two facades improved the patient and staff comfort, in acordance with the standards of the Grenelle de l'environment. It also improves the safety of the establishment, by providing emergency services accessibility to the twelve floors from the outside. The total height of the building is 39 meters.

The idea of renovation is a double facade ventilated on the twelve levels, with a thickness of one meter and bridges on all levels. The outer glass creates a thermal barrier that creates a buffer space along the building. This space is tempered in winter like a greenhouse and ventilated in summer thanks to high and low vents which accelerate the air inside by the chimney effect. The facade is self-cleaning (BIOCLEAN glazing) and it is necessary that rainwater trickles on the glasses for cleaning. For this, the profile of the sunshade is an inverted slope and brings the water along the facade. A gap between the facade and the bonnet of the sunshade allows the flow of rainwater [21].

2.3. Self-cleaning ceramic tiles facades

The HYDROTECT® technology, the Bios Self-Cleaning® ceramics in facings and ventilated walls provide important responses through their self-cleaning. In particular, Bios Self-Cleaning® contains titanium dioxide (TiO_2). The self-cleaning property of Bios Self-Cleaning® is effective but it should be kept in mind that: they cannot remove all the stains, such as stains that stick to the facing quickly, massively and stubbornly, e.g. silicone sealants, they cannot remove rust or crystals and no self-cleaning process may take place without rain or exposure to UV rays.

Residential commission in Germany brought Daniel Libeskind back to Berlin for his first residential project in the city. The project, known as Saphire, located on a busy corner in the Mitte neighborhood in central Berlin, presented a design challenge, figure 6. The three-dimensional, geometric-patterned stoneware tile adorning the facade is another design signature. Designed by Daniel Libeskind for Casalgrande Padana, the panels are technologically engineered to self-clean and aid in air purification [22].

Of the 3,600 tiles supplied, only 500 were made in a standard production format. The remaining 3,100 tiles are custom shapes made using controlled linear and water jet cuts according to precise drawings. Additionally, every tile was specifically positioned to reflect the A or B sides of the pattern (the two positions of the tiles when rotated by 180 degrees). This specificity allowed the architects to control the overall patterning and reflective effects of the facade. The ventilated facade was assembled utilizing a standard anchorage system [23].

Fig. 6 Daniel Libeskind - his first residential project in Berlin (© Hufton+Crow Photography) [22,23]

The concept for the Vanke Pavilion, situated on the southeast edge of the Lake Arena, figure 7, incorporates three ideas drawn from the Chinese culture related to food: the shi-tang, a traditional Chinese dining hall; the landscape, the fundamental element to life; and the dragon, which is metaphorically related to farming and sustenance. All three of these concepts are incorporated in the Vanke pavilion.

The Vanke pavilion is clad in more than 4,000 red metalized tiles that Libeskind designed with the Italian company Casalgrande Padana. The geometric ceramic panels not only create an expressive pattern that is evocative of a dragon-like skin, but they also possess highly sustainable self-cleaning and air purification properties. The three-dimensional surface is coated with a metallic coloration that changes as light and viewpoints shift. The tiles are installed with

a state-of-the-art cladding support system that gives a rhythmic pattern and mathematical form to an otherwise supple, twisting shape [24].

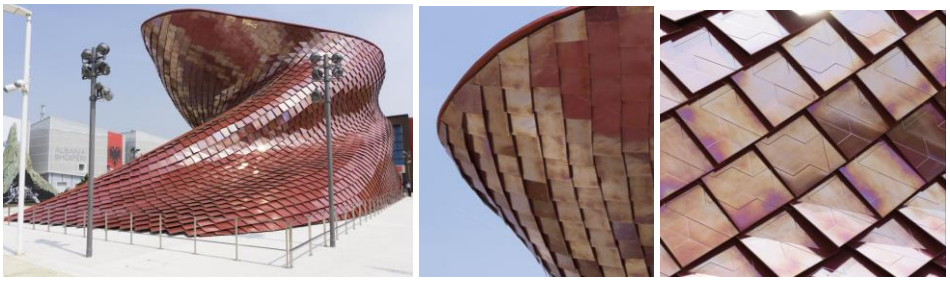

Fig. 7 Vanke pavilion - Daniel Libeskind - the geometric ceramic panels [24].

2.4. Self-cleaning porcelain tiles facades

Beaumont Tiles has laminated porcelain tiles with potential for innovation in architecture and interior design. Key features of the Coverlam porcelain rectified tiles include resistance to UV light, chemicals, wear, fire and frost; easy-to-clean surface preventing mould and bacteria; eco-friendly material using 2-3 times less raw quarry materials than any other type of porcelain tile, and fired in a hybrid kiln (gas and electricity) requiring less energy to produce; recyclable material; and Hydrotect treatment (titanium dioxide coating) giving self-cleaning, antibacterial and odour-elimination properties [25].

Coverlam porcelain rectified tiles are ideal for ventilated facades, as well as smaller buildings and private houses. One of the most interecting projects is located in the coastal town of Alcossebre. It is a part of a Strategic Plan for Tourism Developmet in agreement with the Polytechnic University of Valencia and whose purpose is to promote tourism in the area through small spaces, buildings and activities of design, figure 8. Three different types of ceramics, with different thicknesses, formats, colors, finishes and applications are used. One of three pieces of ceramics used, Coverlam, is a laminated porcelain slab with 5mm thickness and 300x100cm size from Grespania. This piece is installed in a rainscreen and wall cladding [26].

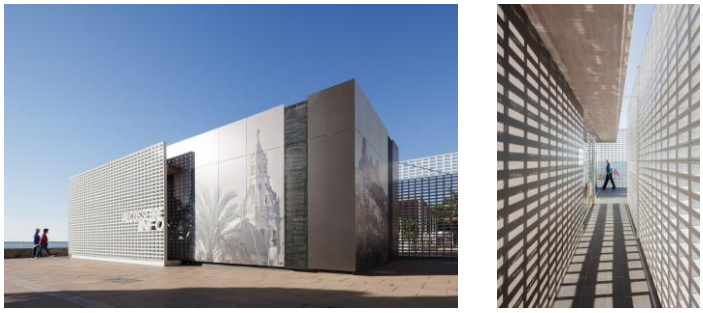

Fig. 8 Tourist info pavilion in Alcossebre, Spain – H & C tiles [26].

2.5. Self-cleaning sintered stone tiles facades

Spanish hard surfaces company Neolith recently launched the collection of façade tile systems Skyline. The slabs are covered with Cincinnati, Ohio based surface treatment manufacturer Pureti's proprietary aqueous and titanium dioxide nanoparticle–based coating that creates self-cleaning and air purifying surfaces.

Made from 100 - percent natural raw materials such as granite minerals, silica, and natural oxides they can be installed as ventilated façades. Through sintering technology, the product undergoes exposure to extreme heat and pressure to create a nonporous, durable surface. Pureti credits two chemical processes that make the coating technology possible: photocatalysis and superhydrophilicity. Superhydrophilicity is initiated by contact with water, as in the case of rain or precipitation. As the water expands over the treated surface, the thin film of titanium dioxide nanoparticles formed from photocatalysis washes away dirt particles off the façade, reducing the need for frequent cleaning of the building's exterior.

Luxury tower in Manhattan's Hudson Square, 570 Broome, 25-story, has a façade which cleans the air, figure 9 a) and figure 9 b). The building is clad in 2,000 square meters of Neolith paneling - a material comprised of raw minerals that have undergone high heat and pressure to mimic the appearance of natural stone - that is coated with a titanium dioxide nanoparticle-based treatment called Pureti. The building is situated next to New York's traffic-ridden Holland Tunnel, making its presence even more welcome in the area [27].

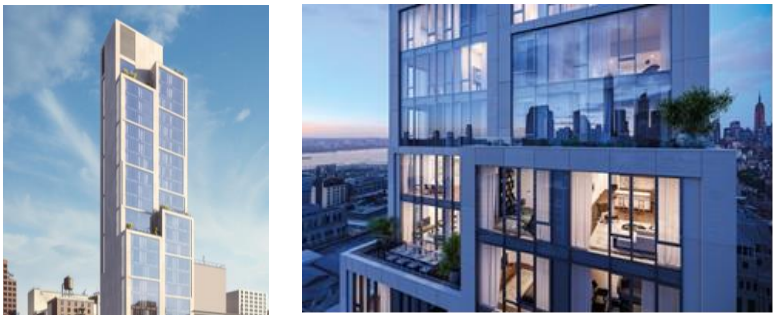

Fig. 9 a) The rendering of 570 Broome in New York City [28]
b) 570 Broome in New York City - Neolith paneling with Pureti coat [27]

2.5. Self-cleaning concrete facades

New photocatalytic cements can be used to produce concrete and plaster products that save on maintenance costs while they ensure a cleaner environment. Italcementi tests have demonstrated that a road paved with concrete made with the photocatalytic cement can reduce NOX levels by 20 to 80%, depending on atmospheric conditions. A building with photocatalytic precast concrete cladding can do the same. Italcementi is one of the most famous companies that produce and develop photocatalytic cements.

TX Active®, TX Aria and TX Aria are products with photocatalytic properties, developed by Italcementi.

The products containing TX Active® are able to abate air noxious organic and inorganic substances and they preserve over time the aesthetic quality of the finished products. TX

Active® is an environmental friendly product for mortars, paints, precast elements and pavements plasters.

Concrete containing TX Arca will resist most organic and inorganic pollutants that gather on the surface causing discoloration. TX Arca with its self-cleaning effect, is the cement complying with the requirements set forth in European Standard EN 197/1 and is specifically designed for building prestigious architectural structures.

In addition to the self cleaning effect, concrete made with this TX Aria cement, will remove significant amounts of environmental pollutants (Nitrogen Oxides, Sulfur Oxides, Volatile Organic Compounds, Ammonia, Carbon Monoxide. Organic chlorides, aldehydes, polycondensated aromatics) [29].

About 20 years ago, the United Nations identified Mexico City as the single most polluted city on the planet. In 1992, Mexico City's levels of sulphur dioxide, suspended particulate matter, carbon monoxide, ozone, lead, and nitrogen dioxide all exceeded the World Health Organization's health protection guidelines. The Torre de Especialidades is an addition to the Hospital Manuel Gea Gonzales, located in the southern Tlalpan neighborhood of Mexico City. The tower was built as part of an ongoing $20 billion government project to improve the city's health infrastructure.

The hospital building is shielded by an eye-catching 100-yard-long façade made with special tiles called "proSolve370e," that have air-scrubbing abilities. The mass-produced tiles, created by Berlin-based architecture firm Elegant Embellishments, are coated with titanium dioxide. The architects hope is that the building can counteract the impact of about 8,750 of all cars driven in Mexico City and provide a slightly fresher air in the hospital's immediate area. In addition, the innovative lattice-like design of the tile shapes "slow wind speeds and create turbulence, for better distribution of pollutants across the active surfaces, figure 10.

Fig. 10 The hospital building called the Torr e de Especialidades, Mexico City [30, 31].

The omni-directionality of the quasicrystalline geometry is especially suitable to catch things from all directions. The façade produces shadows in the inside of the building, helping to keep it fresh and cool. That way the amount of air conditioning needed to cool it is kept at it's lowest possible level, helping save electric energy [30,31].

The pavilion, the city of Milan, Italy for Expo 2015 consists of the permanent building Palazzo Italia (6 levels, built area 14,398 sqm) includes: exhibition spaces, auditorium, delegations spaces, offices, events spaces, meeting spaces, restaurant. The building is designed in a sustainable way thanks to the contribution of photovoltaic glass in the roof and the 9,000 square meters of photocatalytic concrete that has titanium dioxide for the

branched facade, figure 11 a) and 11 b). For the design of this "skin" Nemesi has created a unique and original geometric texture that evokes the intertwining random branches. The full external façade of Palazzo Italia is clad in over 700 i.active BIODYNAMIC panels realized by Styl-Comp with Italcementi's patented TX Active technology [32].

Fig. 11 a) The pavilion, the city of Milan, Italy for Expo 2015 [32],
b) The pavilion, Milan, Italy for Expo 2015 –the part of the photocatalytic façade [32].

One of the most famous buildings with photocatalitics concrete is the Jubilee Church (also known as the Dives in Misericordia) in Rome, completed in 2003. The soaring structure was designed by the award-winning international architectural firm of Richard Meier & Partners Architects LLP. It is a composition of 256 precast, post-tensioned concrete elements assembled into curved white "sails" that rise 85 feet into the sky, figure 12 [33].

Fig. 12 Via di Tor Tre Teste, Rome, Italy left [33], right [34].

CONCLUSIONS

The constant evolution of facade systems is leading to the use of high performance technology. There is a wide range of innovation enabled by technologies for processing materials and integrating currently available materials for creation of new generation facades. The PICADA Project has permitted the development of a full range of photocatalytic facade coatings that display both de-soiling and de-polluting properties, thanks to the introduction of nano-particles of anatase titanium dioxide. Titanium dioxide (TiO_2) is highly resistant to

environmental pollution, marine environments, performs well in even severely aggressive environments. These properties make titanium a material well suited for architectural applications for ecological self-cleaning facades. The said performances have been demonstrated through an extensive laboratory testing programme as well as outdoor and indoor field trials [15].

The world is increasingly seeking to design buildings with photocatalytic self-cleaning facades of various materials such as: glass, ceramic, artificial stone and photocatalytic concrete. The permanent application of products such as photocatalytic coatings, the level of pollution of the environment would be significantly reduced. A wide range of products with these abilities offers a solution for a variety of building types and facade shapes. As it is presented in the paper, the choice of material is no longer an obstacle in the struggle for a healthier and cleaner environment..

It is concluded that structures with self-cleaning facades significantly influence the improvement of air quality in urban areas, therefore, the quality of life itself.

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FOTOKATALITIČKE SAMOČISTEĆE FASADE U ARHITEKTONSKOM PROJEKTOVANJU

Održive i pristupačne tehnologije su važan aspekt energetske efikasnosti i očuvanja životne sredine. Zagađenje životne sredine je jedan od uzroka lošeg kvaliteta vazduha. Emisije gasova svakodnevnog saobraćaja se neprestano povećavaju, i često prevazilaze dozvoljene koncnetracije u atmosferi.Razvoj samočistećih materijala - fotokatalitičkih građevinskih materijala, pogotovo kada se primene na fasade mogu doprineti obezbeđenju čistog vazduha i poboljšanja održivosti. Oni predstavljaju rešenja za smanjenje koncentracija zagađenja u urbanim područjima koji najviše obećavaju, pokazujući efikasnost i pravu vrednost u smislu eko-održivosti. Rad objašnjava mehanizam samočišćenja fasada, njihove tipove u arhitektonskom projektovanju i važnost njihove primene.

Ključne reči: *fasade, samočišćenje, titanijum dioksid, fotokataliza, staklo, beton, keramika, arhitektonsko projektovanje.*

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INFLUENCE OF USED WASTE CATHODE RAY TUBE GLASS ON ALKALI SILICATE REACTION AND MECHANICAL PROPERTIES OF MORTAR MIXTURES

UDC 666.971

Jelena Bijeljić[1,2], Nenad Ristić[2], Zoran Grdić[2], Gordana Topličić-Ćurčić[2], Nenad Stojković[1]

[1]College of Applied Technical Science Niš, Serbia
[2]University of Niš, Faculty of Civil Engineering and Architecture, Serbia

Abstract. *Rapid transition of electronic device manufacturing industry has led towards the increase of glass waste quantities, which are still being speculated. This resulted in increasing research on the use of waste glass in many different industries. In this study, the impact of using grounded waste cathode ray tube (CRT) glass as aggregate replacement (AR) on the alkali-silica reaction (ASR), mechanical properties and structure and microscopy of mortar were examined and reported. Crushed waste CRT aggregate was used to replace 0, 25, 50, 75 and 100% of natural limestone aggregate in mortar bars. ASR expansion values of mortar with added waste glass were investigated and tested for observation period according to Ultra-accelerated mortar-bar test. The results showed that the increase of AR percentage resulted in higher susceptibility to ASR. Mechanical properties and microscopy of mortar mixtures showed the potential of using waste CRT glass, due to the small difference between tested mixtures.*

Key words: *mortar, cathode ray tube glass, alkali-silicate reaction, mechanical properties, microscopy, aggregate replacement*

1. INTRODUCTION

In recent years, due to a greater demand for newer and more efficient products, the world has become a consumer-oriented society, which has ultimately led to the generation of various types of waste in huge quantities, some of them still being unknown [1]. Statistical reports prove that the European Union countries generate more than 33 Mt of different types of glass [2]. Due to rapid transition of screen manufacturing industry, there has been a rise in use of liquid crystal displays (LCD) in the form of electronic devices, but mostly in monitors

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Corresponding author: Jelena Bijeljić
College of Applied Technical Science, Aleksandra Medvedeva 20, 18000 Niš, Serbia
E-mail: jelena.bijeljic@vtsnis.edu.rs

and television sets. Such devices, which have more energy efficient displays than cathode ray tube glass (CRT), are also one of the leading environmental problems from the ecological point of view [3][4][5]. Since nowadays building and construction industry want to follow sustainability trends, glass is put to use with various applications whose justification is proven by several scientific studies in the field of building materials [6]. Some of the possible applications of waste glass in construction industry are in concrete paving blocks products, drainage application, roadway constructions, special concrete types, architectural applications, admixtures in brick manufacturing, foam glass, tableware glass, glass fibres, glazing ceramics. etc. [7][8]. Glass that is used in cathode tubes is based either on lead silicates (curved glass from the funnel coated with coating of lead and iron, which is hazardous waste) or aluminium silicate (in the form of curved glass that contains aluminium, titanium and vanadium coated by coatings of aluminium basis, and the flat screen glass powdered on by phosphate powder, composed of aluminum, vanadium, titanium, barium and lead to the limit of 0,085%, which is non-hazardous waste).

When it was discovered that waste glass might be used in construction industry as a building material, researchers also found out that glass is unstable in regard to alkali-silicate reaction (ASR) occurrence. Failures or deterioration of concrete structures, due to ASR, results from the reactivity within the concrete material, which leads to appearance of cracks on the surface and inside the volume of a hardened product. ASR is a phenomenon of concrete durability problem, although in most cases the aggregates used are chemically inert materials [9]. Several studies were carried out to examine possible ASR of reused waste glass in concrete and concrete products [1]. Monteiro P.J.M. et all. (1997) [10] used ASTM C 1260 method to measure the mortar bar specimen's expansion, microstructure and gel composition of mortar mixtures containing natural pouzzolan, fly-ash, and slag, made with two different types of Portland cement (PC). Yuksel et all. (2013) [7] investigated evaluation of three different tests (ASTM C1293, Rilem AAR-2, and microbar test method) for determining ASR reactivity of glass aggregate. Moncea et all. (2012) [11] investigated immobilization of waste CRT glass with high content of Pb and mechanical properties of mortar mixtures in three types of matrices Portland cement, slag cement and alkali activated slag binder. Tung-Chai Ling et al. (2013) [12] investigated the effects of particle size of CRT glass on properties of cement mortar made by using glass as sand replacement. Nirut Lairaksa et al. (2012) [13] reported possible use of CRT glass as a fine aggregate in a self-compacting. Hongjian Du. et all (2013) [14] investigated the influence of content, color and particle size of waste glass to ASR expansion of mortar. Also, they conducted a research on mortar mixtures where cement was replaced by mineral admixtures such as fly ash, silica fume, glass powder and ground granulated blast - furnace slag. D. Grdić et al. [15] investigated the change of properties of fresh and hardened cement mortar which occurred due to replacement of the aggregate with the CRT glass. Also, authors recommended that further research should be done on influence of ASR on mortar properties, shrinking due to drying, and modulus of elasticity. Rashad Alaa (2014) [2] studied fresh properties, mechanical properties, ASR, abrasion resistance, water absorption, etc. of mortar and concrete. In his study, mixtures containing waste glass as fine aggregate replacement have been tested.

For the purpose of determining ASR, several tests for ASR investigation can be used. During this research, it was found out that in most cases Rilem standards can be used to successfully identify the ASR reactivity of a tested material or mixture in short research

period. The accelerated mortar bar test according to previous research seems to be a good precision test which tends to be the most effective [16].

In this study, the effect of CRT glass in mortar on ASR and mechanical properties was examined and reported. The ASR was investigated using standard Rilem TC 106-2 AAR Ultra-accelerated mortar-bar test (UAMBT) [17].

2. Alkali Aggregate Reaction in Mortar

Alkali-aggregate reaction has two forms and they are: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR) [18]. ASR is a critical factor which determines the quantity of glass-sand content used in mixtures. While using waste glass in mortar or concrete, in the form of partial substitute of cement or aggregate, there is always a possible reaction in cementitious matrix or mortar [19]. Some aggregates have a possibility of reacting with alkali hydroxides in mortar or concrete, which has an impact on expansion and cracking of concrete in the service period [18]. In general, this phenomenon arises between alkali oxides, constitutes of cement, and aggregates that contain reactive silica foams [20]. In fact, when amorphous silica in glass is susceptible to attraction by the alkaline environment it would depolymerize to form a monomer $Si(OH)_4$. Further, monomer reacts with alkalis such as K+, Na+, and Ca+ to form ASR gel that can absorb water, induce inertial stress, and at the end induce severe cracking and damage [14]. In general, ASR is a phenomenon of reaction between the hydroxyl ions (OH^-) in the pore solution and reactive silica-based ones on the aggregate. The alkalis initially contribute to the high concentration of hydroxyl ions in solution and formation of expansive alkali-silica gel. When poorly-crystalline hydrous silica is exposed to a strong alkaline solution, there is an acid-base reaction between the hydroxyl ions in solution and the acidic silanol (Si–OH) groups [21]. ASR causes expansion that takes place in two characteristic phases. The first phase is characterized by ASR gel showing, while in second, ASR gel combines with the moisture of the media, which causes expansion [20]. Previous research showed that using of low alkali cements might significantly reduce or completely eliminate this effect [19]. In general, ASR is a phenomenon in glass concrete or mortar that is still hard to predict before implementing competitive tests [14].

2.1. Materials and methods

Nowadays there is a real need for immediate detection of alkali reactivity of concrete made of alkali reactive aggregates. The potential alkali reactivity of aggregates comes forward in shape of mortar bar expansion [22]. Mortar bars consisting of alkali-reactive aggregates should be tested by rapid tests, far quicker than traditional alkali aggregate reactivity tests. Most common alkali reactivity detection tests are summarized in Tab. 1. Some of them are adopted as national standards for testing ASR in concrete products. On the other hand, one must have in mind that the national level regulations on ASR are usually developed based on local experience. Although it is expected that longer tests result in higher accuracy. Their main aim is to improve and optimize concrete mix design and flexibility of aggregate material, and incorporate aggregate properties the option of performance testing in their possible provisions [22][23].

Table 1 Alkali reactivity detection tests [9]

Name of the test	Procedure of using
Rilem TC 106-2 AAR Ultra-accelerated mortar-bar test (UAMBT)	In accordance to ASTM C 227 standard, mortar bars 25 mm x 25 mm x 285 mm or according to Note 1 40 mm x 40 mm x 160 mm in size should be prepared. After 24 hours prisms should be demolded and initial length should be measured. Prisms are then placed in water and heated in the oven to 80°C for the next 24 hours, initial length should be measured, zero expansion must be taken before specimens cooling. Prisms should be immersed into 1M NaOH solution already heated to 80°C. Specimen expansion must be observed periodically for 14 days. Mix design is recommended, so water/cement ratio is 0.47 by mass. Proportion of the dry materials is 1 part of cement to 2.25 part of the aggregates by mass. According to standard ISO 6274, a set of sieves should be settled to 4 mm, 2 mm, 1 mm, 500 μm, 250 μm and 125 μm [16].
ASTM C227 Mortar bar test	In this test, mortar bars should be placed into the heat-sealed. Courts for placing should be made of polyethylene, in the form of bags, and filled with approximately 10 ml of water. Expansion should be observed during period of 24 months. Expansion results are limited to 0.05% and 0.10% to the period of 3 and 6 months respectively. Late expansions of alkali-silicate reactive aggregates cannot be higher than 0.10% at 18-24 months period [24].
Danish salt method	Three ASTM mortar bars are exposed to NaCl solution that should be heated to 50°C. Expansion values are limited to 0.10% in the salt solution. Depending of aggregate, reports should be given on weeks 8 and 20 [9].
Chinese autoclave test	According to this method, mortar bars made of proportion material and mix design suggested in ASTM, with aggregate size 0,15 – 0,75 mm, are demolded after one day, cured at 100 °C stream curing for 4 hours, and later immersed into 10% KOH 150 °C heated solution for 6 hours [9][25].
NBRI method	This method is obtained by Oberholster and Davies. Mortar bars should be exposed to 1M NaOH solution at 80°C for the period of 14 days. Expansion should be measured in warm conditions. Expansions are limited to 0.10 to 0.25% [9].
Duncan method	Mortar bar standard ASTM dimensions are exposed to 100% relative humidity and to temperature. Heating temperature should be seated to 64°C for the observed period of 12, 16 and 26 weeks. Mortar expansion is limited to 0.05% [9][26].

3. EXPERIMENTAL PROGRAM

In order to assess the ASR reaction and mechanical properties of mortar bars, 40 mm x 40 mm x 160 mm bars were cast using Rilem TC 106-2 AAR Ultra accelerated mortar bar test (UAMBT). The reference mortar (E) comprised of cement and natural crushed limestone aggregate. Replacement ratios were selected as 25, 50, 75 and full replacement (100%) of aggregate with waste CRT glass (AR) by mass. These mixtures were designed as 25% (25 AR), 50% (50 AR), 75% (75 AR) and 100% (100 AR). The mixture proportions of mortar are shown in Table 2.

Table 2 Relative proportions of material used for preparation of mortar bar mixtures

Mixture name		E	25 AR	50 AR	75 AR	100 AR
w/c		0.47	0.47	0.47	0.47	0.47
cement		600	600	600	600	600
Mass retained between sieves (g)	Mineral aggregate					
	0.125-0.25 mm	202.5	151.87	101.25	50.63	0
	0.25-0.5 mm	337.5	253.12	168.75	84.38	0
	0.5-1 mm	337.5	253.12	168.75	84.38	0
	1 - 2 mm	337.5	253.12	168.75	84.38	0
	2 - 4 mm	135.0	101.25	67.50	33.75	0
	Waste CRT glass					
	0.125-0.25 mm	0	50.63	101.25	151.87	202.5
	0.25- 0.5 mm	0	84.38	168.75	253.12	337.5
	0.5- 1 mm	0	84.38	168.75	253.12	337.5
	1- 2 mm	0	84.38	168.75	253.12	337.5
	2- 4 mm	0	33.75	67.50	101.2	135.0

3.1. Materials

In this study, Portland cement, CEM I 52,5R [27] manufactured by CRH Popovac Serbia, with alkali content of 1.03% was used. The chemical composition of Portland cement is given it Table 3.

Table 3 Chemical composition of used cement CEM I 52,5R

Chemical element	%	Chemical element	%
LOi	2,26	MgO	2,2
IR	0,09	SO_3	3,05
SiO_2	19,3	K_2O	0,91
Al_2O_3	4,28	Na_2O	0,21
Fe_2O_3	2,87	P_2O_5	0,06
CaO	62,8	Cl	0,008

The purpose of the study was to compare the results of ASR and mechanical properties of mortar bars containing waste CRT aggregate with mortar containing crushed mineral aggregate. Crushed limestone aggregate used for making mortar bars was from Dolac quarry. The aggregate used was sieved with sieves according to standard, having square apertures of 4 mm, 2 mm, 1 mm, 500 μm, 250 μm and 125 μm, with maximum nominal size of 4 mm [28].

Used recycled panel glass of recycled CRT was granted by "Jugo-Impex" d.o.o. Niš company and crushed by fabric mill. By using "hot wire" method, screen glass was removed. This step was important due to different chemical composition of the glass. Taken from the device, glass was laboratory tested by removing harmful film from the outer and the inner tube of the CRT glass funnel. Several attempts of experiments were made. The coating of lead and iron on the outer side of the funnel was rinsed with regular water and removed in its entirety. Lead and iron based coating on the inner side of the funnel was hard to remove, except with mechanical procedures. Glass was immersed in 10% solution of nitric acid for 24 h. After the period of treatment, there has been no reaction leading to removal of the surface coating. The surface was treated with nitric acid in higher density, which has given no results. Aluminum based coating, on the outside was rinsed with water in the presence of abrasive paste. Aluminum based coating, on the inside, was submerged in 10% solution of hydro- chloric acid for 24 h. Reaction between aluminum and the acid was complete. Another possibility of removal is mechanical treatment of the surface in the form of scraping. Chemical composition of non-hazardous glass that is used without negative impact is given in Tab. 4. Used waste glass aggregate was sieved using sieves according to standard [28] non-hazardous CRT glass was sieved to sieves 4 mm, 2 mm, 1 mm, 500 μm, 250 μm and 125 μm.

No chemical admixtures were used in the experiment. Standard tap water was used during the mortar production in all mixtures.

Table 4 Chemical composition of used waste CRT glass

Chemical element	mg/kg	Chemical element	mg/kg
As	0,0	Pb	27,5
Be	0,2	Sb	9,5
Cd	0,2	Se	2,0
Co	10,3	Sn	5,7
Cr	6,0	Te	5,5
Cu	0,0	Tl	4,7
Mn	2,7	V	74,5
Ni	51,5	Zn	2100

4. RESULTS AND DISCUSSION

4.1. ASR expansion

According to RILEM TC 106-2 AAR standard that was used, the results obtained within 14 days of soaking observation period exhibited a potentially harmful expansion (Fig. 1). Measurements were taken at 2, 7, 10 and 14 days. The observed period showed turbulent reactions that had been expected as chemical reactions between cement, aggregate and water. Measurements showed shrinkage and ASR expansion processes in the observed specimens in various percentages using crushed CRT glass as a replacement for crushed limestone aggregate. For the observed period of 2 days, the lowest percentage of expansion is found in the mixture group 50 AR (0,04%), while the highest percentage of expansion is found in specimens from the group 100 AR (0,23%). When observing period was 7 days, all observed specimens, except from group E, show the expansion process. The highest percentage of expansion has been found in samples of group 75 AR (0,60%), while the smallest percentage of expansion has been

found from the specimens in group 25 AR (0,21%). When observing period was 10 days, the lowest expansion belongs to mixture 25 AR (0,31%), while the highest percentage is shown in mixture 100 AR (0,82%). Finally, while observation period was 14 days, as expected, the highest and lowest percentage expansion belong to the samples of groups 100 AR (1,15%) and 25 AR (0,42%) respectively. It should be noted that ASR expansion of 25 AR was slightly lower than that of 100 AR, probably due to the lower amount of CRT glass. The results show that 25% replacement of natural crushed aggregate with CRT glass might be sufficient for controlling mortar bars. Expansion showed cracks visible on the surface of all specimens (Fig. 4) of 75 AR and 100 AR groups.

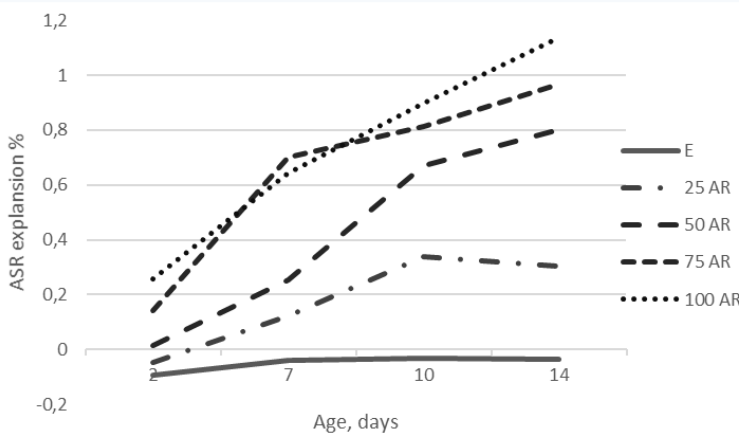

Fig. 1 Expansion of mortar bars containing waste CRT glass.

Shrinking is characteristic for reference (E) specimens and specimens where the crushed limestone aggregate was replaced by crushed CRT aggregate in the amount of 25% (25 AR) for a measurement on 2 days. Measured values for reference show that the greatest shrinking values were at the beginning of the observation period, then they show rapidly lower values that were constant during other measures. At 2, 7, 10 and 14 days, the measures were 0,086 %, 0,038%, 0,02 % and 0,03% respectively. The measured value for 25 AR that records shrinking at 2 days was 0,04%. Other values of mixture 25 AR show expansion. Recorded values at 7 days were 0,21%, and they increased by approximately 50% respectively at each subsequent measurement step. Other curves that represent the behavior of samples during the observed period show only expansion.

4.2. Mechanical properties of mortar bars

The compressive and tensile strength of 14 days old specimens with different replacements of natural aggregate with waste CRT glass are shown in Fig. 2. and Fig. 3. Considering that compressive and tensile strength of mortar bars is the most important mechanical property of the mixture, the results show satisfactory initial mechanical characteristics compared to control mixture E.

The results of compressive strength show expected reduction which corresponds to this percentage of natural aggregate replacement by waste CRT glass.

The measured strength values show maximum strength that fits to reference E (60,04 N/mm^2). Mixture 25 AR shows value 56,99 N/mm^2, that is for 5,1% reduced value than E. Mixture 50 AR shows compressive strength value reduced for 2,56% in comparison to 25 AR, which is for 7,6% lower strength than in mixture E. Measured values of 75 AG and 100 AR are 49,31 N/mm^2 and 42,23 N/mm^2 respectively. Difference in percentage of compressive strength values between E and 100 AR are 29,9%. Compressive strength diagram shows the expected trend of declining strength, which corresponds to the percentage of aggregate replacement by waste CRT glass. Percentage of compressive strength of mixture 50 AR is higher than arithmetic mean of the mixtures E and 100 AR, which proves a small difference of compressive strength reduction of mixture 25 AR and 50 AR.

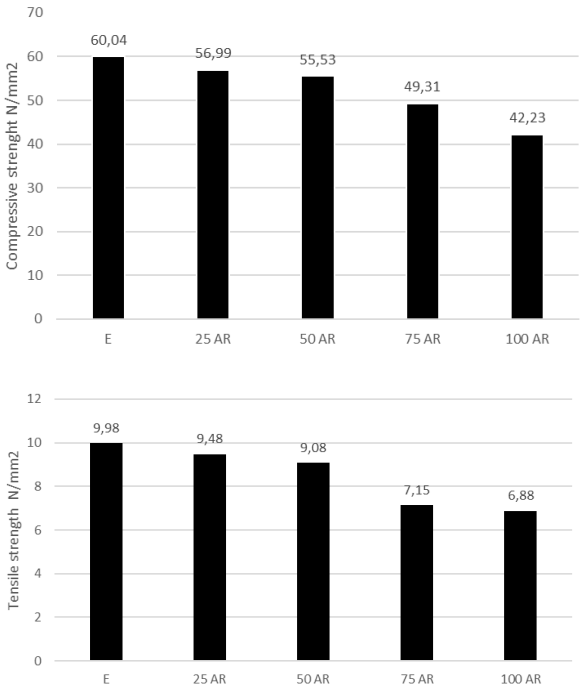

Fig. 2 and 3 Compressive and tensile strength of mortar bar with added waste CRT glass after 14 days.

The results of tensile strength show reduction, like in compressive strength diagram which also corresponds to percentage of aggregate replacement by waste CRT glass.

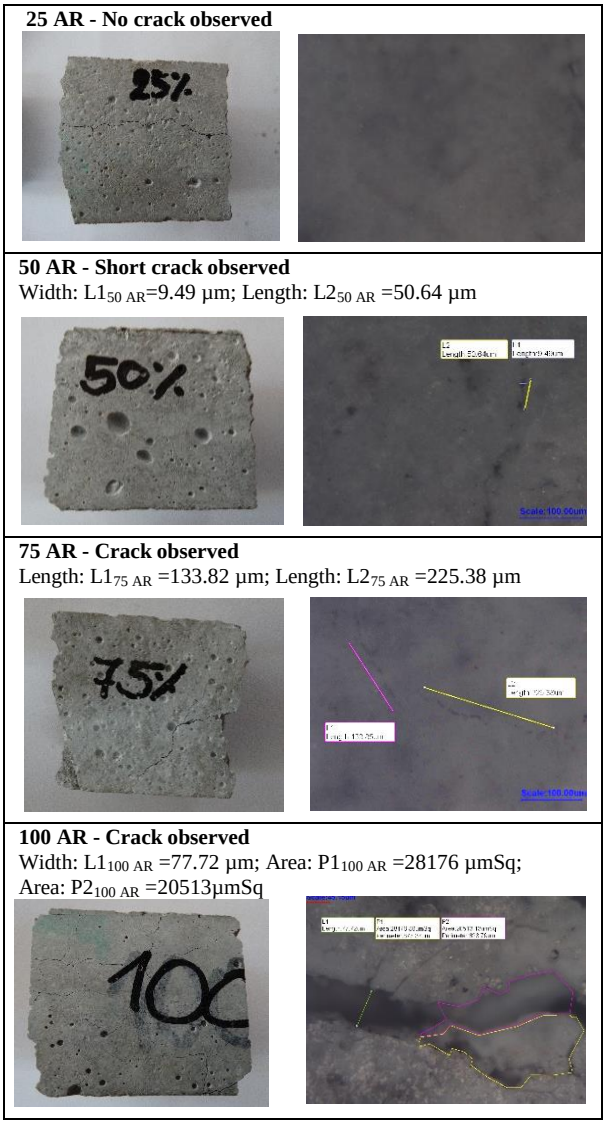

Fig. 4 Microscopy of AR mortar bars

The measured strength values show maximum strength of mixture E (9,98 N/mm^2). Mixtures 25 AR, 50 AR, 75 AR and 100 AR show tensile strength measured values 9,48 N/mm^2, 9,08 N/mm^2, 7,15 N/mm^2, 6,88 N/mm^2 respectively. Mixture 25 AR shows 5% lower tensile strength values than control mixture. Mixture named by 50 AR shows 4,2 % reduced values than mixture named by 25 AR, and 9% reduced values than mixture E. Like with compressive strength diagram, in the Fig. 3. that shows tensile strength, one can notice the downward trend in strength, which corresponds to the percentage of aggregate

replacement by waste CRT glass. Values of compressive strength of mixture 50 AR are above arithmetic mean of E and 100 AR mixture values.

The photos of microscopy observed specimens are shown in Fig. 4. Cracks are visible on surface mixtures designated as 50 AR, 70 AR and 100 AR. Mixtures designated as 25 AR did not have microscopy surface visible cracks. By using microscopy, characteristic crack values were obtained on the samples surface. The measured values L150 AR and L250 AR of mixture 50 AR presents values of width 9,49 μm and length 50,64 μm, respectively, are visible on the samples surface. The measured cracks values named as L175 AR and L275 AR of mixture 75 AR presents length values 133,82 μm and 225,38 μm respectively. Measured crack L275 AR shows 4,45 times longer crack length value than L250 AR. Mixture 100 AR have characteristic crack width L1100 AR (77,72 μm), and areas P1100 AR (28176 μmSq) and P2100 AR (20513 μmSq). Measured L1100 AR width crack value is 8,2 times longer than measured width of L150 AR.

5. CONCLUSION

In accordance with test duration standard, observation of mortar shrinkage and expansion processes, led to the conclusion that during the observation period on ASR had a noticeable impact on the expansion of mortar with ground CRT glass used to replace a crushed limestone aggregate. The impact of ASR on expansion increased with higher percentage of recycled CRT glass used to replace crushed limestone aggregate. Expansion had a noticeable impact on the surface cracks. Reduced compressive and tensile strength values were attributed to significantly smoother surface of the CRT glass aggregates, as well as the fact that recycled glass aggregate had a harmful coating that prevented proper adhesion of the recycled glass aggregate's grains and cement matrix. Aside from being prescribed by the RILEM TC 106-2 AAR guidelines used in this research, 14 days testing period is significant for the fact that the most important chemical reactions in the mixture occur during that time period. Mechanical properties of mortar mixtures showed the potential of using waste CRT glass, due to the small difference between strength of tested mixtures.

Further research should be conducted using the same testing methodology and guidelines using cements that contain mineral additives and mineral supplements as partially substitute of cement or aggregate. That might be in order to further reduce effects on ASR and improve mechanical properties of mortar bars and concrete.

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ISPITIVANJE UTICAJA KATODNOG STAKLA NA POJAVU ALKALNO SILIKATNE REAKCIJE I MEHANIČKE KARAKTERISTIKE MALTERSKIH MEŠAVINA

Razvoj industrije elektronskih uređaja poslednjih godina doveo je do znatnog povećanja nastalog staklenog otpada, čije količine još uvek nisu u potpunosti poznate. To je rezultiralo razvojem istraživanja koja se često baziraju na upotrebi otpadnog stakla u raznim proizvođačkim industrijama. U ovom radu ispitivan je uticaj otpadnog mlevenog stakla katodnih cevi (CRT staklo) kao delimične i potpune zamene agregata (AR) u malterskim mešavinama i uticaj takvog agregata na pojavu alkalno silikatne reakcije (ASR), mehaničke karakteristike, strukturu i mikroskopiju ispitivanih mešavina. Mleveno CRT staklo korišćeno je kao zamena prirodnog agregata u procentualnoj zastupljenosti od 0, 25, 50, 75 i 100%. Količina nastale ASR reakcije na uzorcima malterskih prizmi je ispitivana i testirana prema Ultra-accelerated mortar-bar test-u. Rezultati ispitivanja pokazuju da sa procetualnim povećanjem AR dolazi do pojave većeg uticaja ASR. Mehaničke karakteristike i mikroskopija malterksih mešavina u konačnom pokazuju veliki potencijal korišćenja CRT stakla.

Ključne reči: *malter, staklo katodnih cevi, alkalno-silikatna reakcija, mehaničke karakteristike, mikroskopija, zamena agregata*.

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THE CHALLENGES OF PLANNING IN THE FIELD OF CULTURAL HERITAGE IN SERBIA

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Ana Niković, Božidar Manić

Institute of Architecture and Urban & Spatial Planning of Serbia (IAUS), Belgrade, Serbia

Abstract. *Serbia is characterized by a rich cultural heritage and cultural diversity, as well as by a developed system of protecting cultural property. The current trend is that of a constant increase of the number of registered cultural properties under protection. Urban settlements in Serbia are characterized by specific typological characteristics and recognizable architectural typologies that are valuable architectural heritage as well as an urban identity factor. Together, protected cultural property and architectural heritage belong to a wider concept of urban heritage in the sense comprised in the modern charters on the protection of cultural heritage (HUL). The primary starting point of the paper is that the law and plans in Serbia must become more sensitive to the context. In addition to protecting registered property, the protection of buildings and other structures that are not cultural heritage should also be introduced. However, current planning practice in Serbia does not sufficiently recognize cultural heritage in the wider sense of urban heritage, nor does it affirm it as an important resource for sustainable development. By analyzing the planning context, the problems and challenges in terms of institutional, legal and governance frameworks, as well as planning methodologies, can be identified. The paper is a contribution to the contextual analysis within the National Strategy for the Sustainable and Integral Urban Development of Serbia (currently developing within a wider team of experts), with the aim of affirming the cultural potential of Serbia and incorporating the topic of cultural heritage as a resource for sustainable development into Serbia's development programs and projects.*

Key words: *cultural heritage, urban heritage, planning, Serbia.*

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Corresponding author: Ana Niković
Institute of Architecture and Urban & Spatial Planning of Serbia, Kralja Aleksandra Blvd. 73/II, 11000 Belgrade, Serbia
E-mail: anan@iaus.ac.rs

1. INTRODUCTION

Serbia is characterized by a rich cultural heritage and by a developed system for the protection of cultural property, as well as by the positive trend of a constant increase of the number of registered cultural properties. In addition, Serbia is a signatory to several international charters in the field of protecting cultural heritage, which, since the UNESCO's Convention concerning the protection of the world cultural and natural heritage (1972), have been constantly developing to extend the concept of cultural heritage, emphasizing its universal values, and calling on signatories to adapt their institutional and legal frameworks to new trends in conservation. From the aspect of sustainable urban development, the Convention for the Protection of the Architectural Heritage of Europe (1985) defines architectural heritage very broadly to include monuments, groups of buildings and localities. It reminds us that buildings that are not under institutional protection also have an important role in creating a quality urban and rural environment, and they cannot be excluded from the program of renewal, preservation and adaptation for new purposes, which stimulates the economic, social and cultural development of states and regions. This promotes a cross-sectoral and integrative approach to the protection of cultural heritage, which is at the core of contemporary urban development policies, as is the most recently adopted UNESCO's Recommendation on the Historic Urban Landscape (HUL) [1]. This charter has not been ratified in Serbia, but the scientific and professional community are familiar with the latest trends in conservation and there are efforts to integrate them into practice (e.g. Šekarić, 2013).

However, despite the existence of favorable preconditions for improving an already developed system of protection, in Serbia, as in the majority of developing countries there is a problem with discrepancies between the institutional and legal framework and international recommendations. Cultural heritage continues to include primarily individual monuments, which in terms of their number dominate the structure of registered cultural property (see section 1). In this way, structures of vernacular architecture, industrial heritage, Modern architecture and valuable ambient units most commonly are not objects of protection or conservation and restoration programs, even though they possess significant architectural, urban, civilizational value and/or are important landmarks of cultural and historical development.

This approach to the valorization of the built structure leads, on the one hand, to neglecting the surroundings of protected entities, and very often also to the degradation of ambient units, especially by means of illegal construction, which in Serbia presents a special problem within urban development (see, for example, Meili, M. et al, 2012). On the other hand, we have a problem with the deterioration of urban settlements and valuable examples of architecture which are not recognized through institutional protection, or through plans and strategies. These problems can only be resolved through an interdisciplinary approach that includes a holistic understanding of space – its significance, character and identity. The absence of an interdisciplinary approach is not only a characteristic of developing countries, but rather a global problem that arises as a result of insufficient communication between

[1] In accordance with the HUL Convention (EU Report 2004 - Sustainable Development of Urban Historical Areas through Active Integration within Towns) - urban heritage includes 3 main categories: monumental heritage of exceptional cultural value; non-exceptional elements of heritage but which are shown in a coherent manner with relative richness, and new urban elements (e.g. buildings, open public spaces and infrastructure).

different professions involved in the creation and management of space (Niković and Roter Blagojević, 2018).

The precise need is for holistic strategies and coordinated actions among all participants involved in the urban development processes of modern cities, on the basis of key international documents dealing with the sustainable development of modern cities (i.e., EC, Leipzig charter, 2007). A particular emphasis is placed on the importance of establishing a territorial approach to preserving cultural heritage that involves connecting cultural heritage with all aspects of the space[2].

The paper presents an analysis of the planning context for cultural heritage in Serbia. It presents the institutional and legal framework in which the protection, planning and management of cultural heritage take place in Serbia. A particular emphasis is placed on the treatment of cultural heritage in planning documents, the subject of institutional protection, and the regime of protecting cultural property. The second section emphasizes the importance of cultural and historical heritage for strengthening the urban identity of settlements in Serbia as an important lever of sustainable development. The third section presents initiatives for including Serbia in international trends in which its cultural potential is recognized, especially as a part of the international cultural heritage.

2. Approach to the Protection and Planning of Cultural Heritage

In Serbia, the protection of cultural heritage is under the jurisdiction of public institutions – the competent Ministry of Culture and Information of the Republic of Serbia and the Republic Institute for the Protection of Cultural Monuments, and the networks of provincial, regional and city institutions. The Republic institute holds a Central Register of Immovable Cultural Property (CR) divided into four categories: cultural monuments, spatial cultural and historical complexes, archaeological sites and landmarks, each of which can be classified according to the statutory criteria as property of great or exceptional significance.

According to information available from the Republic Institute for the Protection of Cultural Monuments (http://www.heritage.gov.rs/cirilica/nepokretna_kulturna_dobra.php) until 2018, 2536 immovable cultural properties were recorded in the CR, of which 2192 are cultural monuments, 77 spatial cultural-historical units, 191 archaeological sites and 77 landmarks. Of the 782 objects categorized as immovable cultural property there are 200 of exceptional importance and 582 of great importance. Among the immovable cultural property of exceptional importance, there are 155 cultural monuments, 11 spatial cultural-historical units, 18 archaeological sites and 16 landmarks, and among the immovable cultural property of great importance are 512 cultural monuments, 28 spatial cultural-historical units, 25 archaeological sites and 17 landmarks.

In Serbia there are 12 sites (or 6 entries) under the protection of UNESCO: the Stari Ras medieval complex of monuments and Sopoćani monastery, 4 monasteries in Kosovo,

[2] http://ec.europa.eu/regional_policy/sources/policy/what/territorial-cohesion/territorial_agenda_2020.pdf
The accent is on managing and linking ecological, landscape and cultural values in certain regions. It is also understood to include activities that emphasize the preservation of these values. 'We support the protection, rehabilitation and utilization of heritage through a place-based approach. Improving regional and local identity by strengthening awareness and responsibility of local and regional communities towards their environments, landscapes, cultures and other unique values is also important'.

the remains of Romulijana palace and three Stećci Medieval Tombstone Graveyard sites. In addition, 11 other sites have been proposed, of which there are: 1 monastery, 3 national parks, 1 nature reserve, 1 archaeological site, 1 historical place, 1 settlement, 1 fortress, 1 rare natural phenomenon and one cultural belt (Danube limes).

Currently, the database that makes up the Central Registry is only available as a tabular display of properties in the order of their declaration and according to the competent institution for the protection of cultural monuments. There is no spatial distribution or connection with the division of the territory of Serbia into spatial units, neither is there a possibility of filtering the database according to different attributes of the cultural property.

The Report on the Implementation of the Spatial Plan of the Republic of Serbia and the state of spatial development from 2014 shows the number of protected cultural properties by administrative districts (Table 1). A comparison of the data from 2014 and 2017 indicates a growth in the number of registered cultural properties[3].

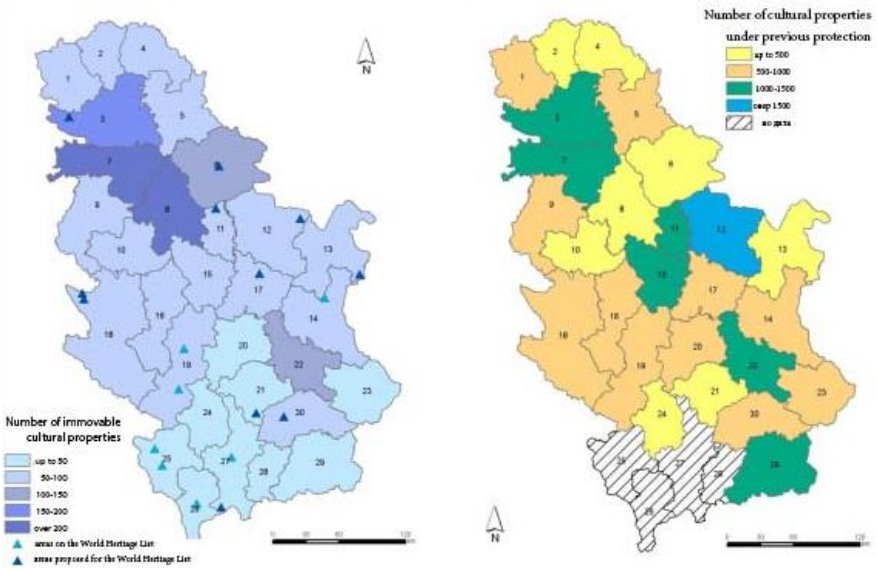

Fig. 1 Left: Number of protected cultural properties in the region.
Right: Number of cultural heritage sites and integral units proposed for protection (source: Report on the implementation of the Spatial Plan of the Republic of Serbia and the state of spatial development from 2014).

[3] This positive trend is not supported by the fact that the declaration of properties enjoying prior protection and their identification as immovable cultural property is slow.

Table 1 Number of cultural goods by category and importance - by administrative district (source: Report on the implementation of the Spatial Plan of the Republic of Serbia and the state of spatial development from 2014).

Area (administrative district)	Type of cultural property				Degree of protection		Total
	Monument of culture	Spatial cultural and historical complex	Archaeological site	Landmark	Exceptional importance	Great importance	
REGION OF BELGRADE							
Belgrade region							413
City of Belgrade	374	9	22	8	14	51	413
REGION OF VOJVODINA							793
West Bačka	58	3	2	1	1	34	64
South Banat	110	2	5	2	8	48	119
South Bačka	156	11	11	8	20	67	186
North Banat	55	1	4	0	4	25	60
North Bačka	81	3	0	4	2	20	88
Central Banat	58	1	1	1	1	33	61
Srem	175	4	16	20	30	124	215
REGION OF ŠUMADIJA AND WESTERN SERBIA							653
Zlatibor	75	3	16	1	13	22	95
Kolubar	83	3	9	3	1	14	98
Mačva	63	3	4	9	6	7	79
Morava	67	1	4	3	5	22	75
Pomoravlje	58	1	4	2	3	10	65
Podunavlje	52	0	1	1	3	7	54
Braničevo	72	1	18	1	2	9	92
Šumadija	84	4	5	2	6	18	95
REGION OF SOUTHERN AND EASTERN SERBIA							576
Bor	40	6	26	1	8	6	73
Zaječar	70	7	3	0	1	5	80
Jablanica	49	0	8	0	1	6	57
Nišava	127	2	9	5	6	12	143
Pirot	29	1	2	0	1	6	32
Pčinja	30	1	1	0	1	9	32
Toplica	21	0	3	0	2	6	24
Rasina	34	2	3	2	2	20	41
Raška	79	4	10	1	11	30	94
REGION OF KOSOVO AND METOHIJA							70
Kosovo	11	1	1	0	12	0	13
Kosovo- Mitrovica	10	0	0	0	6	0	10
Kosovo-Pomoravlje	5	0	0	0	4	0	5
Peć	23	0	0	0	19	0	23
Prizren	19	0	0	0	19	0	19
Total	2168	74	188	75	212	611	2505

The review of property according to the administrative districts given in the 2014 Report provides insight into the spatial distribution of property and the allocation of areas according to the concentration of cultural property (Table 1). Accordingly, it can be concluded that the largest number of registered cultural properties is concentrated in the Belgrade and the Vojvodina region (especially Danube area), while the number of sites on the World Cultural Heritage List is concentrated in other regions (Figure 1).

This difference could be due to the fact that the Belgrade and Vojvodina regions are more developed and that their protection services are more active and supported. This further underlines the relativity of quantitative indicators and the need to connect them with spatial displays and other indicators. Also, quantitative indicators do not indicate the cultural and historical significance of certain parts of Serbia. Some of them, particularly those in western and eastern Serbia and Kosovo, which had great historical significance, now fall into the category of underdeveloped areas of Serbia due to their socio-economic circumstances, and they consequently have less developed protection services[4] .

The Ministry of Culture and Information of RS and UNESCO launched the project "The Digitization of Immovable Cultural Monuments" (http://spomenicikulture.mi.sanu.ac.rs/about.php) that was implemented by a multidisciplinary team at the Mathematical Institute of the Serbian Academy of Sciences and Arts. So far it contains records of 1335 protected immovable cultural monuments. Its most important contribution is the mapping of heritage, as well as the possibility to search by category and type of monument. It particularly highlights development projects, and in this way affirms an integrative approach to the protection, planning and improvement of cultural heritage in Serbia. However, it is necessary for this database to be completed, and to be equally accessible, visible and editable by all institutions involved in the protection, planning and management of the development of cultural heritage.

2.1. The treatment of immovable cultural heritage in planning documents

The Law on Planning and Construction requires institutions for the protection of cultural monuments to be involved in the planning process by issuing documents on measures of protection in the planned areas that contain cultural and historical values, and which must be further integrated into the graphic and textual part of planning documents. In this way, the Law includes institutions for the protection of cultural monuments in the planning system in Serbia, which is based on the principle of hierarchical connections from large-scale spatial/regional plans to more detailed plans – urban, and especially regulatory plans. This legally prescribed procedure opens up the possibility for the strategic goals of protecting cultural heritage found in in general plans to be operationalized at the level of detailed plans.

[4] In Serbia there are 14 institutes for the protection of cultural monuments. Territorial jurisdiction was established by the Decision on determining the territory of the Institutes for the Protection of Cultural Monuments. All institutions are responsible for several cities and/or municipalities. According to the Strategy for the Culture Development of the Republic of Serbia from 2017 to 2027 [2017, draft version], the system for the protection of immovable cultural heritage was decentralized in 2003 in an incomplete manner. Then, the responsibility for financing the core activities of all institutes for the protection of cultural monuments, excluding the Republic Institute, was transferred from the Ministry of Culture to the administration of the cities where their seats are located. Thus, the immovable cultural heritage in the territory of the Republic of Serbia has been placed in an unequal position, since the financing of its protection has become the responsibility of only certain cities, whose capacities are different and, in all cases, insufficient.

In the practice of spatial and urban planning the problem of the inadequate treatment of cultural property can be recognized in planning documents – they are seen as isolated entities without planned relationships with the wider environment that creates their context. This often leads to the degradation of their environment, especially by means of illegal construction, which in the case of Serbia is an irreversible process with a long-term negative effect on the quality of the built environment.

This is supported by the fact that the documents (conditions for the development of plans) issued by the cultural heritage protection services contain only data on declared and registered cultural properties, and their description, category and significance. There are no practical guides or methodologies for the research and evaluation of wider cultural and historical values that can be implemented in planning processes, particularly in terms of cases of regeneration (Niković and Roter Blagojević, 2018). In addition, since it is not legally binding, the possibility is not used for examining a location in detail in regulatory plans through the instrument of urban design, which would encourage a broader understanding of planning solutions by the local community and consequently contribute to more active public participation in the planning procedure. It is important that this theme is also recognized by the conservation experts who revise conservation approaches in the context of planning. They recognize that through the detailed analysis of a location, clear principles can be defined on which a planning solution is based, the application and respect of which could conserve the existing context (Dimitrijević Marković, S., 2012).

As valuable architectural heritage, objects of vernacular architecture, which make up the biggest percentage of the urban fabric in urban areas, are insufficiently recognized, as is the case for industrial heritage. In the practice of protection, the architectural heritage of the 20th century is neglected, which in particular refers to structures of the Modernist architecture and urbanism have arisen since the Second World War and possess significant historical, cultural and civilizational values.[5]

Up to 2018, 2536 immovable cultural properties were registered in the CR, of which only 78 are cultural-historical units. For comparison, only in Belgrade there are 160 properties registered that enjoy previous protection and 34 complexes with architectural and historical value[6]. According to the Cultural Property Law (1994), previous protection involves a status lasting 2 years, which is then lost if the nominated structure is not officially declared a cultural asset and is included in the CR. Consequently, the fate of cultural heritage depends on its treatment in planning documents, i.e. on the methodology applied to analyze the current state and valorize the construction fund. In the current practice, so far, with fewer deviations, there has been little attention given to these planning phases since they are not legally binding.

Based on data that are publicly available, in principle it can be estimated that the protection of cultural heritage is better integrated into planning processes in larger urban settlements. So, for example, in planning documents in Belgrade the term ‘urban protection’ occurs that includes both architecture and the urbanism of Modernism (Master Plan of Belgrade,2016). However, this approach is not represented at the level of Serbia, but is a

[5] Do.co.mo.mo. Serbia is registered within the framework of the Association of Architects of Belgrade (DAB), as a national working group that brings together experts, namely architects, conservators and historians of art and architecture, who deal with the modern movement in architecture and urbanism in Serbia. http://www.docomomo-serbia.org/registar/.

[6] According to data available on the website of the competent institutions for the protection of cultural monuments.

consequence of improving the conservation approach in individual institutions or the position of those processing planning documents. So far, there are no strategic documents at the national level, which would also include other urban settlements.

2.2. The object of protection

So far, Serbia has participated in several programs and projects for the rehabilitation of the architectural and archaeological heritage of South Eastern Europe under the auspices of the Council of Europe and the European Commission (COE, 2014). A document entitled the Priority Intervention List adopted by the Ministry of Culture of the Republic of Serbia (2008) represents a significant contribution to the understanding of cultural heritage in terms of its comprehensiveness, that is, a widening of the scope of protection to also include those structures and units of architectural heritage that are not currently included in the CR. The need is also recognized for improving the documentation techniques, by digitizing heritage and ensuring open access to the digitized material. In addition to digitizing the complete registry, it is particularly important for heritage planning to map immovable cultural properties and characterize their areas through GIS and similar techniques.

The major problem is the lack of harmonization between the current Cultural Property Law and international documents. The law does not recognize the category of cultural landscape, even though since 2011 the European Landscape Convention (Florence, 2000) has been ratified in Serbia. This further increases the gap between the attitudes of professionals which tend towards modern conservation approaches to the protection and planning treatment of cultural heritage on the one hand, and the practice of protection and planning based on the Law, on the other.

Existing definitions of categories of cultural properties given by the Law do not reflect a holistic understanding of space as a specific and unique area in which connections are made between the material and non-material factors of cultural heritage and its surroundings. For some categories, definitions are based on their material factors (morphological, architectural, urban values), while others are based on their intangible factors: historical, cultural, and memorial values[7].

Widening the scope of protection from individual monuments to wider urban and rural units and the cultural landscape, particularly the historical landscape, is the basis of modern conservation approaches, but it is an imperative of sustainable urban development. It requires a platform for interdisciplinary cooperation for establishing a balanced, integrative and sustainable process of managing space.

[7] One problem is the categories of cultural properties and the definition of two categories related to historical places in the *Cultural Property Law* (RS, 1994): *cultural-historical complexes* are defined as urban and rural settlements, or parts of them, and areas with several immovable cultural properties of special cultural and historical importance; and landmarks/places of significance/*heritage sites* are defined as areas relating to important historical event, spaces with natural and cultural values or memorial complexes. We can see that in those two categories tangible and intangible values are separated: the category *cultural-historical complexes* considers urban and rural settlements and focuses on its tangible values (morphological, architectural, spatial etc.); and the category landmarks/*heritage sites* is focused on historical, cultural, natural and memorial sites and their intangible values (historical, cultural, memorial, etc.). The Law does not recognize the historical place holistic as a specific and unique area which reflects the relationship between tangible and intangible heritage and the natural environment.

3. Built Heritage Affirming the Identity of Urban Settlements in Serbia

The urban and rural settlements of Serbia were formed and gained their character and identity over a long period of time – through developmental stages spoken about by the material remains of different civilizations that have settled on the Balkan Peninsula from prehistoric times to today – Roman, Byzantine and Ottoman to the modern European civilization, including the period of socialism. In addition to the material remains recorded in the CR as cultural property, important factors in the character and identity of settlements are their geomorphologic characteristics and elements of the urban and physical structure observed at different levels of detail – the street system, public spaces, buildings, construction details and materials.

All these elements represent important cultural potential. However, the typology of settlements and the typology of urban and physical structures that are based on the identification and classification of these characteristics and elements are not adequately identified in the legal and planning documents. The rules of construction in the regulatory plans are not often defined in accordance with the character of the subject area, but are transferred from higher-order plans without re-examination in relation to the specificity of a particular site. Also, it is often the case that the same rules of construction apply to all parts of a settlement regardless of the differences in their visual and cultural identity.

In accordance with the Law on Planning and Construction (2014) for urban renewal zones, the detailed regulation plan elaborates a compositional or design plan. In addition, for specific areas covered by planning documents, it is not mandatory to carry out spatial checks, which would be useful for examining the limitations and possibilities of a particular location, and in particular for the valorization of the architectural heritage that does not have the status of immovable cultural property along with its urban protection.

In the last three decades in Serbia there have been forms of construction and transformations that are not harmonized with the principles of sustainable development. The problem of insufficient recognition and differentiation of the characteristics of the urban structure in the planning, design and construction procedures is reflected in the distortion of the identity of urban settlements. It additionally negatively affects the quality of the environment and the possibilities for sustainable development. Non-critical interventions in the space, and in particular partial construction, disturbs the balance of elements that must be present in the concept of architectural and urban solutions - greenery, open space, relationship with the street and neighboring buildings and plots. Partial construction is a consequence of the dominance of private interest in decision-making, which moves along the line of maximum exploitation of the construction potential of a location.

Based on the analysis of the existing state of the urban and physical structure in the settlements of Serbia, the necessity for the reconstruction of unregulated urban districts was noticed. There are problems concerning the absence of horizontal and vertical regulations, the lack of harmonization of the dimensions of old and new buildings, the insufficient width of the street regulation both according to the height of buildings and in relation to the functioning of pedestrian traffic, the high density of construction at the level of the block, where the percentage of poor construction resources in the interior of the blocks is high, and the inadequate treatment of open spaces in the city – squares, the neglect of green areas, inactive space – “pockets”; there is also the unresolved issue of economic objects that are

not in use and that are building resources in the process of deteriorating (Strategija održivog razvoja opštine Stari Grad, 2012).

Neither planning methodology nor instruments to implement plans have been developed, which, instead of partial construction at the level of the individual plot, would result in the planning and implementation of future construction at the level of the whole urban unit, primarily blocks, including the maintenance of these units.

The Spatial Plan of the Republic of Serbia distinguishes priority cultural areas that enjoy special treatment. As in the case of cultural heritage, there is no digitization of architectural heritage. It is necessary to establish a cadastre of spatial and physical structures that can be used in planning and design procedures. A methodology for the operationalization of the objectives for developing cultural areas by means of planning documents has not been developed.

3.1. Awareness of the importance of cultural and architectural heritage

There is a developed awareness among the scientific and professional public about the importance of culture and the protection of cultural and architectural heritage. A field that connects the disciplines of planning and conservation is also suggested, such as urban morphology. It could be a useful tool for consolidating knowledge about urban heritage, as well as being a common research platform on the urban form that facilitates the integration of theory into practice (Niković and Manić, 2017, Niković, 2015).

However, if we observe the general state of consciousness about architectural heritage, we come to the following data. According to the research by the Tourist Organization of Serbia (2016) the main destinations for foreign tourists in Serbia are cities, and the main motive for visiting them is the cultural and historical heritage. On the other hand, an analysis of the attitudes and habits of domestic tourists shows that the most visited destinations are mountains, and that the main motive for visiting the countryside is clean air. Cultural and historical heritage is ranked 10^{th} on a list of priority motives, which speaks very clearly about the insufficient presentation of heritage and education of the local population. This further points to the universal value of the cultural heritage represented in Serbia and the need for its promotion as a resource for sustainable development.

One of the causes of the insufficiently developed consciousness on cultural heritage by the local population is certainly the underdeveloped interpretation, animation and mediation at heritage sites and cultural institutions. After decades of isolation and unfavorable economic circumstances, the awareness of cultural heritage as a common world heritage has been lost. The mechanisms for financing programs and projects that revitalize cultural and architectural heritage are not sufficiently developed. At the moment, the main source of funding is the national budget, although back in the 1980s the percentage of the contribution towards culture was reduced. A particular problem is the insufficient participation of the public and the passivity of local communities in the planning and design processes in protected zones. One of the causes of this is the lack of information, which could be improved by the presentation of heritage in the media.

4. International Programs and Projects

International projects and programs are important instruments in the development of an integrative approach to planning settlements in Serbia, through which cultural heritage is affirmed as an integral part of European cultural heritage. Serbia has already been or is currently involved in some of them (in particular, programs and projects involving an integrated approach to the planning of the Danube area).

In accordance with The Strategy for the Culture Development of the Republic of Serbia from 2017 to 2027 [draft version], regarding Serbia's international cooperation, strategic goals were set out in the field of culture: strengthening bilateral cooperation, the improvement of multilateral cooperation and the process of European integration.

Multilateral cooperation involves cultural cooperation between the member states of international organizations, and the introduction of international standards and generally accepted norms and principles that contribute to the common good.

In the framework of multilateral cooperation, cooperation with UNESCO, the Council of Europe, and the countries of central and eastern Europe and China is especially emphasized, in particular the improvement of regional cooperation.

Cooperation with UNESCO includes the protection and preservation of cultural heritage (5 UNESCO conventions, of which Serbia has ratified 4).

The process of European integration envisages involvement in European Union programs such as the Creative Europe Program, the program to support the city of Novi Sad as the European Capital of Culture for 2021 and the European Heritage Label program; then participation in European Union funds is envisaged – IPA funds for European Union candidate countries. In addition, involvement in Serbian projects for the implementation of the European Strategy for the Danube Region (EUSDR), as well as the Adriatic-Ionian Strategy (EUSAIR) and their programs, is important.

One instrument for strengthening the role of heritage is national urban policies (NUP) and another is strategic national documents. In this way, an inter-sectoral approach to the treatment of urban heritage is made possible. The United Nations New Urban Agenda and the Leipzig Charter propose the adoption of national development policies and local and national partnership as one of the key drivers of change. National urban policies are tools to support the implementation of the New Urban Agenda, the goals of sustainable development and other global agreements such as, for example, the agreement on climate change protection.

The report "Ten Years after the Leipzig Charter" (2017) is the first attempt to provide a comprehensive picture of the level of progress of the NUP process. Although urban changes and possibilities are contextually different and institutions vary from country to country, systematic qualitative informatics provides lessons and identifies good practices regarding the development of a national urban policy. The report offers comparative results not only in terms of the phases and elaboration of policies in each country, but also the sectors and other specific issues that the policy can cover. This creates ground for further analytical work with precise and clear information.

If we take Germany as an example of a highly developed country that first created a National Policy and Slovenia, which like Serbia is contextually closer to a country that at the same time managed to make a significant shift towards national policy through its own Spatial Development Strategy, we come to the following results. In Germany, the culture of construction and the improvement of urban design are seen as one of the key fields of

work. In Slovenia, the strategy focuses on vital and attractive cities and urban settlements through the quality of management and planning, especially for cultural heritage. Key measures for strategic urban development are the reconstruction and revitalization of built areas, as well as land conversion.

The National Strategy for Sustainable and Integrated Urban Development of Serbia provides a chance to recreate a common platform to review existing contributions and to review urban development goals. The harmonization of different national policies according to the New Urban Agenda and Leipzig Charter as foundational documents makes a comparative analysis of progress towards global goals possible. A comparative analysis of the situation in the countries that have advanced in terms of their national policies shows that cultural heritage occupies a high position and represents a significant indicator of development – existing in the case of Germany and desired in the case of Slovenia. The common characteristic that can be noticed is the territorial approach – connecting urban settlements and their integrated and harmonized development.

5. CONCLUSION

Current planning practice in Serbia does not affirm cultural heritage as an important development resource. Instead of programs and projects that enable structures and whole units of immovable cultural property to be integrated into modern development trends, due to the application of the strictest measures of protection (practices of the passive protection regime) immovable cultural property is most commonly exposed to degradation. In addition, structures of vernacular architecture that make up the largest percentage of the urban tissue in urban settlements, as well as industrial heritage, are insufficiently recognized as valuable architectural heritage. In the practice of protection, the architectural heritage of the 20th century is neglected, which in particular refers to the objects of Modernist architecture and urbanism that have arisen since the Second World War and possess significant historical, cultural and civilizational value.

The mechanisms for financing programs and projects that revitalize cultural and architectural heritage are not sufficiently developed. A particular problem is the insufficient participation of the public and the passivity of local communities in the planning and design processes in protected zones. Some of the causes of this are the lack of information, which could be improved by the presentation of heritage in the media.

Through the paper several key challenges concerning planning in the field of architectural heritage in Serbia can be seen:

- Improving the institutional and legal framework for the protection, planning and management of cultural heritage – harmonization with international recommendations, conventions and ratified charters; expanding the subject of protection and strengthening cross-sectoral cooperation through the introduction of an integrative approach to the protection of architectural heritage;
- Improving the system of management and finance – the preparation of development programs and projects that would contribute to integrating cultural monuments into their surroundings and the contemporary trends of life. On the other hand, implementing projects in the field of culture and the protection of heritage in both individual and groups of urban settlements and their rural surroundings – the development of a “Serbian brand” (spa and spa villages) and cultural route projects (projects in the Danube area,

wine routes, the routes of Roman emperors, connecting objects and whole units that belong to specific architectural styles e.g. the Moravian School of Architecture, etc.);

- Improving planning methodology by introducing an integrative approach to planning and the concept of urban protection in plans; the introduction of practical guides and methodologies for the contextual analysis and valorization of the construction fund; spatial checks of individual locations; typological classifications of urban and physical and urban structures.

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IZAZOVI PLANIRANJA KULTURNOG NASLEĐA U SRBIJI

Srbija se odlikuje bogatim kulturnim nasleđem i kulturnim diverzitetom, kao i razvijenim sistemom zaštite kulturnih dobara. Prisutan je trend stalnog povećavanja broja registrovanih kulturnih dobara pod zaštitom. Urbana naselja u Srbiji se odlikuju specifičnim tipološkim karakteristikama i prepoznatljivim arhitektonskim tipologijama koje predstavljaju dragoceno graditeljsko nasleđe i faktor urbanog identiteta. Zajedno, zaštićena kulturna dobra i graditeljsko nasleđe pripadaju širem pojmu urbanog nasleđa u onom smislu kako se poima u savremenim poveljama o zaštiti kulturnog nasleđa. Osnovno polazište rada je da zakon i planovi u Srbiji moraju postati osetljiviji na kontekst. Pored zaštite registrovanih dobara, treba uvesti i urbanističku zaštitu objekata i celina koje nisu kulturna dobra. Međutim, aktuelna planerska praksa u Srbiji nedovoljno prepoznaje kulturno nasleđe

u širem smislu urbanog nasleđa, niti ga afirmiše kao važan resurs održivog razvoja. Analizom konteksta planiranja uočavaju se problemi i izazovi u pogledu institucionalnog, pravnog i upravljačkog okvira, kao i metodologije planiranja. Rad predstavlja prilog kontekstualnoj analizi u okviru Nacionalne strategije održivog i integralnog urbanog razvoja Srbije, sa ciljem da se afirmiše kulturni potencijal Srbije i da se tema kulturnog nasleđa kao resursa održivog razvoja ugradi u razvojne programe i projekte za Srbiju.

Ključne reči: *kulturno nasleđe, urbano nasleđe, planiranje, Srbija.*

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DEVELOPMENT OF A COMPUTER PROGRAM FOR THE DESIGN OF LATERALLY UNRESTRAINED STEEL BEAMS

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Oladimeji B. Olalusi, Tony Dirisu, Chinwuba Arum

The Federal University of Technology Akure, Nigeria

Abstract. *This study presents the design results of a C-sharp based computer program developed for the design of laterally unrestrained I-section steel beams. The program was developed based on the stipulations of BS 5950 and Eurocode 3 (EC3) design standards. Several sets of steel beam models having the same cross-sectional dimensions but different laterally unrestrained span lengths, were designed using the developed program, and the results were validated using an established software, Staad Pro. The design results obtained were found similar to the results obtained using Staad Pro. For a specific beam section with constant loadings, as the span length of the laterally unrestrained compression flange increases the buckling capacity reduces, thus the longer the beam, the more it is susceptible to lateral torsional buckling. Comparison of the results obtained using BS 5950 to those of EC 3 at different laterally unrestrained span lengths revealed that the areas of design sections obtained for BS 5950 are 21.5%, on the average, higher than those of EC3. Thus, beams with laterally unrestrained compression flange designed according to the requirements of EC 3 are more economical. The difference in results is because of the differences in the principles of design and measures used between the two standards.*

Key words: *laterally unrestrained beams, Eurocode 3, BS 5950, C-sharp, lateral torsional buckling*

INTRODUCTION

Over the course of history, structural engineers have made significant contributions and improvements to the environment we live in today. As the prices of materials continue to increase, engineers are forced to reduce the costs of construction and shorten the implementation period to maintain their competitiveness. As a result, a new design trend was born: the use of the analysis and design software to evaluate feasible design options,

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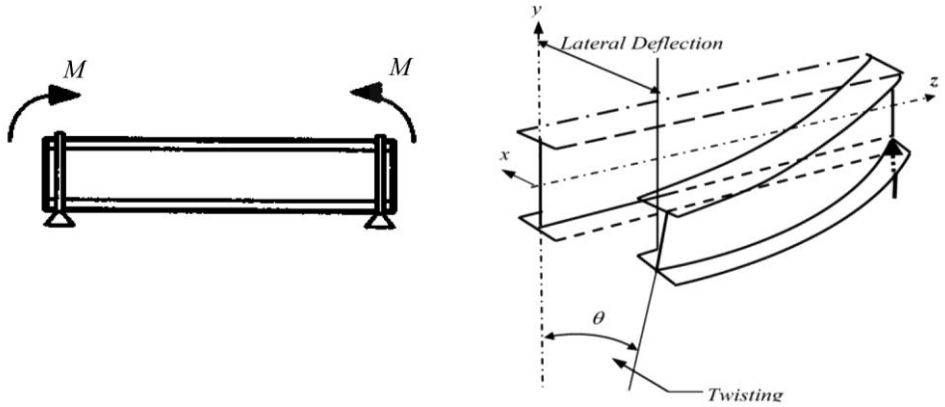
Corresponding author: Oladimeji B. Olalusi
The Federal University of Technology Akure, P.M.B. 704, Akure, Nigeria
E-mail: dimejibenlusy@yahoo.co.uk

replacing the conventional design methods [1]. The introduction of software usage in the structural engineering industry has greatly reduced the complexities of different aspects in the analysis and design of projects, as well as the amount of time necessary to complete the designs [2]. Concurrently, this leads to greater savings and reductions in costs.

Beams are critical members of civil engineering structures. Their principal function is to transmit vertical loads by means of bending action into, for example, the columns in a rectangular building frame or the abutments in a bridge which support them. Beams span between supports to carry transverse loads which are resisted by bending and shear. The compression flange of an I-beam acts like a column and will buckle sideways if the beam is not sufficiently stiff or the flange is not restrained laterally [3]. An unrestrained beam is susceptible to lateral torsional buckling. Lateral-torsional buckling (LTB) is a limit-state of structural usefulness where the deformation of a beam changes from predominantly in-plane deflection to a combination of lateral deflection and twisting while the load capacity remains first constant, before dropping off due to large deflections [4]. LTB occurs when the compression portion of a beam is no longer sufficient in strength, and instead, the beam is restrained by the tension portion of the beam which causes deflection or twisting to occur [5]. The lateral torsional behaviour of a steel beam is illustrated in Figure 1.



a) Original beam b) Laterally buckled beam

Fig. 1 Steel beam undergoing lateral-torsional buckling
(Source: Chan [6])

In the structural design of steel beams, reference to a standard/ code is essential. A standard or code serves as a reference document with relevant guidance. Today, many countries in the world have published their own codes of practice. These codes were produced through thorough research and past experiences of experts in respective fields. Some countries with no particular codes of practices adopt an established standard code as the national reference [6]. The most commonly used code of practice in Nigeria for steel design is BS 5950. Several non-European countries including South Africa, Saudi Arabia, Sri Lanka and Malaysia have based their national codes on the European standards. Eurocodes are recognized as the most advanced and completely integrated sets of structural codes which can be adjusted and modified for use in any region in the world. It is believed that Eurocode is more comprehensive and better developed compared to any other standard

[7]. In a nutshell, it is essential to study the design provisions of Eurocode 3 [8] and BS 5950 [9] in order to have an in-depth understanding of their differences.

RESEARCH OBJECTIVES

The aim of this study is to develop a computer program for the design of simply supported laterally unrestrained I-section steel beams based on the requirements of BS 5950 and Eurocode 3. The program will be developed using the C- sharp programming language. The results from the developed program will be validated using an established software- Staad-pro. The study will also review the differences in design provisions for the design of laterally unrestrained I-section steel beams based on Eurocode 3 and BS 5950. The design results of steel beams designed according to BS 5950 will be compared to Eurocode 3. The comparison will be made in terms of bending moment and shear due to design loads, beam sections and areas of the various sections obtained using the two codes.

RESEARCH METHODOLOGY

The overall process of the research and the computer program development, according to [10, 11], can be classified into the following stages

- Review of the design of laterally unrestrained beam according to the stipulations of BS 5950 and Eurocode 3
- Coding the BS 5950 and Eurocode 3 design provisions into computer algorithm using Csharp programming
- Development of the Graphical User Interface
- Testing the developed code and verification of results

The above procedure will be followed in this research. A review of the design stipulations by the relevant codes has already been carried out in the introduction section. The rest of the procedure as outlined above will now follow systematically

Design concepts of Eurocode 3 and BS 5950

EC3 is based on the limit state design which covers the ultimate limit state and serviceability state. Loadings are multiplied or divided with a given partial safety factor to ensure structures are designed with a certain degree of reliability. EC 3 complies with the principles and requirements for the safety and serviceability of structures. The basis of design and verification are given in EN 1990 [12] (Basis of structural design). Furthermore, there are two limit states concepts used in BS 5950 namely, the ultimate limit states and serviceability limit state. The partial safety factor is applied to loadings to increase the reliability of the structure.

An unrestrained beam section, according to BS 5950 and EC3, must be checked for bending resistance and lateral torsional buckling. The differences in the design provisions are outlined in Table 1.

Table 1 Beam design provisions

Eurocode 3[2005]		Elements	BS 5950[2000]	
		Partial Safety Factor for Action (Load)		
G_K = 1.35		Permanent Action (Load)	DL = 1.4	
Q_K = 1.50		Variable Action (Load)	LL = 1.6	
Flange Subject to Compression	Web Subject to Bending	Cross Section Classification	Flange Subject to Compression	Web Subject to Bending
9Ɛ	72Ɛ	*Class 1*	9Ɛ	80Ɛ
10Ɛ	83Ɛ	*Class 2*	10Ɛ	100Ɛ
14Ɛ	124Ɛ	*Class 3*	15Ɛ	120Ɛ
$\boldsymbol{\varepsilon = (275/f_y)^{0.5}}$		Coefficient, Ɛ	$\varepsilon = (275/p_y)^{0.5}$	
$\boldsymbol{V_{pl,Rd} = A_v\,(f_y/\sqrt{3})\gamma_{mo}}$		Shear capacity check	$P_v = 0.6 p_y A_v$	
			$A_v =$ tD	
$\boldsymbol{M_{pl,Rd} = W_{pl,Rd}\, f_y\,/\gamma_{mo}}$		Moment capacity check	$M_c = p_y$S	
$\boldsymbol{M_{b,Rd} = \chi_{LT}\, W_y\, f_y\,/\gamma_{m1}}$		Buckling resistance check	$M_b = \mathrm{p}_b S_x$	

where, P_v is the shear capacity of a member. p_y is the design strength of steel. A_v is the effective shear area. D is the depth of section. t is the thickness of web. S is the plastic modulus. M_c is the plastic moment

Coding the beam design provisions

The C# programming language was used as the language to convert the EC3 and BS 5950 design provisions for unrestrained steel beam into an algorithm. Figure 2 shows the interface for the coding of the design provisions into an algorithm.

Development of graphical user interface (GUI)

A combination of programming in C# and Microsoft Visual Studio is used here to allow an artistic application to be created. Microsoft C# was chosen for this project mainly because of its advantage of presenting a visually appealing and interactive graphical user interface as well as a robust language to create code that correctly executes the desired tasks when adequately programmed. The graphical interface was created using a windows application called Windows Presentation Foundation (WPF) in visual studio.Net (Figure 3). The flowchart for the development of the program using C# programming language is illustrated in Figure 4.

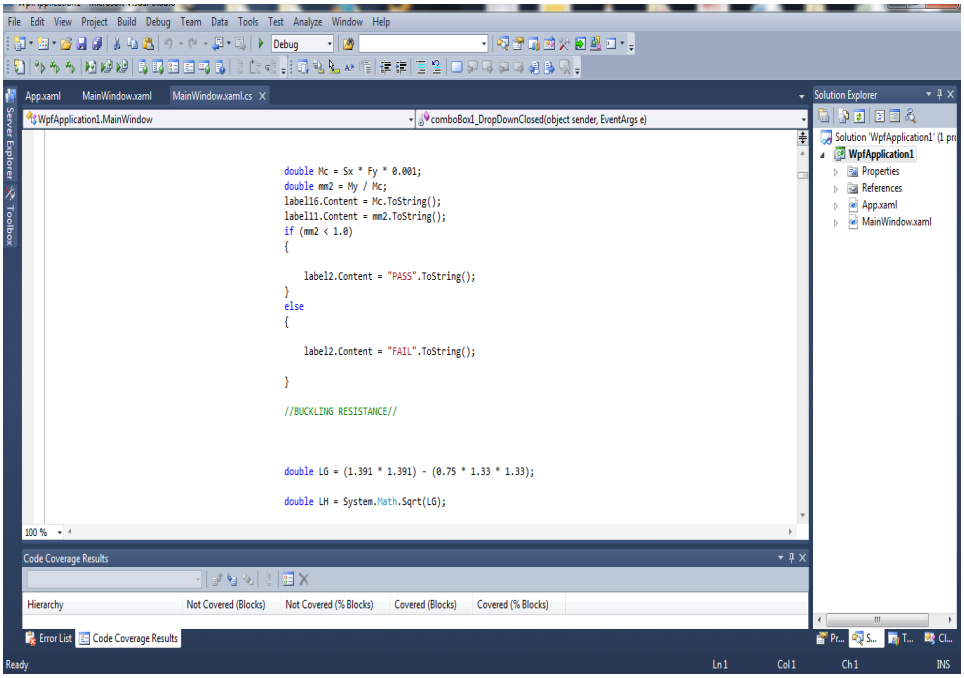


Fig. 2 Csharp coding environment

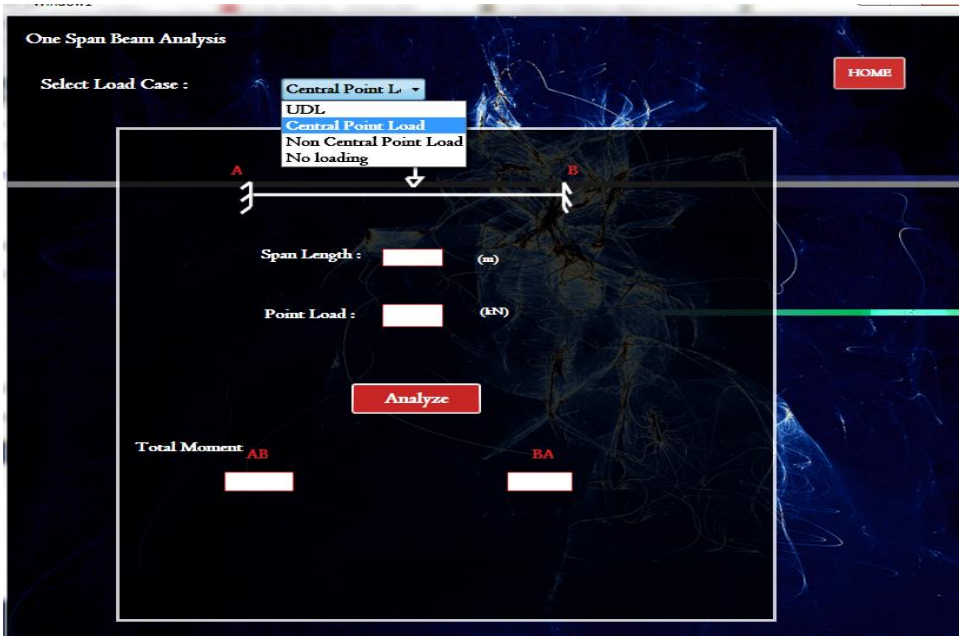


Fig. 3 Graphical User Interface of the program (analysis section)

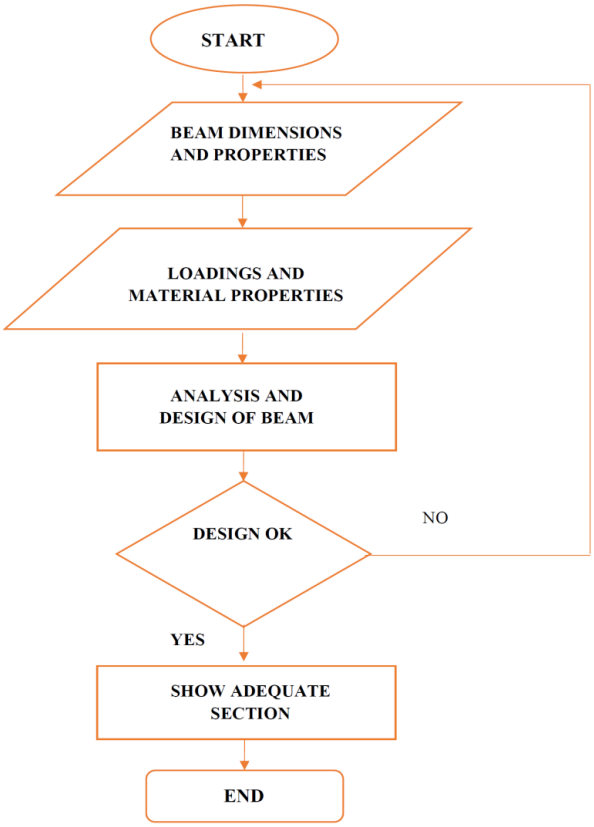


Fig. 4 Flowchart for the Development of the program using C# programming language

Testing the developed program and verification of results

A steel beam in Grade S275 was chosen for design. Several sets of simply supported laterally unrestrained beam models were designed using the developed algorithm for BS 5950 and EC3. Beam spans were varied from 2 m to 14 m at step size of 2 m and at constant values of dead (permanent) and imposed (variable) loads, the design bending moments and shears were computed. This was done in order to show the difference in the values of the bending moment and shear obtained using BS 5950 and EC3 for both the Staad.Pro software and the developed C-sharp program. The dead and imposed loads on the beams are shown in Table 2. On the basis of the bending moments and shears obtained, design was carried out according to both codes using each of Staad.Pro and the developed C-sharp program and adequate beam sections were selected. The design carried out using the Staad Pro software application was used to validate the design results obtained using the developed program.

Table 2 Beam loadings

Load Contributor	Dead Load	Live Load
Load (kN/m)	45	55

Other relevant information includes the following: Young Modulus, E = 210 GPa. Steel Grade, P_y = S275 N/mm^2

RESULTS AND DISCUSSION

Several sets of beam geometries were set to compare the design results of the beams designed according to BS 5950 and EC 3.

Beam design bending moment and shear

The design moment and shear of the beams at varying span length were compared and tabulated as shown in Tables 2 and 3 respectively. The tables reveal that an increase in span length for the test cases translates to an increase in the bending moment and shear. A similar trend was observed in the developed program and Staad Pro. Generally, from Table 4, the calculation based on EC3 had reduced member design shear compared to BS 5950. This can be attributed to the different shear design formulations specified by both codes.

Table 3 Comparison of Beam design bending moment at varying span length

Beam No.	Span Length (m)	Developed Program		Staad-Pro	
		BS 5950 (kNm)	EC 3 (kNm)	BS 5950 (kNm)	EC 3 (kNm)
I2A	2	132	97	131.81	97.08
I4B	4	246	181	243.50	181.23
I6C	6	333	246	332.23	246.4
I8D	8	431	353	431.22	353.93
I10E	10	533	404	533.75	404.53
I12F	12	591	479	591.56	479.92
I14G	14	869	764	869.53	764.90

Table 4 Comparison of beam design shear at varying span length

Beam No.	Developed Program		Staad-Pro	
	BS 5950 (kN)	EC 3 (kN)	BS 5950 (kN)	EC 3 (kN)
I2A	266	246	262.41	245.12
I4B	434	421	435.50	425
I6C	546	477	540.30	479.34
I8D	679	651	671.74	655.41
I10E	774	676	778.44	677.42
I12F	847	797	845.53	798.22
I14G	1072	942	1068.22	943.12

Beam Cross-sectional area

The optimum sections identified for each beam and the cross-sectional area of beams at varying span length are the same using Staad- Pro and the developed program. The optimum design sections obtained, and the area of sections are presented in Table 5 and 5 respectively. The percentage difference between the results was calculated as Equation 1, and the results are shown in Table 6.

$$\%\, difference = \frac{|Result\ for\ BS\ 5950 - Result\ for\ EC\ 3|}{Result\ for\ BS\ 5950} \times 100\ \% \qquad (1)$$

Tables 5 indicate that the comparison of BS 5950 design results and EC 3 design results gave an average difference of 21.5 % for the area of sections obtained. This shows that beams designed using the requirements of EC 3 are economical. Close examination of Table 5 reveals that the area of the beam section (and by extension, the weight of the beam also) increases as the span length increases. This shows that the longer the span, the greater the weight of the beams.

Table 5 Comparison of beam design section sizes at varying span lengths using the developed program and Staad Pro.

Beam No.	Span length (m)	Developed program		Staad Pro	
		BS 5950 (Section)	EC3 (Section)	BS 5950 (Section)	EC3 (Section)
I2A	2	254 × 146 × 37	254 × 102 × 28	254 × 146 × 37	254 × 102 × 28
I4B	4	356 × 171 × 51	356 × 127 × 39	356 × 171 × 51	356 × 127 × 39
I6C	6	356 × 171 × 67	356 × 171 × 51	356 × 171 × 67	356 × 171 × 51
I8D	8	457 × 191 × 74	457 × 152 × 60	457 × 191 × 74	457 × 152 × 60
I10E	10	457 × 191 × 89	457 × 191 × 67	457 × 191 × 89	457 × 191 × 67
I12F	12	457 × 191 × 98	457 x 191 × 82	457 × 191 × 98	457 × 191 × 82
I14G	14	610 x 229 × 113	533 x 210 × 92	610 x 229 × 113	533 × 210 × 92

Table 6 Comparison of the area of sections for the beams at varying span length using the developed program and Staad Pro

Beam No.	Span Length (m)	Developed program			Staad Pro		
		BS 5950 (m^2)	EC 3 (m^2)	% Difference	BS 5950 (m^2)	EC 3 (m^2)	% Difference
I2A	2	47.2	36.1	23.5	47.2	36.1	23.5
I4B	4	64.9	49.8	23.3	64.9	49.8	23.3
I6C	6	85.5	64.9	24.1	85.5	64.9	24.1
I8D	8	94.6	76.2	19.5	94.6	76.2	19.5
I10E	10	114	85.6	24.9	114	85.6	24.9
I12F	12	125	104	16.8	125	104	16.8
I14G	14	144	117	18.8	144	117	18.8
			Average	21.5%		Average	21.5%

Beam buckling capacity

The buckling capacity of a specific beam Test Section (Beam designation I2A) with design section 254 × 146 × 37 (Table 5) and constant beam loadings (Table 2) was evaluated at varying laterally unrestrained span lengths. The obtained buckling capacities are presented in Table 7. The elastic critical moment for lateral-torsional buckling is calculated according to EC 3 [8] and BS 5950 [9] procedures. From the table, it was observed that the buckling capacity decreases considerably for both BS 5950 and EC 3 as the length of the span increases. A similar result was obtained using the developed program and Staad-Pro. It is logical to conclude that the longer the unrestrained length of the beam, the more it is susceptible to lateral torsional buckling. From Table 7, the lateral torsional buckling moment resistance values are smaller for EC3 than those of the BS 5950. In other words, using EC3 is more economical than BS 5950. One of the reasons why these results are different for both code of practice is because of the lower value of partial factor for both the imposed and the dead loads for EC3 compared to the BS 5950.

Table 7 Comparison of buckling capacity beam I2A at varying span length

Design Section	Span Length (m)	BS 5950 (kNm)	EC 3 (kNm)
254 × 146 × 37	2	104.6	102.3
254 × 146 × 37	4	66.96	62.9
254 × 146 × 37	6	47.37	46.3
254 × 146 × 37	8	36.65	32
254 × 146 × 37	10	29.99	28

CONCLUSION

A simple task-specific computer program for the design of I-section steel beams susceptible to lateral torsional buckling using the requirements of Eurocode 3 and BS 5950 has been developed. The program was developed using the Microsoft C-sharp programming language. The design results obtained using the developed program were similar to the results obtained using the established standard software Staad-Pro. Besides, this research has established the similarities and differences in the design provisions of Eurocode 3 and BS 5950. For a specific beam section with constant loadings, as the span length increases the buckling capacity reduces, thus the longer the beam, the more it is susceptible to lateral torsional buckling. The comparison of BS 5950 design results and EC 3 design results gave an average difference of 21.5 % for the area of sections obtained in favour of EC3 procedure. For instance, for a 10 m long beam, with grade S275, designed using BS 5950 requirements, the area of section obtained is 144 m^2 whereas an area of section of 85.6 m^2 was obtained for the same beam designed using the requirements of EC 3. This shows that the beam designed using the requirements of EC 3 is more economical. There is a slight difference in terms of the design process between EC3 and BS 5950.

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RAZVOJ KOMPJUTERSKOG PROGRAMA ZA PROJEKTOVANJE ČELIČNIH NOSAČA SLOBODNIH NA OBA KRAJA

Ovi istraživanje predstavlja rezultate korišćenja kompjuterskog programa koji se zasniva na C-sharp softveru, razvijenom u cilju projektovanja čeličnih nosača I profila slobodno oslonjenih na oba kraja. Program je razvijen na osnovu onoga što propisuju BS 5950 i Eurocode 3 (EC3) standardi projektovanja.Korišćenjem razvijenog programa, projektovano je nekoliko grupa modela čeličnih nosača sa istim dimenzijama poprečnog preseka ali sa različitim rasponima, slobodno oslonjenih na oba kraja. Rezultati su provereni korišćenjem postojećeg programa, Staad Pro. Došlo se do saznanja da su dobijeni rezultati projektovanja slični onima koji su dobijeni korišćenjem Staad Pro softvera. Kod specificiranih preseka nosača pri konstantnim opterećenjima, povećanje raspona slobodno oslonjenih greda na oba kraja smanjuje čvrstoću na savijanje, tako da što je duži nosač, to je osetljiviji na bočno torziono izvijanje. Poređenje rezultata dobijenih korišćenjem BS 5950 sa onima dobijenih korišćenjem EC 3 različitih dužina raspona nosača slobodnih na oba kraja otkriva da su vrednosti dobijene korišćenjem BS 5950 u proseku 21.5%, više od onih dobijenih korišćenjem EC3. Stoga su nosači sa bočno neukleštenim pritisnutim flanšama projektovani u skladu sa zahtevima EC 3 ekonomičniji. Razlika u rezultatima dolazi od razlika u principima projektovanja i merama korišćenjim u ova dva standarda.

Ključne reči: *grede slobodno oslonjene na oba kraja, Eurokod 3, BS 950, C-Sharp, bočno torziono savijanje*

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CURING: THE EASIEST AND CHEAPEST METHOD TO INCREASE THE DURABILITY AND STRENGTH OF CONCRETE

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Badrinarayan Rath, Shirish Deo, Gangadhar Ramtekkar

National Institute of Technology, Raipur, India

Abstract. *Curing is a process which follows immediately after placing and finishing of concrete. It maintains a satisfactory moisture content and temperature in concrete for a period of time so that the desired properties may develop. Curing has a strong influence on the properties of hardened concrete. With proper curing concrete becomes stronger, more impermeable, and more resistant to stress, abrasion, and freezing and thawing. Using of fiber in concrete may improve these properties but it increases the cost of concrete. This paper reports the results of a study conducted to assess the effect of ages of curing on durability and strength of fiber and non fiber reinforced concrete. Also a comparative study of cost per unit strength and cost per unit service life period is done in between fiber reinforced concrete and non fiber reinforced concrete with proper curing. The concrete cubes were prepared by varying three water cement ratios and by curing them for a different number of curing days. Bulk electrical resistivity test, ultrasonic pulse velocity test, compressive strength test, flexural strength test and carbonation depth test of the cured cubes were performed. From the test results it is found that proper curing of traditional concrete is more economical than fiber reinforced concrete in achieving the same strength and durability.*

Key Words: *Curing, Durability, Strength, Life Cycle Cost*.

1. INTRODUCTION

Curing of concrete maintains a satisfactory moisture content and temperature in concrete during its early stage for release of heat of hydration and continuation of hydration reaction. It plays a major role in developing a good micro structure of concrete by increasing its durability and strength. Various researchers have reported that initial wet curing time is important for concrete quality development. An initial curing of 7 days was found more beneficial for the strength development of light weight concrete [Haque (2007)]. However, the initial curing period should be extended to 14 days when cement is partially replaced with supplementary cementitious materials [Bonavetti V. et.al.(2000)]. This is due to the

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Corresponding author: Badrinarayan Rath
National Institute of Technology, G.E. Road, Raipur,Chhatisgarh - 492010, India
E-mail: badri.04@hotmail.com

slow hydration reactions between supplementary cementitious materials and the calcium hydroxide [Al-Gahtani(2010)]. When water is added to Portland cement a chemical reaction called hydration takes place. The completion of hydration process influences the strength and durability of the concrete [I.G. Richardson (1999), Mannan et.al. (2002), Tasdemir (2003), Oritz et.al. (2005), McCartera and Ben-Salehb(2001)]. Degree of hydration, as well as the age of curing, exposure to aggressive environment, etc., also affects the strength and pore system of concrete [Rakesh Kumar and B. Bhattacharjee (2003)]. Freshly mixed concrete normally contains more water than is required for hydration of the cement, but due to evaporation excessive loss of water can delay or prevent the entire hydration process. Some researchers investigated compressive strength development, sorptivity, carbonation depth and the chloride permeability of concrete cured both in air and in water [Bai et.al. (2002), Duran (2005), Guneyisi and Gesoglu (2009)]. It is found that water-cured samples have higher compressive strength and sorptivity, lower carbonation depth and the chloride permeability than samples cured in air. The objective of curing is to provide an appropriate environmental condition within a concrete structure (temperature and humidity) to ensure the progress of hydration reactions causing the filling and segmentation of capillary voids by hydrated compounds [Guneyisi et.al. (2007)]. An important role of curing is to control the rate and extent of moisture loss from concrete during the cement hydration. With proper curing, concrete becomes stronger, more impermeable, and more resistant to stress, abrasion, and freezing and thawing.

The exact assessment of life time of a concrete structure from a given concrete mixture is very difficult. Many standard codes suggest prescriptive specifications, assuming that they will result in an appropriate durability. In the new European Standard EN206+A1, different exposure classes are defined and among them XC exposure classes deal with carbonation. I.S. 456 (2000) also classified levels of severity during the working life of concrete in five different environmental exposure conditions. Minimum binder content and maximum water binder ratio are also specified.

2. RESEARCH SIGNIFICANCE

Proper curing of concrete affects severely the properties of hardened concrete such as strength, permeability, abrasion resistance, resistance to freezing-thawing, resistance to carbonation and corrosion. Curing can be shown to have a marked effect on the hydration of cements as well as on its resistivity. Nowadays local contractors do not have the awareness about importance of proper curing of structure, hence for completion of task before time and for earning a good sum by saving on curing. Even if concrete is made with proper specifications, due to the lack of proper curing concrete fails to achieve the required strength and durability. Many people tried to show the importance of curing with the help of compressive strength and flexural strength. Very few researches were carried to understand the importance of curing with non destructive testing. In present study bulk electrical resistivity and ultra pulse velocity were measured at 7 days, 28 days, 56 days and 119 days on concrete cubes and hydration rate of six types of fiber and non fiber reinforced concrete mixes is observed. Also compressive strength and carbonation depth are found for the above curing days. Life time period of each mix is determined from electrical resistivity and carbonation depth. A comparative study of fiber and non fiber reinforced concrete was done for cost per unit strength and cost per unit time period (in years).

3. MATERIALS AND METHODS

3.1. Materials

Cement: Locally available ordinary Portland Cement (OPC) 43 Grade was used in the present investigation. This Cement confirms all the requirements of the IS 12269-1987.

Sand: Sand was collected from Mahanadi River Basin and used as fine aggregate. By sieve analysis sand was confirmed in zone-II of IS-383 (1970) with the fineness modulus 2.67.

Aggregate: Locally available crushed stone of maximum size 10 mm was used as a coarse aggregate. The fineness modulus of coarse aggregate was 5.9. The volume of coarse aggregate per unit volume of total aggregate was taken as 0.5 based on the lab trials providing maximum vibrated bulk density.

Fiber: Glass fibers with constant volume of fraction i.e. 0.1% of total volume were used in the present investigation. This particular volume of fraction was optimized with shrinkage and slump characteristics. Addition of fiber decreases shrinkage and slump and reduction of slump could increase the voids hence optimum value of fiber dose was decided within limits of shrinkage and workability. The dose of fiber is fixed as 0.1% by volume on the basis of test results of trial mix which is shown in Table-1 (a). The length of fiber was 12 mm and diameter was 14 μm.

Super Plasticizer: A high range water reducing admixture was used. It is based on selected water soluble sulphonated polymers, each of which acts optimally on the various constituents of Portland cement. The dose of the super plasticizer was 0.75% of weight of cementitious materials and it was kept constant for every mix to maintain minimum slump of 25 mm.

3.2. Mix Proportions

The mix design was prepared using three water cement ratios such as 0.35, 0.4 and 0.45 with glass fiber and without glass fiber as shown in Table-1(b). Two types of concrete were prepared named as controlled concrete i.e. non fiber reinforced concrete and fiber reinforced concrete. The volumetric ratio of fine aggregate to coarse aggregate was 1:1 for maintaining the maximum density of combined aggregate. Lower slump was obtained, due to using of 10 mm size aggregate with addition of 0.1% of glass fiber. Hence super plasticizer was added to get minimum slump of 25 mm. Weighed quantity of coarse and fine aggregates were mixed thoroughly for about 1 minute in 0.04 m^3 capacity mixer and cement was added to this dry mix until a uniform colour was obtained. Measured quantity of water was added along with admixture of 0.75% of cementitious materials.

Table-1(a) Trial Mix Results of Shrinkage and Slump Height for Different Doses of Fiber

Dose of	Shrinkage (μm)			Slump Height (mm)		
Fiber (%)	w/c=0.35	w/c=0.4	w/c=0.45	w/c=0.35	w/c=0.4	w/c=0.45
0.000	256.42	308.85	372.16	36	41	51
0.025	215.67	273.56	318.45	35	39	48
0.050	182.65	225.73	265.23	32	37	45
0.075	135.13	179.07	218.96	28	34	40
0.100	110.26	135.80	160.03	25	29	35
0.125	75.93	95.34	110.65	21	25	30
0.150	40.56	55.45	65.84	17	20	25

Table-1(b) Mix Proportions of Concrete Containing Different Water Cement Ratios

Mix	w/c	Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)	Fiber (kg/m^3)	Slump (mm)
Non Fiber Reinforced Concrete								
C1	0.35	450	917	959	157	3.40	0	36
C2	0.4	413	914	956	165	3.10	0	41
C3	0.45	367	934	977	165	2.75	0	51
Fiber Reinforced Concrete								
F1	0.35	450	917	959	157	3.37	2.65	25
F2	0.4	413	914	956	165	3.10	2.65	29
F3	0.45	367	934	977	165	2.75	2.65	35

3.3. Casting and Testing Procedure

Cubes of 100 mm X 100 mm X 100 mm size of each concrete mixture were cast in two series for determining the bulk electrical resistivity, ultrasonic pulse velocity, compressive strength and carbonation depth. In series-1, 72 cubes were cast for Ultrasonic Pulse Velocity (UPV), Electrical Resistivity (ER) and Compressive Strength Test and other 18 cubes were cast in Series-2 to determine carbonation depth. The specimens were de-molded after 24 hours and were cured in water for 7, 28, 56 and 119 days. After curing for the stipulated period, the 72 cubes of Series-1 were taken out from the tank and tested for bulk electrical resistivity test followed by ultrasonic pulse velocity test. The results are given in Figure-2 and Figure-3.

(a) Electrical Resistivity Meter (b) Ultrasonic Pulse Velocity Test (c) Carbonation Chamber

Fig.1 Different Equipments for Checking Durability of Concrete

Table 2 Carbonation Depth (mm) for Non Fiber and Fiber Reinforced Concrete of Different w/c

Mix	C1	C2	C3	F1	F2	F3
Carbonation Depth (mm)	1.0	2.5	5.0	0.75	2.0	4.0

After that the cubes were kept in compressive testing machine to determine corresponding compressive strength of 7, 28, 56 and 119 days curing. Other 18 cubes of Series-2 were cured for 28 days in water and kept in the carbonation chamber for 28

days. The dose of carbon dioxide was kept at 5%, temperature 35^0C and 70% humidity. After the curing period the specimen was broken into two halves and 1% phenolphthalein solution was applied on the broken surface. After some time pink colour was seen in uncarbonated portion of concrete and no color change was observed in carbonated concrete. The carbonation depth was measured by using measuring scale and quoted in Table-2. In order to investigate the influence of curing on fiber and non fiber reinforced concrete flexural strength was tested on 72 beams of six different mixes. The beam specimens were cast in mould of size 100 mm X 100 mm X 500 mm according to prescription of IS 10086:1982. After casting they were allowed to harden at room temperature for 24 hours prior to demoulding and then cured in water for 28 days and 90 days before testing. After completion of required curing days, the beams were kept on flexural testing machine. The specimens were loaded to complete failure with a constant cross head speed and failure load is noted. Three specimens were tested at each testing age and their average flexural strength was calculated and tabulated as shown in Table-3.

Table 3 Flexural Strength (MPa) for Non Fiber and Fiber Reinforced Concrete of Different w/c

Mix		C1	C2	C3	F1	F2	F3
Flexural Strength	28 Days	3.15	2.55	2.0	4.45	3.60	2.75
(MPa)	90 Days	3.75	3.05	2.38	5.32	4.29	3.27

4. Result and Discussion

4.1. Electrical Resistivity Test

Bulk Electrical Resistivity test was conducted on 100 mm X 100mm X 100 mm cube at 7 days, 28 days, 56 days and 119 days. It is noticed that the electrical resistivity of each mix of fiber and non fiber reinforced concrete shows higher values for longer periods of curing. Electrical resistivity value of 28 days of curing is 40% more than 7 days of curing and it is near about double at 56 days of curing. At 119 days of curing ER value is 150% more than 7 days of curing and twice of 28 days of curing. Hence it is concluded that long age curing seals pores in concrete due to better hydration by forming a CSH gel and can be protected from chloride and carbon dioxide penetration. From Figure-2 it is seen that electrical resistivity values of 56 days plain concrete can be achieved at 28 days by adding 0.1% fiber. But addition of fiber increases the cost of concrete.

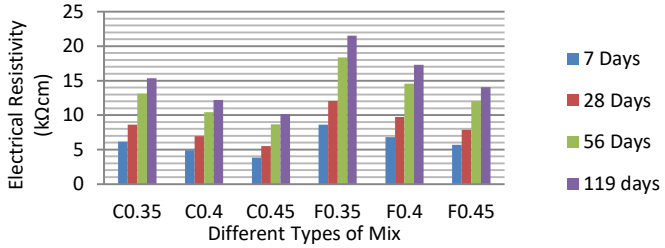

Fig. 2 Electrical Resistivity of Fiber and Non Fiber Reinforced Concrete for Different Curing Age

4.2. Ultrasonic Pulse Velocity Test

To assess the quality and homogeneity of cement concrete a UPV test was conducted for six different mixes as per guide lines of IS: 13311 (Part-1):1992. Since all the test results of UPV are more than or equal to 4.5 it is evident that all the test specimens fall under excellent category. The highest UPV value was shown on 119 days curing cubes and the lowest value on 7 days curing cubes. Hence it is concluded that a long term curing process will increase the UPV value of concrete. UPV values of fiber reinforced concrete is nearly about up to 3.0% higher than of non fiber reinforced concrete of the same water cement ratios.

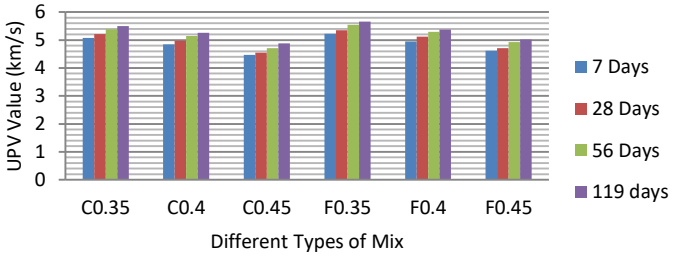

Fig. 3 UPV Values of Fiber and Non Fiber Reinforced Concrete for Different Curing Age

4.3. Carbonation Depth

The carbonation depths of different mixes at 28 days of water curing are shown in Table-4. The carbonation depth of fiber reinforced concrete is 20% - 25% higher than of non fiber reinforced concrete at same water cement ratio. Also the carbonation depth shows a low value at low water cement ratio, due to lower water voids. Carbonation depth of w/c= 0.35 is one fifth of the carbonation depth of w/c=0.45.

4.4. Compressive Strength Test

Compressive strength result of 7, 28, 56 and 119 days for six different mixes are plotted in Figure-4(a). It is seen that the compressive strength gradually increases as the curing period increases and water cement ratio decreases. The compressive strengths are 18%, 40% and 48% higher at corresponding curing of 28, 56 and 119 days than at 7 days curing. It is also noticed that compressive strength of F3 and C2 as well as F2 and C1 are neary about the same. Hence the compressive strength can be achieved at low water cement ratios by addition of fiber. Again the compressive strength of non fiber reinforced concrete at 28 days and 56 days curing shows nearer value with the compressive strength of fiber reinforced concrete at 7 days and 28 days of curing for all water cement ratios. Addition of fiber gives early strength to concrete but it increases the cost of construction. To achieve such strength by the curing process will be cheaper than by fiber reinforced concrete. Also it is seen that the UPV value increased in a parabolic way with increasing of compressive strength for any age of curing. A correlation between compressive strength vs UPV at 28 days of curing is shown in Figure-4(b).

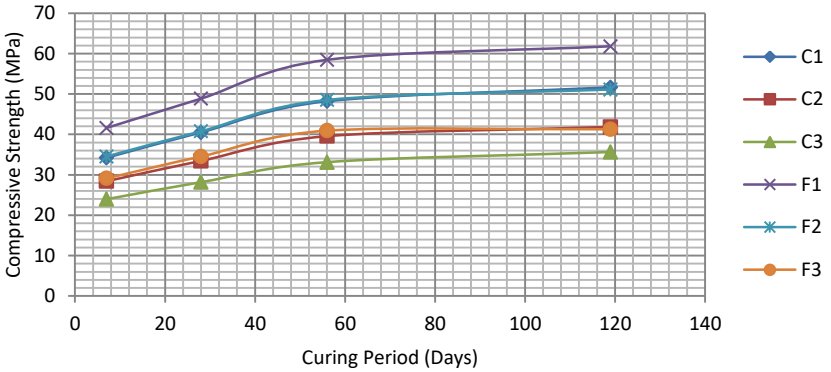

Fig. 4(a) Compressive Strength of Fiber and Non Fiber Reinforced Concrete for Different Curing Age

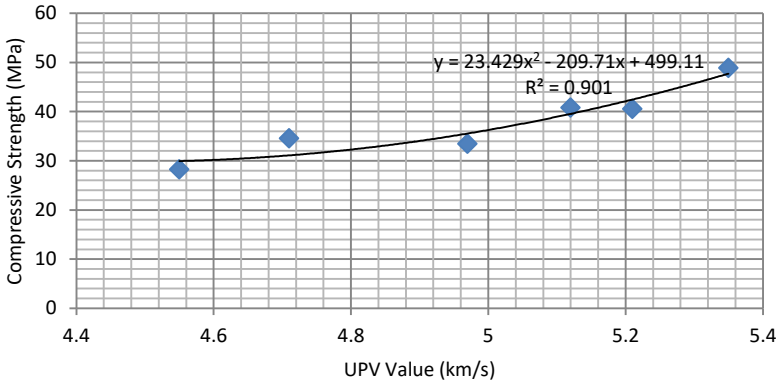

Fig. 4(b) Correlation between Compressive Strength and UPV value at 28 days of Curing Period

4.5. Flexural Strength Test

Test results of flexural strength for various curing days are tabulated in Table-5. It is seen that flexural strength of all mixes at 90 days of curing is about 20% more than flexural strength at 28 days of curing. When fiber is added the flexural strength increases about 40% w.r.t. of non fiber reinforced concrete with that corresponding water cement ratios. Flexural strength of non fiber reinforced concrete of 0.35 w/c at 28 days of curing (i.e. 3.15 MPa) is near about equal to flexural strength of fiber reinforced concrete of 0.45 w/c at 90 days of curing (i.e. 3.27 MPa). Hence it can be concluded that the flexural strength of non fiber reinforced concrete can be achieved to be equal to flexural strength of fiber reinforced concrete by prolonging water curing.

4.6. Dynamic Modulus of Elasticity

For designing the structure the designer requires not only compressive strength but also stiffness. The traditional method for computing the stiffness is by measuring

dynamic modulus of elasticity. Nilsen and Aitcin (1992) established an equation for dynamic modulus of elasticity from compressive strength and ultrasonic pulse velocity test result as follows.

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

Where: Ed – Dynamic Modulus of Elasticity in MPa
γ – Density of Concrete in kg/m^3
v – Ultrasonic Pulse Velocity Value
μ – Poissons Ratio.

Table 4 Dynamic Modulus of Elasticity of Concrete of Different Mixes at 28 Days Curing

Mix	γ (kg/m^3)	v (km/s)	μ	f_c (MPa)	E_d (GPa)
C1	2400	5.21	0.2	40.51	58.63
C2	2400	4.97	0.2	33.45	53.35
C3	2400	4.55	0.2	28.18	44.71
F1	2400	5.35	0.2	48.86	61.82
F2	2400	5.12	0.2	40.28	56.62
F3	2400	4.71	0.2	34.93	47.91

It is noticed that the value of modulus of elasticity is higher for fiber reinforced concrete with low water cement ratios. The dynamic modulus of elasticity of fiber reinforced concrete is 5%, 6% and 7% higher than non fiber reinforced concrete at water cement ratios 0.35, 0.4 and 0.45 respectively at 28 days of curing. The addition of fiber increases the strength however at a higher cost. Figure-5 indicates that prolonged curing of concrete has increased the dynamic modulus of elasticity of concrete. It also indicates that a value higher than 28 days dynamic young's modulus of elasticity of FRC could be achieved at 56 days of curing.

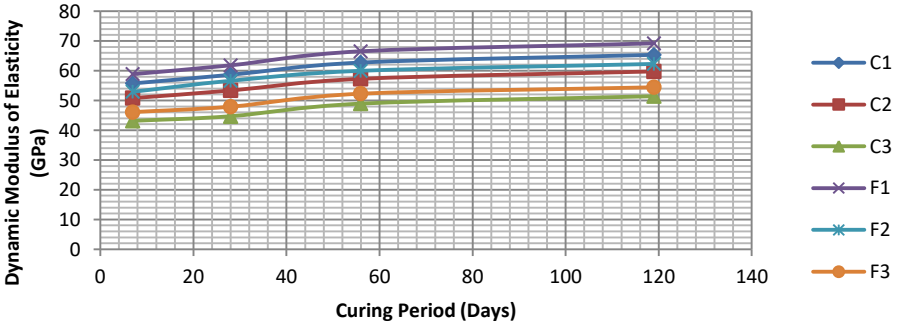

Fig. 5 Dynamic Modulus of Elasticity of Various Mixes of Concrete for Different Curing Age

4.7. Service Life Period

Carmen Andrade (2010), expressed following relation between electrical resistivity (ρ) and service life period (t) with cover depth (X) of structural member.

$$X = \sqrt{\frac{K}{\rho_0 \left(\frac{t_e}{t_0}\right)^q r}} \sqrt{t}$$

By using the above formula the service life period of six different mixes are determined. It is assumed that the type of exposer class is X_{c3} i.e. concrete surfaces subjected to water contact and environmental condition is cyclic wet and dry. According to EN206 coefficient of carbon dioxide permeability is 3000 Ωcm^3/year for cyclic wet and dry. But in carbonation chamber exposer condition is higher than environmental condition. Hence K value is considered as 5000 Ωcm^3/year. According to Bhargava and Banthia (2007), coefficient of permeability (K) for 0.1% volume of fraction of fiber reinforced concrete is approximately 0.57 times of plain concrete. Hence the value of K is taken as 2850 Ωcm^3/year for fiber reinforced concrete. Generally the clear cover of structural member is taken as 25 mm. Here the term X is taken as uncarbonated cover depth i.e. 25 mm - carbonation depth of concrete and tabulated in Table-7 for various mixes.

In this experiment following parametric values are taken for above formula

X = Un Carbonated Cover Depth

K = Coefficient of CarbonDioxide permeability

= 5000 $\Omega cm^3/Year$ (non fiber reinforced concrete)

= 2850 $\Omega cm^3/Year$ (fiber reinforced concrete)

ρ_0 = Electrical resistivity at 28 days

t_e = 10 years

t_0 = 28 Days = 0.0767 Years

q = Aging factor during 10 years = 0.3

r = Cement binding factor = 1.8

t = Life Time or Service Life Period

Table 5 Service Life Period of Various Mixes.

Mix	K(Ωcm^3/year)	ρ (kΩ cm)	r	CD (mm)	X (cm)	t (years)
C1	5000	8.61	1.8	1.0	2.9	112.37
C2	5000	6.94	1.8	2.5	2.75	81.44
C3	5000	5.51	1.8	5.0	2.5	53.44
F1	2850	12.05	1.8	0.75	2.92	280.69
F2	2850	9.73	1.8	2.0	2.8	207.69
F3	2850	7.89	1.8	4.0	2.6	145.21

4.8. Cost Benefit Analysis

To analyze the effect of curing on the cost of concrete, cost per unit strength of different curing periods is shown in Figure-6. It can be observed that the production cost of concrete for achieving compressive strength of 1 N/mm^2 shows a lower value for long age curing. From Figure-6 it is seen that the rate of decreasing cost is very high up to 56 days of curing. Beyond this cost per unit strength gradually increases. The cost per unit strength of concrete at 119 days of curing is slightly higher than at 56 days of curing. It happens because of cost of curing increases more as compared to increasing of compressive strength at higher age of curing period. Hence curing of structure for 56 days is recommended to local contractors. Also the best performance among the mixes on the basis of strength and durability at minimum cost, cost per unit strength and cost per unit service period at 119 days curing is tabulated in Table-8 (a) and 8 (b).

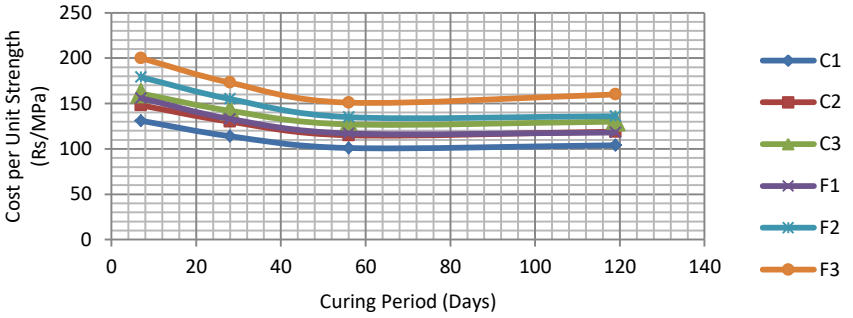

Fig. 6 Cost per Unit Compressive Strength (Rs/MPa) for Different Curing Periods

It is seen that the values of C_A, C_B, and C_C are lower for control concrete (non fiber reinforced concrete) than for fiber reinforced concrete. The cost of glass fiber reinforced concrete is more as compared to non fiber reinforced concrete for gaining of unit strength. Hence water curing is the cheapest method to gain the required strength rather than using additive such as glass fiber. On the other hand cost of C_D is lower for fiber reinforced concrete i.e. the durability cost of fiber reinforced concrete is lower than of non fiber reinforced concrete to survive one year. That means durability cost will go down by using glass fiber as an additive.

Table 6(a) Cost of Different Mix per Unit Strength and Unit Service Life Period

Mix	Cement (Kg/m^3)	Sand (Kg/m^3)	Aggre-gate (Kg/m^3)	Water (Kg/m^3)	Admix-ture (Kg/m^3)	Fiber (Kg/m^3)	Cost (Rs)	C_A (Rs/MPa)	C_B (Rs/MPa)	C_C (Rs/ GPa)	C_D (Rs/ Year)
C1	450	917	959	157	3.4	0	4642.35	114.59	1473.76	79.18	41.31
C2	413	914	956	165	3.1	0	4342.50	129.82	1702.94	81.39	53.32
C3	367	934	977	165	2.75	0	3998.50	141.89	1999.25	89.43	74.82
F1	450	917	959	157	3.4	2.65	6629.85	132.61	1489.85	107.24	23.61
F2	413	914	956	165	3.1	2.65	6330.00	155.22	1758.33	111.79	30.47
F3	367	934	977	165	2.75	2.65	5986.00	173.35	2176.72	124.94	41.22

Table 6(b) Cost of Different Ingredients used in Concrete

Particulars	Cement	Sand	Aggregate	Admixture	Fiber
Rate (Rs/Kg)	6	0.45	0.55	225	750

Note: Rate of water is taken as Rs 240/- (Lump sum Amount) for 28 days curing
C_A: Cost per Unit Compressive Strength (Rs/Mpa) at 28 days curing
C_B: Cost per Unit Flexural Strength (Rs/MPa) at 28 days curing
C_C: Cost per Unit Dynamic Modulus of Elasticity (Rs/ GPa) at 28 days curing
C_D: Cost per Unit service Life Period (Rs/ Year) 28 days curing.

5. CONCLUSION

From the results of the present study the following conclusions can be drawn

1. Compressive strength, flexural strength, electrical resistivity, ultrasonic pulse velocity and modulus of elasticity of concrete are higher at 119 curing days under standard conditions.
2. At 119 days curing electrical resistivity value becomes twice and compressive strength is 1.25 times of 28 days of curing. There is a little change in UPV value from 28 days of curing to 119 days of curing.
3. The rate of change of test results of electrical resistivity, compressive strength and flexural strength is high up to 56 days curing. Hence it is recommended to cure concrete structure at least 56 days continuously by local builders and contractors. Sometimes it is not acceptable to wait 56 days to gain specified concrete strength. However at 28 days curing concrete gains around 80% strength. It is recommended that concrete should be cured for at least 28 days.
4. The time of construction also influences the total cost of construction especially in construction of high rise buildings, bridges and similar structures. Hence 56 days of curing is not always possible, this can only be option in some cases.
5. Addition of 0.1% glass fiber increases the test results of compressive strength, flexural strength, electrical resistivity, ultrasonic pulse velocity and modulus of elasticity by 20%, 42%, 40%, 2% and 5.5% than non fiber reinforced concrete. Also service life period of fiber reinforced concrete is 2.5 times longer than of the non fiber reinforced concrete. But addition of fiber increases the cost of concrete by 30% than non fiber reinforced concrete.
6. The durability of fiber reinforced concrete is higher than non fiber reinforced concrete and does not requir any reaping for a long time. Sometimes repair and maintenance works become essential for a structure.
7. Cost per unit strength of non fiber reinforced concrete is lower than the fiber reinforced concrete at same curing period. Hence it can be concluded that curing is the cheapest method for gaining the strength of concrete.
8. Test results of electrical resistivity and ultra sonic pulse velocity of non fiber reinforced concrete at 28 days curing is near about to equal to 7 days curing of glass fiber reinforced concrete. Addition of fiber in concrete is a laborious process for construction sites without advanced mixtures to avoid fiber balling, achieving homogeneity and making them workable. Hence curing is the easiest method to achieve similar strength and durability of fiber reinforced concrete.

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NEGA BETONA: NAJLAKŠI I EKONOMSKI NAJPOVOLJNIJI METOD POVEĆANJA TRAJNOSTI I ČVRSTOĆE BETONA

Nega betona je process koji sledi neposredno nakon ugradnje i finiširanja betona. Cilj nege je da održi zadovoljavajući sadržaj vlage i temeraturu betona u određenom periodu, tako da može doći do razvoja željenih svojstava. Nega ima velik uticaj na osobine očvrslog betona. Uz odgovarajuću negu, beton postaje jači, neproposniji i otporniji na napone, habanje, smrzavanje i odmrzavanje topljenje. Korišćenje vlakana u betonu može da popravi ove osobine, ali to povećava cenu betona. Ovaj rad saopštava rezultate studije koja je provedena da bi se ocenio uticaj starosti nege na trajnost i čvrstoću betona ojačanog vlaknima i onih bez vlakana. Takođe, data je uporedna analiza koštanja po jedinici čvrstoće i po jedinici perioda eksploatacije betona ojačanih vlaknima, i betona bez vlakana ali sa odgovarajućom negom. Betonske kocke su bile pripremane tako što su varirana tri vodocementna faktora, i tako što su negovane različit broj dana. Sprovedena su ispitivanja električnog otpora, brzine prolaza ultrazvučnog pulsa, čvrstoće na savijanje i dubine karbonacije negovanih kocki. Rezultati testa su pokazali da je propisna nega tradicionalnog betona ekonomičnija od betona ojačanog vlaknima, kada je u pitanju dostizanje istih čvrstoća i trajnosti.

Key Words: *nega, trajnost, čvrstoća, troškovi eksploatacije.*

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OPPORTUNITIES FOR DEVELOPMENT OF TOURIST POTENTIALS IN PROTECTED AREAS OF THE WATER STORAGE RESERVOIRS, ON THE EXAMPLE OF SPATIAL PLANS OF THE SPECIAL PURPOSE AREAS IN SERBIA

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Nataša Danilović Hristić, Nebojša Stefanović, Jasna Petrić

Institute of Architecture and Urban & Spatial Planning of Serbia (IAUS), Belgrade, Serbia

Abstract. *Areas of large and medium-sized water storage reservoirs whose hydro-potential is used for water supply of settlements and/or as part of the energy system, at the same time, and under certain conditions and limitations, can represent the locations for the development of tourism. This potentially conflicting situation may be resolved through the planning process and development of Spatial Plans of the Special Purpose Areas (SPSPAs). A major challenge with water storage reservoirs of multiple purposes is in "sharing" water amongst competing users with an aim of providing sustainable development of a wider territory and, simultaneously, to safeguard the health safety of the water at the source (water storage reservoir).This paper deals with planning treatment - by a new generation of SPSPAs in Serbia - of the areas that cover new and already formed water storage reservoirs and with prudent activation of their tourist potentials.*

Key words: *water storage reservoir, tourism, spatial plan, protection*

1. INTRODUCTION

1.1. Sustainable spatial development

Guiding principles of sustainable development are founded on regionally balanced development goals: promotion of territorial and social cohesion through steady social and economic development and competitiveness; improvements in traffic communication and accessibility; development of various urban functions, access to information and knowledge; mitigation of the negative environmental impacts; protection of natural resources and cultural heritage, energy resource base development; incentives to sustainable tourism

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Corresponding author: Nataša Danilović Hristić
Institute of Architecture and Urban & Spatial Planning of Serbia, Kralja Aleksandra Blvd. 73/II, 11000 Belgrade, Serbia
E-mail: natasadh@iaus.ac.rs

development, and limitation of the natural hazard's impact. Globally, a scarcity of freshwater represents a pressing issue ever since the disturbing figures on groundwater depletion throughout the world (1) were revealed. Reliability of water delivery is the key reason for water storage reservoirs becoming such an important element in a water supply system. They were built more than 4,000 years ago and it should be stressed that decline of any civilization in the past began with neglecting and ruining of these systems (2). Water storage reservoirs, which are dominantly multipurpose ones, can advance sustainable development objectives if they are carefully planned, constructed, put in operation, managed and governed. This implies fostering equity across water storage reservoir users and ecosystems in line with agreed sustainability objectives (3). From the aspect of touristic facilities development in the areas of water storage reservoirs, since the functions and expressed needs overlap territorially, sustainable development principles presume the protection and rational use of natural resources with respect to constraints deriving from planning of the infrastructure facilities that meet the population requirements, alongside simultaneous promotion of the high-quality varieties of tourism (4), and with respect to the analysis of potentials for development of recreation and weekend zones to meet the urban population needs without compromising implementation of natural and cultural heritage protection and promotion. Key prerequisites for this are fundamental knowledge on ecosystems and number of visitors which can be sustained by a certain territory, as well as the implementation of control instruments such as Strategic Environmental Assessment.

1.2. Spatial Plans of the Special Purpose Areas

The current Law on Planning and Construction (5) defines on which territories of interest determined by the Spatial Plan of the Republic of Serbia (6), and topics of relevance it is necessary to develop a Spatial Plan of the Special Purpose Area (hereinafter: SPSPA): an area with natural, cultural, historical or ambient values; an area with the possibility of exploiting mineral resources; an area with the capacity for using tourism potentials; an area with the possibility of using hydro-potential; realisation of projects for which the Government of the Republic of Serbia determines significance; and construction of facilities for which a building permit is issued by a Ministry in charge of construction or by a competent authority of the autonomous province. The overlapping and matching of the needs of protection and exploitation, i.e. of more intensive use in any form, is the essence of making these plans. The protection of their potential is defined by a certain regime, which determines any other type of use. SPSPAs have a dual role – contextually they make a strategic development framework and provide protection of the space, of its characteristics and special values, and by introducing the elements of detailed elaboration, i.e. rules of use, arrangement and construction, in the models of implementation, they enable realization of structures and systems (7, 8). It is not a rare case that the protected areas are indeed the zone of interest for possible expansion of tourist regions and complexes, therefore they represent the brand and target for development, and require planning of accommodation capacities, accompanying infrastructure and road network. Estimate on how and to what extent the protected areas will be developed, e.g. what the limit is, according to what structure and dynamics, or phases of development, all that is crucial for synchronisation with constraints of prescribed regimes of protection. For this reason, it is compulsory to develop a Strategic Environmental Assessment (SEA) of the planned environmental solutions (9), which should indicate the capacity of the space in terms of changes which are introduced by the SPSPA.

Indeed, there is a continuing dilemma whether protection or development should take a lead in this process; what is the price of regulation and improvements; and therefore a compromise solution is needed, while the sustainability of the system, in all of its forms, is an indispensable factor for each SPSPA, especially if within the scope of the SPSPA there are multiple attractive and significant aspects.. In such cases, as a rule of thumb, the inclination is towards reduction of conflicts and balance between the modern demands of life and economic efficiency on the one hand and the quality of the environment on the other. In these SPSPAs, there is evidently a symbiosis of spatial and urban planning, including even the details from the project documentation, which is certainly a positive fact and contributes in a way that, alongside guidelines for further elaboration, SPSPAs contain already prepared elements for direct implementation (10).

2. PLANNING THE AREA OF WATER STORAGE RESERVOIRS

2.1. Methods, sample and choice of a case-study area

In the current practice of spatial planning in the Republic of Serbia, the development of SPSPAs for the areas of water storage reservoirs is distinguished as a special group of plans by the importance and number of plans (around ten adopted SPSPAs). The purpose is related to the use of water as the most important potential and irreplaceable resource (hydro potential) in the zones of large and medium water storage reservoirs. Knowing that the functions of water storage reservoirs are typically to provide water for one or more purposes, such as water supply, flood and drought management, irrigation, electricity generation, environmental services, fisheries and recreational activities (amenity use), the development of SPSPAs has the following aims: for the purpose of water supply (source of potable water) for the settlements (including a dam, water catchment with a sanitary catchment area, water treatment plant and a distribution system; and as part of the water management and energy system, for the needs of electricity generation (dam, pumped storage type and in-stream hydroelectric power plants with a distribution system).

As the examples for the analysis of applied rules of arrangement, construction and use of space, preferably with two functions at least, the following spatial plans have been chosen: SPSPA of water supply source within the regional sub-system Rzav (11), SPSPA of the catchment of the water storage reservoir „Stuborovni" (12), SPSPA of the catchment of the water storage reservoir „Ćelije" (13), and SPSPA of the catchment of the water storage reservoir „Grlište" (14). SPSPAs contain a set of rules and measures that define the arrangement of space and construction, but the degree of detail varies depending on the period when SPSPAs were made. Plans of the "latest generation" have a number of defined rules, criteria and standards, while older plans provide orienting guidelines for the planned locations and corridor routes. Another factor influencing the level of detail is the availability of supporting technical documentation that is incorporated into the planning solution.

2.2. Impact of the special purpose on the scope and content of the SPSPA

SPSPAs for water storage reservoirs are specific in a way that they involve the redefinition of the existing land use and potential resettlement, but also they presume a quite limited but still certain possibility of introducing some new uses and functions, such as, the definition of tourist zones and recreational space for a part of the coast and aquatic

surface. A special purpose of these plans is represented in two main aspects: their technical nature relating to the system and facilities in the function of electricity production or water supply, and protection of the area of the water source, i.e. sanitary protection of the catchment in case the basic function of the water storage reservoir is water supply. More complex are the SPSPAs in which exist the aspect of water source protection, and where as an additional or accompanying purpose there can be elaborated the tourism development, choice of its type, locations and capacities. Also, the aspect of protection may include the protection of natural areas (15) and cultural goods (16) located within the scope of the planned catchment. The development of this type of SPSPAs is determined as well by the Law on Water (17), the Rulebook on the way of determining and maintaining the sanitary protection zones of water supply sources (18) and Water Master Plan of the Republic of Serbia (19). The Law on Water defines aquatic land for the public use, i.e. as public good, applying to all surfaces that are permanently or occasionally covered by water and where special hydrological, geomorphological and biological relations are formed, and it distinguishes aquatic land of running water (which consists of the river basin in case of high water and of coastal land) and aquatic land of stagnant water (consisting of basin and of belt of land by the basin up to the highest recorded water level). Coastal land is in function of the aquatic one and is primarily used for protection and maintaining of the accompanying facilities and for water management in general. Defining an integral water supply system in the entire territory of the Republic, results in the regional organization of the water systems and subsystems. This concept has an impact on determining the boundary of an SPSPA, which is more in line with the geographical and hydrological characteristics of the basin and terrain than with the administrative division of municipalities and regions. The area in the scope of an SPSPA encompasses the water storage reservoir's catchment area, which represents the water source and the wider zone of protection of the water source, hence in the practice, the boundaries of an SPSPA are determined by the cadastre municipalities' boundaries or by morphological boundaries of the catchment. The area by the dam where the facilities of the water source system are planned is also included in the scope of an SPSPA.

2.3. Typical characteristics of the analysed SPSPAs

SPSPAs for "Rzav" and for "Stuborovni" were developed for the planned water storage reservoirs, while the SPSPAs for "Ćelije" and for "Grlište" were developed for the existing water storage reservoirs. A striking example is the SPSPA for "Rzav" in which the concept of water use and the regulation of the water regime is considered within two regional systems of water supply, with their subsystems, which are in a planned and functional interaction because they are the only "export" systems of water of macro regional scale, thus conditioning realisation of a long-term development of the region. In addition, these systems have considerably greater potentials for regulating the flow of all other catchment areas in Serbia, first by allowing for annual regulation of flows and then, in the later phases, for several years regulation of flows.

Key themes in this type of SPSPAs are the protection of the water catchment basin and ensuring the required level of quality of water for the systematic water supply of settlements (according to the projected gross consumption norm expressed in L/user per day, with an estimated net loss within the network reaching at maximum 15 ÷ 18% and with approximation which is aligned with the periods of necessary reductions). This purpose also includes flood

protection measures in the vicinity of the water storage reservoir, in particular mitigation of possible flood waves in the downstream part, then protection of soil from erosion, as well as protection from wastewaters, i.e. providing conditions for plants for water treatment if the regime of protection in the zone of water source allows this, and it prescribes special conditions in the surroundings, e.g. for agricultural land. Within the analysed SPSPAs, one can distinguish the following key principles of planned development of these areas: protection and improvement of water quality in the water storage reservoir, sustainable use and protection of water, agricultural and forest land and relativisation of conflicts between the use of water source and sustainable development of communities. The main goals which can be identified are:

- sustainable use of water resources, provision of permanent and integrated protection and improvement of water quality of water supply sources,
- spatial provision for the functioning and construction of water management infrastructure and facilities,
- improvement of water quality parameters in water storage reservoir by permanent provision of class I and class I/II quality of all watercourses within catchment area,
- water supply of the settlements in the coverage of the system with more than 97% security of supply, alongside compulsory water supply of at least 70% of the required quantities, while in the periods of necessary reductions, the planned gross consumption norms are 300 L/user per day,
- regulation of water regimes and protection of settlements from floods of fifty years water peaks, mitigation of flood waves in downstream parts,
- improvement of the low water regimes and achievement of complete ecological protection of the watercourses,
- creation of conditions for compensation to the local communities, and
- creation of conditions for leisure, recreation and education of visitors.

The determined zones of sanitary protection of water storage reservoirs are the starting points for preparing the planning conceptions, land-use and regimes of protection (Table 1). The report on the zones of sanitary protection of a water source contains analytically defined boundaries of these zones, and by the SPSPA the zones are elaborated in more detail and the regimes of land-use and their maintenance are determined.

Table 1 Zones of sanitary protection

Zones of sanitary protection	*Land-use and regimes of protection*
The immediate protection (I)	the artificial lake (including the top of barrier construction – dam), its coastal area whose width is 10 m in horizontal projection from the point of maximum level of water achieved, tributary river along its entire course and the zones on both sides of it, at least 10 m in horizontal projection from the water level which occurs once in ten years.
The zone of inner protection (II)	the zone around the artificial lake whose width is 500 m in horizontal projection from the boundary of the zone of immediate sanitary protection.
The wider zone of protection (III)	area beyond the zone of inner protection up to the boundary encompassing the territory of the water catchment area.

The zone I of immediate sanitary protection features the regime of strict sanitary control which prohibits any construction of facilities and plants that are not in the function of water supply system or which do not serve the preservation and maintenance of dams and water storage reservoir's facilities. It is planned to remove all existing facilities that are not in the function of water supply system or sanitary repair or grassing of terrain. It is also prohibited: to dig deeper water beds, to extract gravel and sand, to allow movements of vehicles that are not in the function of water storage reservoir, to allow disposal of any type of waste and to take cattle to drink water from the water storage reservoir. It is forbidden to: conduct water sports that involve swimming of people, have caged fish farming or to fish with fishing nets. In the zone II of inner sanitary protection it is forbidden to construct residential and catering facilities or facilities which endanger the health safety of the water at the source, however it is possible to keep here the existing residential and economic facilities of households, the existing holiday homes (with possibility of their reconstruction) if they do not endanger the health safety of the water at the source, and with the obligation of provision of sanitary safety collection and water treatment of all waste waters. In case the state roads of the categories I and II intersect this zone, they remain in function until the realisation of the planned bypasses. The construction of infrastructure network should be in line with the regime of protection. It is prohibited to use pesticides, or to use chemical fertilizers. Regarding the types of vegetation cultivation, preference is given to meadows with more precious and medical herbs. The use of forests is in the function of protection from the erosion, and only their selective cutting is permitted. It is prohibited to form municipal waste landfills in this zone as well as cemeteries, to exploit stone or other mining works. In both zones (I and II), with the prior acquisition of water conditions, it is allowed to organise the coastal area, to construct pedestrian and bicycle paths, areas for rest and viewpoints, all with the aim of tourist-recreational use of the water storage reservoir's coast, as well as to use electrically powered vessels, or vessels with oars and sails only and to allow fishing for recreational purposes. In the zone III the following activities are forbidden: uncontrolled disposal of municipal waste; the production, storage and transportation of dangerous materials, oil and petroleum products, with the exemption of stations for the fuel supply; conduction of the mining works, entering in the layer which covers the underground water and removing the layer which covers the aquifer, the exploitation of radioactive materials and mineral resources; construction of roads which are not accompanied by drainage channels; and intensive use of pesticides and chemical fertilizers. It is allowed to develop production facilities which use "clean" technology, and which do not represent large water consumers and do not generate solid or liquid waste and hazardous substances. Here is also permitted to build facilities for the processing of agricultural products, where it is possible to apply water recirculation during technological process, e.g. having smaller quantities of wastewater purified to the prescribed class of quality before they are discharged into the recipient. In settlements and zones with residential, tourist and other facilities, it is necessary to provide a sanitary secure collection and treatment of waste waters, or drainage of waste waters outside the water storage reservoir catchment area, which requires construction of a sewage system and appropriate wastewater treatment plants with tertiary treatment.

The construction of the dam and of the accompanying infrastructure facilities for water supply, and in particular the formation of a water storage reservoir, implies the permanent occupation of significant areas. In the analysed SPSPAs, the coverage of existing or planned aquatic land varies between 140 and 900 hectares. Also, the analysis shows that the share of

protection zones in the total area of the SPSPAs for water storage reservoirs varies from 45% to almost 100% (Table 2). Within the total area encompassed by each of the analysed SPSPAs, land-uses which are dedicated to "other" land (not aimed as agriculture or forest land) vary between 2% and 8%. These shares of "other" land include: water storage reservoirs (lakes), dams and accompanying facilities, residential area, public facilities, industry and tourism facilities and infrastructure.

Table 2 Balance of surfaces according to the zones of sanitary protection

SPSPA	Zone of immediate protection - I (km^2)	Zone of inner protection - II (km^2)	Wider zone of protection - III (km^2)	Outside zones of protection (km^2)	Total area (km^2)
Rzav	9,04	34,71	393,08	0,44	437,27
Stuborovni	3,35	8,24	104,58	54,41	170,58
Ćelije	4,66	13,66	592,48	323,99	934,79
Grlište	1,41	6,95	174,53	217,31	400,20

The methodological approach to the development of SPSPAs for protected catchment areas of water storage reservoirs is such that in special focus of the planning concept is the impact of special purpose on other functions in the area, and that ultimately is also a legal obligation. However, the particularity of these plans is the emphasis on the importance of planned technical solutions, which mostly relate to facilities in the function of water supply – water storage reservoirs (lakes), dam facilities, hydro power plants, various types of pipelines, water treatment plants, reservoirs, etc.

3. TOURIST POTENTIALS

3.1. Planned tourism development and diversity of proposals

Considering that tourism (20), i.e. leisure-related industry, is in the expansion because it has a significant share in income, this particular purpose is gaining in importance in planning as well. At the same time, tourism is an initiative for the development, revitalisation and preservation of particular environments, which due to their inaccessibility, lack of contents which influence living (and employment) conditions, experience depopulation and noticeable outflow of the inhabitants. From the aspect of the development of modern tourism for domestic and foreign users, especially in the case of steady tourism, which implies longer stay in the place of tourist attraction, the existence of smaller or bigger sites with the original, well-preserved and protected environment is very important. The goal is to enrich the tourist offer with new contents – even in the tourist places traditionally known for one of their special features with the aim of attracting various categories of guests throughout the year (21). The size of any type of a tourist region (homogeneous/ heterogeneous) depends on spatial concentration of tourist assets, their identification, valorisation, functions and elements of the complementary development of various sectors of the economy. Since tourism is nowadays one of the main drivers of economic growth, there should be emphasised that sustainable tourism, which is a special and highly desirable category of tourism, should be carefully planned and moderated, that it should differ from a mass

tourism on the basis of acknowledging principles of respecting the size, nature, characteristics and capacities for accommodating tourists and the needs of local population, i.e. it should establish a tolerance threshold. Also, sustainable tourism requires development of preliminary environmental impact analysis for each tourist project; it takes a responsible analysis of choice and creation of new economic activities as well as of the local jobs; it uses local potentials and at the same time it informs tourists about the importance of appreciation of cultural heritage (22, 23).

3.2. Potential tourist activities in the area of water storage reservoir

In addition to the aforementioned facilities and infrastructure systems, a special aspect in all analysed SPSPAs is the development of tourism and tourist sites as accompanying or additional special purposes in the area. On one hand, the lake's aquatic surface, due to the attractive water element, as well as the predominantly natural surroundings and hilly-mountainous relief represent added benefits, while on the other hand, binding and strict sanitary protection regimes of the water storage reservoirs do limit the development of other activities or narrow down the scope of potential activities (at the water storage reservoir, tributary rivers and in the parts by the dam), which is why the planning of water storage reservoir's catchment area is a particularly demanding task. The dominant forms of tourism that are planned in the catchment areas of protected water storage reservoirs are: aquatic tourism with mostly summer season offer (swimming, rowing, sailing, fishing); mountain tourism in the surrounding area with a variety of all year-round offer; then hunting, ecological, ethnological and other forms of tourism on other natural surfaces; rural tourism with all year-round offer, including the production of eco-food and craft products with ethno motives; transit tourism, etc. Excluding the transit tourism, during the first stages, all other tourism modalities are typically planned as of visitors type and just to a smaller extent as steady tourism, however, in the following development stages, there should be an emphasis on enhancement of steady tourism share which should be in balance with the concept of protection and requirements of the water source protection. This includes the organization of various sports and recreation activities on water, boat rides, fishing, tourist accommodation in vicinity of water (hotels, weekend settlements, campsites), and it is possible to use the surrounding land for the purpose of ethno/rural tourism, hunting or eco-tourism. Certainly, some of preconditions are: easy traffic accessibility and good infrastructure supply, presence of a visitor centre (24), abundance of contents and offer, combined with various cultural manifestations, educational programs and integrated and harmonised degree of service according to the regime of protection. An example of the detailed concept of tourism development, both in the area of the protected water catchment area and in the wider regional context, is set in the SPSPA of the catchment area of the water storage reservoir "Ćelije" (Table 3), which supplies the inhabitants of Kruševac and surrounding settlements with high quality drinking water. The artificial lake "Ćelije" consists of three morphologically different parts (basins): the deepest basin for water catchment; Vasićki basin (in the canyon); and Zlatarski basin (the most upstream one, which is the shallowest and the widest of all three basins). The total surface of the lake is around 3 km^2 (water catchment area is 592.5 km^2), and the deepest part of the lake goes to approximately 41 m.

Table 3 The SPSPA "Ćelije" - operative goals in the domain of tourism development

	The SPSPA "Ćelije" - operative goals in the domain of tourism development:
1	improvement of integrated tourist offer of the area, which is harmonized with the regimes and measures of protection of water quality, of natural and cultural values;
2	provision of conditions for satisfying all year-round demand of urban population from nearby bigger towns for specialized sports and recreational, health, cultural and leisure activities and amenities;
3	advance of tourism and recreation activities on the water, on the banks of water storage reservoir and by its larger tributaries, development of mountain, rural and ecological tourism and recreation hunting;
4	modernisation, communal provision and commercialisation of the accommodation capacities, particularly in the rural households, as well as in the weekend houses;
5	improvement of the efficiency in tourism development management, with a priority to coordinate the activities and harmonization of the interests of protection of the water storage reservoir and nature;
6	development of geological tourism in order to provide the tourists with basic knowledge of geo objects

Further, based on the main potentials, the initiated and planned development of tourism in the area of the SPSPA "Ćelije" follows a dispersed model. An integral tourist offer is based on ethno-tradition, through genuine accommodation facilities and organisation of commercial clubs for individual sports and recreation as parts of the tourist offer, and on production and positioning of traditional and environmentally-friendly food, craft products, etc. The scope of the water catchment area of the water storage reservoir is planned as a visitor and transit destination on the main existing tourist route towards the mountain centre of Kopaonik, in the function of summer sports and recreation locations. The development of visitors' places is based on the gravitation zone of demand, which includes the towns and cities: Kruševac, Niš, Prokuplje, Trstenik, Aleksandrovac, Brus and Blace. The following amenities are planned within the water storage reservoir "Ćelije" area:

- in the area by the dam, outside the water catchment area, there shall be established aqua-location with the capacity of up to 2,000 one-time visitors, and this facility shall consist of capacities for swimming, water-polo, water jumps, recreation and leisure programmes, canoe descents, program for children entertainment, terrains for mini sports, camping site with the capacity of 500 visitors, accompanied by appropriate leisure, restaurant, sanitary and service facilities, parking lots etc.;
- the transit location for the accommodation "Ćelije", at the northern border of the water catchment area, outside the zone II of the water storage reservoir, with tourist apartments and guest houses with a capacity of up to 300 beds, and with the required accompanying facilities, provided that their waste waters are treated and taken away from these facilities and out of the water catchment area; rural villages with an average capacity of 600 beds in rural households;
- rural tourism settlement Majdevo/Suvaja, which is inspired by the aqua-location by the dam, which consists of guest houses and lodgings with the approximate capacity of 500 beds;
- the location of water and in-land sports on the west-southwest coast of the water storage reservoir within the zones I and II of protection, with a capacity of up to 2,000 one-time visitors (in the zone I – with beach for swimming, swimming pools, rowing,

sailing and boarding, driving in electric boats, etc.; in the zone II - with a camp for 200 campers, with small sport grounds, accompanied by the required catering, sanitary and service facilities);

- organised fishing trails and places – envisaged to be positioned along the coast but outside the location of water and in-land sports.

In this way, the necessary intervention in space, which is related to providing stable water supply and/or energy production, and which causes a significant impact on the landscape, can attract users and become in some other way cost-effective and incentive economic category.

4. Conditions and Constraints for the Overlapping of Purposes

The concept of planning the development of tourism, tourist capacities and infrastructure inside or in vicinity of the protected areas, makes a special mark when planning the area of special purposes. The practice so far has shown that the need for development and for keeping the attractiveness of protected goods of a territory inflicts the planning of tourism development as an accompanying special purpose, which is why resolving the conflicts and achieving a balance between development and protection is an imperative in future planning of the special purpose areas in the Republic of Serbia. The forms of "soft tourism", e.g. eco-tourism, which are carefully adapted to the local and regional contexts, can offer significant opportunities and future perspectives to many regions, especially to the less developed ones. The implementation of integral policies is at the same time focused on the protection, management and planning of the area and on raising the awareness of residents, organisations and local/regional governances about the value of the territory, its economic importance and the possibilities of preserving sensitive ecosystems. Priority is given to the requirement for nature protection and landscape conservation as well as to the integration with housing and other related functions, then with agriculture and forestry, through the payment of compensation and incentives to local communities in order to adapt land use to local conditions, keeping in mind preservation of biodiversity and landscapes. When it comes to combining and overlapping uses of the area, it can be said that water management and tourism have not yet achieved a higher level of mutual coordination or the more permanent one. This situation is the consequence of the fact that tourism is still an activity with low level of accumulative capacity and under the conditions of fragmentation of economic subjects, touristic activity is not ready to commission and finance appropriate water management studies and terrain work. Namely, this relates to the water supply systems for tourist centres, as well as to hydrographic entities that can be used for tourist recreation, sports and nautical purposes. Consequently, there are still centres and regions that have not yet solved the issue of water supply, the ones which bear a lack of drinking water, of water for households, communal and tourist needs, and this situation negatively affects the quality of touristic services, as well as the length of tourist stay and the content of tourist offer. Certainly, it is important to define through the SPSPA not just what, where and under which conditions the activity can be conducted alongside the main (special) purpose, but also it is important to define stages/phases of realization, in order to create realistic conditions for the comprehensive encompass of the offer and employment of all potentials of a location.

5. CONCLUSIONS

The new generation of SPSPAs for water storage reservoirs, with their methodological approach, content and documentation base, provided the possibility for multiple use of space in order to meet the priority needs of water supply (or electricity production) as well as to activate tourist potentials. The underlying conditions are observance of all restrictions related to the establishment of the water protection regimes and for planning of content and locations which are aimed at tourism development. In this way, the attractiveness of new aquatic surfaces is additionally used without compromising the basic function and without disturbing the established balance in a natural environment. In previous practice, according to the analyzed SPSPAs, when demonstrating the capacity for tourism development, the standards which are dominantly applied are either the number of one-time visitors or the number of tourist beds. The proposal is to introduce urbanistic way of presenting the balance of areas by purposes, expressed in hectares (ha) or in gross building area of the planned facilities (GBA, in sq. m). This would allow, inter alia, a better perception of the relation between different uses in the area, of their share in the total area of the SPSPA, and of the capacity to sustain different uses or the load of space. Further improvements to the methodological model can be expected in the sphere of coordinated initiation of a more active participation of the public and different stakeholders, as well as in a closer cooperation between the institutions for protection and planners regarding the evaluation of priorities, finding a compromise and establishing the common goal, especially where the purposes and constraints for the use of space overlap. Certainly, most is expected from the phase of implementation of the planned solutions and in future monitoring of situation at the terrain.

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MOGUĆNOSTI RAZVOJA TURIZMA U ZAŠTIĆENIM PODRUČJIMA VODOAKUMULACIJA, NA PRIMERU PROSTORNIH PLANOVA PODRUČJA POSEBNE NAMENE U SRBIJI

Područja velikih i srednjih akumulacija čiji hidropotencijal služi za potrebe vodosnabdevanja naselja i/ili kao deo energetskog sistema, mogu istovremeno, pod određenim uslovima i ograničenjima da predstavljaju i lokaciju za razvoj turizma. Ova potencijalno konfliktna situacija se rešava kroz proces planiranja i izradu prostornih planova područja posebne namene (PPPPN). Najveći izazov u višenamenskom tretmanu vodoakumumacija, je deljenje resursa među korisnicima, a sa ciljem da se postigne održivi razvoj šireg područja, istovremeno očuva kvalitet vodoizvorišta i vodozahvata. Rad se bavi planskim pristupom u novoj generaciji PPPPN, za planirane i već postojeće vodoakumumacije i osmišljenom aktivacijom njihovih turističkih potencijala.

Ključne reči: *vodoakumulacije, turizam, prostorni plan, zaštita*

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GREENWAYS AS AN ELEMENT OF URBAN PLANNING: BANJA LUKA CASE STUDY

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Tanja Trkulja[1], Ljiljana Došenović[2], Nikola Matić[3]

[1]University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Bosnia and Herzegovina
[2]University of Banja Luka, Faculty of Forestry, Bosnia and Herzegovina
[3]University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Bosnia and Herzegovina

Abstract. *The continuous presence of the landscape concept in planning and design of the Banja Luka area until the end of the 20th century influenced the formation of the identity of Banja Luka as a green city. However, in the last twenty years, there is an absence of the green city concept from planning and designing of Banja Luka's area. In order to improve the state of urban greenery and achieve the satisfactory condition of the endangered landscape elements, this paper re-examines their significance for the city. The green infrastructure has ecological, social and aesthetic functions and it becomes an imperative in defining the strategic goals of a sustainable city. The study showed, that there are possibilities of increasing the size of green areas and improving the quality of green areas in the built city tissue. One of those possibilities is transformation of the existing brownfields into green areas. From the perspective of urban planning, the purpose of this paper is to point out the possibility of implementing the greenways in the city structure for the case study in Banja Luka. In this context, the research focuses on the area of the former Incel factory and the ability to transform the abandoned railways into a greenway. In this research, the sustainable spatial development context of Banja Luka is regarded as a permanent category which includes, among the others, the ambient values, the spirit of the place and the features of a green city are important for the city's inhabitants.*

Key words: *urban planning, brownfields, green city, greenways, Banja Luka, Incel factory*

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Corresponding author: Tanja Trkulja
University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Vojvode Stepe Stepanovića 77/3
78 000 Banja Luka, Bosnia and Herzegovina
E-mail: tanja.trkulja@aggf.unibl.org

1. INTRODUCTION

An awareness of the need to preserve natural ecosystems and of their adequate treatment, both in the urban context and wider, is becoming an imperative of human activities and spatial development. Green spaces of a city are important ecosystems that can provide more utilitarian functions, both in terms of infrastructure and ecology. In order to improve the city's life quality, it is necessary to raise the issue of green spaces' presence, the way of their future use and adequate landscaping. The natural context of cities should be preserved in all future visions of their development and arrangement.

The urban design of public open spaces in Bosnia and Herzegovina is currently focused on transforming the city's natural resources to the built environment. We are witnesses of an increasing degradation of the natural context of cities, including the city of Banja Luka, which is our case study. Banja Luka is the largest city in the western part of Bosnia and Herzegovina and in Republic of Srpska. The city developed on the Vrbas river banks in the Banja Luka basin, which represents the transition zone from the Dinara-mountain areas to the Pannonian-lowland areas (The Urbanisation Plan of Banja Luka from 1975). Banja Luka is characterised by road connection with the region and the countries of the Western and Eastern Europe, as well as the rail transport connection through the Novi Grad – Banja Luka – Doboj railroad with Zagreb and the Central Europe (Official Gazette of the Republic of Srpska, No 05/2011).

Banja Luka has built its recognisable identity of the green city over centuries and it possesses a specific landscape structure following its urban environment and vice versa. However, the image of Banja Luka as a green city is becoming increasingly lost because green urban spaces have often been considered as potential building plots. Due to the expressed needs for building land, green spaces are increasingly receiving the treatment of spatial resources for new construction. This is a big problem, which needs to be solved. An evidence for this is in the frequent changes of the Regulatory Plans of the central zone of the city, where green spaces are lost in order to get land for constructions of new residential and business buildings, which are densely allocated without green infrastructure around. The origin of the urban forms of green spaces can be searched in "layers" (Tjallingii, 2005), which do not have linear chronology. In the process of urban planning, these forms need to be upgraded in order to increase the number of green spaces as well as to increase their quality and design.

The research problem was initiated by the decrease of green areas and increase of brownfields, which has not been substantially explored in the Republic of Srpska. Brownfields are the locations which „have been affected by the former uses of the site and surrounding land, are derelict or underused, may have real or perceived contamination problems, are mainly in developed urban areas and require intervention to bring them back to beneficial use" (CABERNET, 2006: 23). The potentials of these spaces in Republic of Srpska have not been recognised yet. There is no single database, records, categorisations and classification with all the necessary information that are crucial for taking the steps towards their renewal. Furthermore, the Spatial Planning and Construction Law (Official Gazette of the Republic of Srpska, No 40/2013) does not recognise the term brownfield as a special land use category. Currently, the term brownfield is recognised only in the Spatial Plan of the Republic of Srpska until 2025 (2013: 182). In the past 20 years, illegal construction and expansion of civil land are noticeable, which has had a negative impact on nature and the environment. The Plan aims to establish a system of measures for the

development of built-up areas in a sustainable manner. This implies a more rational construction of urban settlements in the Republic of Srpska by directing the development of urban settlements to already equipped land with the necessary infrastructure, by activating brownfields, balancing with green fields etc. However, the current legislation represents a formal obstacle to the inventory of brownfields. The practical problems of brownfields are mainly solved at the level of local communities because there is still no clear official strategic and management platform at the state level that would stimulate significant investment in brownfields and promote sustainable development. Creating a Strategy on the Regeneration of Brownfields in the Republic of Srpska would enable a complete overview of the problems and potentials of these areas and offer directions for their renewal (Trkulja, 2015). Therefore, there is no clear methodology for addressing the problems of these areas. Apart from the above mentioned problems, there is not enough education and awareness of the stakeholders involved in the brownfield regeneration process, nor are there institutions for their renewal and development. It is important to note that there is no urban planning documentation that has considered the brownfields subject (Trkulja, 2015). Brownfields are often inadequately exploited regardless of their potential to become the bearers of the city's identity, key symbols and visual dominants, as places of social interaction and a positive ecological effect with an increased quantity of high-quality greenery.

This research emphasises the abandoned industrial railways, which represent a special category of brownfields and spatial resource of a city with significant reserves of infrastructure, land plots and greenery. In the focus of the empirical part of this paper is the regeneration of the selected brownfield: the former Incel factory in Banja Luka. The study searched for the formation causes, problems and advantages, which are associated with this area at different spatial levels. Regeneration is encouraged as a method, which pays a special attention to the identity of the green city. In that context, guidance and solution are given in the spirit of contemporary redesigning tendencies. Planner settings indicate the definition of new spatial patterns as there is an increasing interest in the policy of urban environment quality management in relation to land use.

Given its importance in the region, Banja Luka has recently experienced the significant transformation in functional and institutional contexts. The process of city's urbanisation and development into the leading social centre of the Republic of Srpska, establishing the institutions of the entity and state level significance, influenced the increased intensity of private capital investment in development. Demographic factor is a powerful urban matrix development incentive. Today, about 200,000 inhabitants live in the wider city area and they gravitate towards Banja Luka in order to satisfy their educational, healthcare, cultural, commercial, administrative and other needs. The intensity of urban planning in the area of Banja Luka is the best indicator of the city development dynamics. The dynamics of changes and users' needs are the continuous regulators, which influence the process of constant plan changes. Besides the activities aimed at providing planning documentation, Banja Luka still has not got its new urbanisation plan, although the activities for preparing it have already been underway for a long time. The current urbanisation plan has its roots in 1975. One of the important preconditions for sustainable spatial development of the city, which the city has not provided yet, is creating a medium-term development strategy with the necessary development guidelines for numerous activities that are having spatial implications. How much Banja Luka has been changed during the last development period, this is the past two decades, and whether the quantity and quality of the transformation of

physical and green structures have been harmonised concerning the development of city functions, are the research questions of this study (Došenović, Trkulja, Sekulić, 2017).

The first part of this paper gives a general overview of the green spaces in Banja Luka, their development flows, spatial organisation and structure. The Urbanisation Plan of Banja Luka from 1975 (still valid) served as a basic source of data in determining the general representation of the presence and functional organisation of green spaces in the urban area. The emphasis of theoretical research includes the elaboration of definitions, functions, divisions and benefits of greenways. It primarily relates to the promotion of preservation of cultural, natural and landscape heritage, healthy lifestyles and sustainable ecological tourism. The second part of the paper focuses on the case study and consideration of the process of designing one part of the area of the former Incel factory in Banja Luka by transforming the abandoned railway into a greenway. The phases of designing and formulating the concept as well as some elaboration details have been analysed. Thus, the paper completed the process that indicates how contextual conditions (natural, created and general) with different intensity may affect the design of the greenway.

2. OBJECTIVE AND METHODS OF PAPER

The aim of this paper is to point out the possibility of improving the quality of environment and living conditions in the city by applying the concept of green infrastructure and the application of greenways into the city tissue. The appropriate changes in the way of using, designing and developing green spaces contribute to it. One of the goals of sustainable urban development should be the improvement of the green matrix. Consequently, the intention is to point out the extent of the transformation of the green infrastructure in the context of the urban planning and development processes in Banja Luka. As elements of the urban matrix, green spaces rapidly lose their quantitative and qualitative value, disappearing in the long run of urbanisation. The influencing factors that defined morphogenesis of the Banja Luka green spaces were analysed in the light of the changes mentioned above. The results of this research are applied to a specific case study. The selected area could be incorporated into the Banja Luka green matrix supporting the complementarity of the process of brownfields regeneration. In this way, in the process of urban planning, it is possible to improve the existing urban patterns of development and distribution of green spaces.

These lead to the division of research into two parts: theoretical and empirical. Several methodological procedures have been applied in this paper, targeting specific phases. The definition, divisions, functions and benefits of greenways are explained in the first part of this research. This research suggests the state of existing green spaces, possibilities for new planning as well as the tendency of renewal and preservation of such vulnerable urban structures. This part of research is based on the method of critical content analysis: the study of the available literature systematically presents the relevant data of the subject area.

The second part of the research applied the empirical method of data collecting and processing by analysing the case study of the former Incel factory, which is carried out in the field of appropriate monitoring. The field research and processing of collected data are determined through: the methods of structural, functional and causal analysis of relevant data from professional, scientific literature and appropriate planning and programming documentation. By analysing the facts and field research with the in situ method, the study enabled the mapping of industrial railways in the form of catalogue forms, as a modern tool

for brownfields mapping (see more in Trkulja, 2015). In this part of research, the method of scientific analysis was applied (method of analysis of archive material and primary sources, and method of critical analysis of secondary sources content). The results of the scientific analysis are narratively presented and synthesised with valid arguments.

3. THEORETICAL SETTINGS

The purpose of this part of the research is to explain the definition, function and benefits of greenways. It gives a general overview of the system of the green matrix in Banja Luka, its development flows, spatial organisation and structure.

3.1. Definition, function and benefits of greenways

Planning guidelines that include urban environmental quality management policy indicate the interest in the adequate use of devastated land. Brownfields have the potential to contribute to increasing the amount of quality greenery by their regeneration.

This research focuses on abandoned industrial railways, which have the potential for being transformed into greenways, in this way enriching the city green infrastructure. Green infrastructure is viewed as „an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human population" (Benedict and McMahon, 2002: 5). Greenways are a constituent part of green infrastructure. They cover a wide range of green spaces as they can be long-distance, local and urban. Firstly, greenways are recognised as linear open spaces established along either a natural corridor (riverfront, stream valley or ridgeline), or overland along a railway and a canal, altered for recreational use. Secondly, greenways include any natural or landscaped hiking or cycling route. Thirdly, they are open-space connectors that link parks, nature reserves, cultural assets or historical sites with each other and with populated areas. Finally, greenways can also be linear parks marked as parkways or greenbelts (Little, 1990). According to the European Greenways Association (EGWA), they are new-built communication routes reserved exclusively for non-motorised journeys, developed in an integrated manner to enhance both the environment and quality of life of the surrounding area (Lille Declaration, 2000). They are often initiated by the local community in order to meet the needs of the local population and visitors, as well as to encourage healthy lifestyles, nature protection, preservation of cultural heritage, sustainable tourism and mobility (Sopron Declaration, 2006).

According to the Central and Eastern European Greenways (CEG), greenways have four basic functions. The first function is related to sustainable transport and safety, as they promote non-motorised forms of transport and mass transit, encourage mobility and tourism related to hiking, cycling, horse-riding, boating etc. The second function represents promoting healthy lifestyles, as greenways contribute to improving the quality of life of local residents and visitors by encouraging active tourism, recreation and sports in the open air and natural environments. Greenways contribute to development of different types of environment-friendly tourism (including creation and promotion of environmental tourist products) and support grassroots and regional initiatives aimed at cultural, natural and landscape heritage conservation. Therefore, development of eco-tourism and natural and cultural heritage conservation represent their third function. The fourth function is supporting economic and

social development of communities, including enterprise development, because greenways contribute to development of local economies and encourage enterprise among local people.

The greenways functions are directly connected to their benefits, so they have environmental, economic and social benefits for both the individual and the community as a whole. Ecological benefits relate primarily to improving water and air quality, noise absorption, high temperature mitigation – improving the microclimate and preserving the biodiversity by keeping the natural linear habitats (such as the coastal habitats). The economic benefits of greenways relate to the increase of the value of real estate in their vicinity, the increase of the local economy and enterprises as well as the state and local governments. The profit of a community as a whole is linked to the creation of new markets within the community, initiated through the development of tourism and outdoor recreation that contribute to the implementation of new contents in the settlement (restaurants, motels, hotels, rent recreational equipment, etc.). The greenways enable the local people interaction, socialising and occasional encounters. Spending time in nature and greater physical activity has positive effects on both physical and mental health. Namely, the modern way of life, initiated by a massive use of cars, created the problem of inactivity which, combined with the lack of proper nutrition, has led to 'epidemic of obesity'. Also, traffic jams on the roads make the movement of pedestrians and cyclists unsafe. On the other side, greenways make it safe and easier. In urban design, greenways are a constituent part of planning the walking paths and bicycle commuting. They enable mobility and recreation of different users and thus promote the healthy lifestyle of local residents and visitors. Public health experts believe that using greenways as an alternative form of transport or for short day trips would lead to significant improvement of mental health by reducing anxiety and alleviating symptoms of depression. Whether a pristine nature or an urban park, the source of greenery provides the same therapeutic effect. Urban greenways provide additional benefits of fleeing from the noise, and other stresses of the city life (Little, 1990).

Greenways can be planned at the site of devastated railways, because they usually re-use the existing urban infrastructure (Baker et al., 2009). Therefore, the aim of this paper is to point out in the area of urban planning the possibility of implementing the greenways in the process of development of urban matrix of the city of Banja Luka.

3.2. The green matrix system in Banja Luka

The need to preserve the existing and to create the new green spaces in connection with the further development of the city of Banja Luka is obvious and represents the part of the strategy outlined in the previous Urbanisation Plans. The spatial and functional analysis of green spaces in Banja Luka has indicated the essential features of the present development. In The program of City Regulation (Kirjakov, 1952) the author lists out three guidelines (of nine) dedicated to green spaces: two to natural features of green structure and one to the role of landscape architecture objects in the formation of the city's identity. This emphasises the importance of urban greenery and coast of the Vrbas river as structural elements of the urban planning concept and organic links between the city and the river. It also points out that development trends should change the direction of the longitudinal expansion of the city.

The core analysis of the Urbanisation Plan of Banja Luka from 1975 shows that the optimal conditions for a healthy and pleasant life, the establishment of creative harmony of natural and built values as well as the environmental protection were the starting point for defining the basic planning guidelines. It is understandable that the development projection

is followed by all the undesirable emerging processes of transition, urbanisation and population growth. It is therefore concluded that it is necessary to take measures for ensuring enough efficient green infrastructure in order to mitigate the negative consequences and contribute to the protection and improvement of the environment.

The focus of the concept of the Urbanisation Plan of Banja Luka from 1975 represents the introduction of forest massifs into the urban tissue through the greenways of primary roads and the watercourse of the Vrbas and Vrbanja rivers. The green of the southern and south-western forests is introduced through the longitudinal corridor highway, western and eastern transit (main street) continuously throughout the urban area. This plan suggests arranging open green spaces on the green spaces of residential blocks, work zones and recreational spaces. It would be obtained through connecting them into a unique network of urban greenery, forest areas and agricultural landscapes. The existing forest areas have been treated as a category of protected forests. Some of their individual parts are defined as protected forest parks with the area of 1,860 ha.

The concept of the Urbanisation Plan of Banja Luka from 1975 in the domain of the spatial-functional organisation of the urban green area shows the intent to establish a unique system for the whole city territory, which should satisfy the criteria of an even, continuous and homogeneous distribution of green spaces. The comparison of the planned development of green areas to the present situation has shown that a unique system of green spaces has not been established in the entire urban area, but only in its narrow part. Many efforts have been done in order to solve the greenery issue according to modern urban concepts that have only been partly implemented with tremendous difficulties. Namely, the planned concept and green level has been changed by the new regulatory plan. Consequently, the continuity in the system of city's green spaces is also disturbed.

Besides the lack of connection between greenways, there is also a problem of river regulation and open spaces in the city centre that could be integrated into a unique greenery system. Newly-designed green spaces by dimensions, function and spatial form do not correspond to the category they used to belong to. They are often formed without a plan concept, and their contribution to protecting and improving the environment is minimal. Park areas with their dimensions and functions today do not allow the versatile recreational activity of visitors of all ages.

Under the greenery system in the Urbanisation Plan of Banja Luka from 1975, green spaces are a medium of permeation, connecting all other functional systems that are clearly separated. The theme of integrating the green spaces has been set as "a unique system of greenery that in the spatial organisation of urban territory makes the connecting element of the composition of urban structures and essential ecological factor" (pp. 141), pointing to the developmental processes that follow. The concept of green spaces is referred to as the instrument of the city matrix design and is considered to be important for the city planning. The basic network of green areas of the narrow urban area in the raster of corridors' longitudinal and cross networking is immediately followed by the system of parks and recreational centres of general or regional importance to the basic parks, squares and green areas of multi-dwelling housing. Then, there is also a network of urban tree avenues as vegetative nerves of urban tissue and all other green spaces of public, restricted and protective categories.

The last period of green infrastructure development refers to the current, transitional period. During this period, the regulatory plans of individual urban units were drafted. Also, the draft of the New Urbanisation Plan was adopted after the adoption of the Spatial Plan of the Republic of Srpska until 2015 (2008). Urbanisation and all the changes (demographic, sociological, cultural, ethnic and others) that have been happening in the last fifteen years in the Republic of Srpska have had a significant impact on the changes in the design of green infrastructure. The demographic factor (permanent population growth) has led to an increased demand for housing. The transformation process of the urban matrix has become increasingly difficult and contributes to the extension of rural-urban patterns of physical structure. Unfortunately, green areas get the treatment of spatial resources for new construction. This is a major challenge of the future spatial development of the city. Banja Luka goes deep into natural areas, protected green spaces, forest parks, thus creating a peri-urban zone with morphological features without a clear meaning. It is important to point out the appearance of unplanned or illegal construction (without building permits) as a result of slow resolution of housing needs.

Protection of the existing greenery will not be possible without the implementation of various measures in the legal, organisational or financial domains. Also, the citizen's awareness of their living space is not sufficiently developed. The ecological approach is not satisfactory, as evidenced by numerous examples in the context of the protection of cultural-historical and natural heritage. Attempts to solve some of these problems have also appeared in the form of the tenders that the Banja Luka City Administration had called for urban-architectural solutions of certain parks.

4. CONTEXT ANALYSIS

4.1. Contextual issues

Banja Luka has had a dynamic historical development, but in relation to the subject of this paper, it is necessary to address the development of the railway transport and economy. At the very end of the Turkish occupation (1871–1873), the railway Dobrnjin – Novi Grad – Prijedor – Banja Luka was constructed. The railway was intended to be a part of the future Ottoman Transbalkan Railway which would connect Turkey with the Western Europe through Bosnia as the shortest route (Ševo, 1996). Industrial railways of the former Incel factory are selected as a topic of a case study analysis in this paper.

In the Vrbas Banovina of the Kingdom of Yugoslavia, which was established in 1929 having Banja Luka as its most significant city, railway traffic used the 350 km long state lines and 400 km long industrial railways (Vidaković, 2006). During the socialism, Banja Luka was extensively spread to the contact zone with the narrow city centre. The process of industrialisation resulted in the construction of major manufacturing industrial zones: east extending from Vrbanja to Predgradje (which includes a testing grounds of empirical research) and north-west which was located between Zalužani and Ramići. However, The Civil War (1991–1995) has significantly influenced the industrial development of the entire Republic, thus including the city of Banja Luka.

The basic characteristic of the current economic development in Banja Luka is exemplified by the reduction of economic activity and a radical change in the economic structure. It is reflected in a large reduction of the share of manufacturing activities attained

through employment and incomes. During the transition period (from 1995), there has been a decrease in industrial production capacities and significant growth of service industries. A large number of industrial complexes in the city have remained non-functional, leaving over 53% of the city area abandoned, neglected and unused. Furthermore, there is an evident presence of industrial railways that are no longer in use. The economic, ecological, social and cultural potential of these locations indicate their importance to the urban community, thus indicating the necessity of their renewal (Đukić et al., 2014).

4.2. Case study - urban planning context and development of former Incel factory

Based on our practical experiences we noticed, that the spatial resources of Banja Luka, as well as of the entire Republic of Srpska, are used recklessly and inefficiently in the process of its development and expansion. In order to avoid this 'trend', it is necessary to renew the brownfields and reduce the 'pressure' on the green city matrix. The first phase of the renewal process involves the identification, mapping and proper analysis of the problems and potentials of brownfields on the basis of which it is possible to define guidelines for their regeneration.

The analysis of the case study in the Republic of Srpska is preceded by the definition of methodology for identification and the appropriate level of mapping of these areas. The methodology should enable a simple analysis and evaluation of the collected data, as well as the definition of adequate guidelines for regeneration of railway brownfields. We used the methodology, which was by Trkulja (2015). A catalogue form for mapping industrial railway brownfields has been selected as the most appropriate tool for carrying out the set tasks. The catalogue form includes a set of parameters and criteria that enable a detailed analysis of railway brownfields. These parameters and criteria are defined within the ecological, regulatory, cultural and social aspects, and individually for the railways, the green structure, the traffic infrastructure buildings and developed open space (see more in Trkulja, 2015, pp. 133–134).

The former Incel factory is located in the eastern industrial zone of Banja Luka, where the Vrbanja river flows into the Vrbas river. It is about 2 km away from the administrative centre of the city (Figure 1). Incel factory was founded in 1954, and the whole complex was established until 1981 (“Business Zone” Banja Luka, 2011). The Incel factory in Banja Luka was the main stakeholder of the development of chemical and pulp and paper industry. By implementing the programmed capacities, Banja Luka became the largest producer of chemical fibres and pulp in Yugoslavia and one of the major manufacturers of chemical fibres in Europe (The Urbanisation Plan of Banja Luka from 1975).

The latest Civil War (1991–1995) slowed the development path of the Incel factory until its plants stopped operating in 1992 (Djukić et al., 2014). Restructuring and privatisation process followed in 2000 (Mišeljić, 2014). The consulting, mediation and service company “Business zone” Banja Luka has operated the former Incel factory since 2009. The business activity in this area was performed by another 14 business entities that have had the ownership over the facilities and 90 other business entities that have leased and used the office space of the business zone (“Business zone” Banja Luka, 2011).

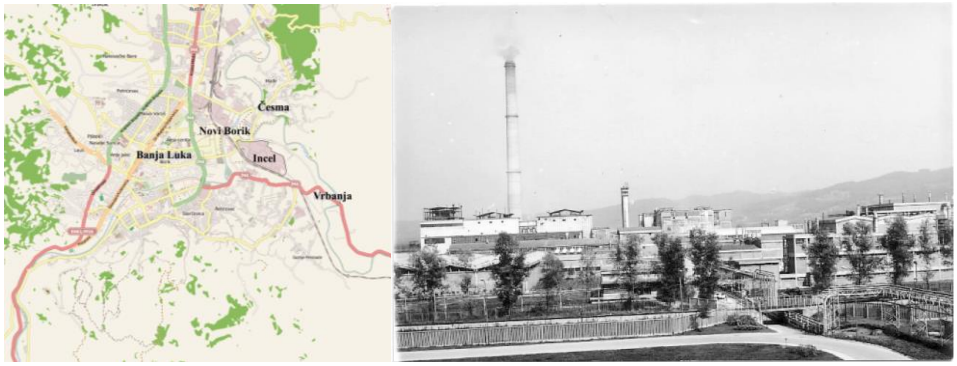

Fig. 1 Present position (left) and the 1979 photograph of the former Incel factory (right) (Source: Authors (left) and http://banjaluka.net/veliki-foto-vremeplov-sta-se-sve-nekad-proizvodilo-u-banjaluci/ (right)).

Regulatory plan of business zone "Medenopolje" in Banja Luka (Official Gazette of the city Banja Luka, No 9/2002) which included the area of former Incel factory, was completed in 2005 (Figure 2).

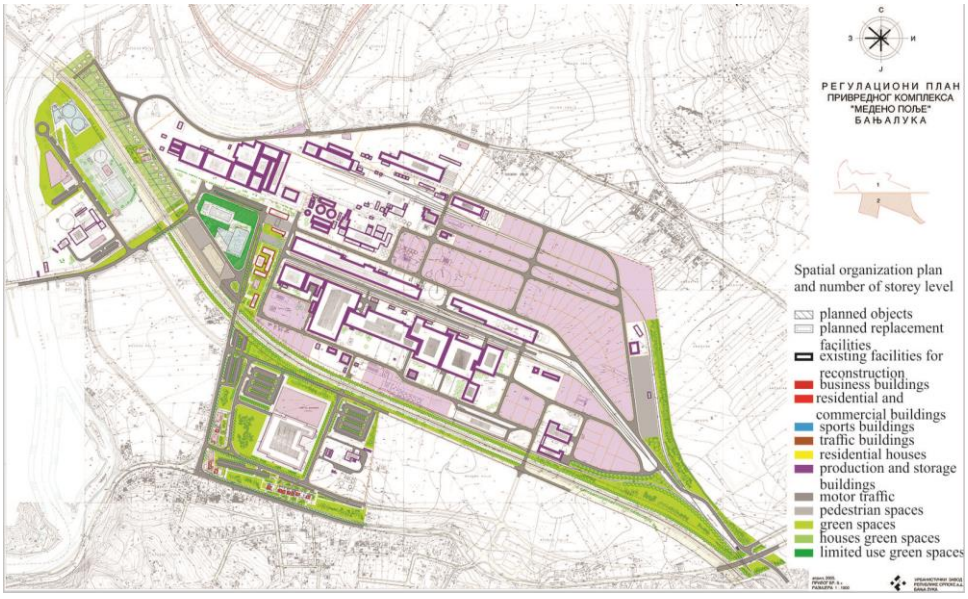

Fig. 2 Regulatory plan of business zone "Medeno polje" in Banja Luka (Official Gazette of the city Banja Luka, No 9/2005)

This Plan predicts the removal of some existing buildings and building of new ones for business, housing, warehousing, sports and parking garages. The plan predicts the construction of a sidewalk of 27,023 m² and bicycle trails of 669 m². When it comes to a green matrix, the Incel as a corporate entity used to pay great attention to the design of its

environment. This is evidenced by numerous plants, groups and individual trees that are 15–40 years old within the whole complex. Within the analysis of the situation, valuable individual examples of trees have been found. This Plan predicts the planting of 1431 decorative trees, such as avenues along the parking space and the railway. One of the basic goals of greening is the binding of the proposed greenway in the green infrastructure network. In relation to all the above, the idea of transforming abandoned railways into the greenway was logical.

The network of industrial railways was about 8 km long (Djukić et al., 2014) and it consisted of 18 routes. The catalogue analysis of railways has showed that 8 routes are still in function (eastern and northern railways). Two are partially in function, six are out of function and two southern routes are dismantled and removed, and the space they took up is either overgrown or filled with gravel (see more in Trkulja, 2015: 143-179). Central industrial railways are non-functional. Their route exists but is not maintained. That is why the location of the central railways has been chosen for the position of the greenway. Despite the many companies that operate at the site of the former factory, large areas are unused and undeveloped, green spaces are neglected and facilities of the old plant are empty. In that sense, Incel disrupts the appearance of the surroundings and represents an environmental problem (Figure 3). Therefore, it is necessary to regenerate the Incel testing grounds and arrange the green spaces in order to solve the ecological problem.

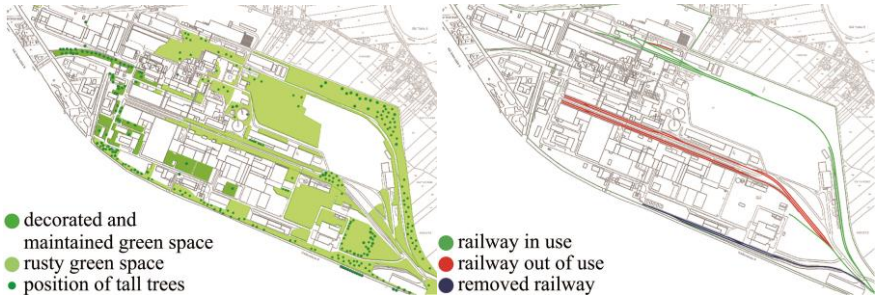

Fig. 3 Analysis of green spaces (left) and industrial railway (right), 1:10000 (Source: Matić, 2017)

4.3. Conceptual design of greenway

Research of resources and potentials of the former Incel factory established the position of greenways at the site of the central railways. Analysis of structures showed that in the north and south of the greenway are the structures with mixed functions that are partially or completely in use. On the west side of the greenway, there are the Independent University of Banja Luka, the Agency for Medicines and Medical Devices of Bosnia and Herzegovina, The Republic Administration for Geodetic and Property Affairs of the of the Republic of Srpska, The Republic of Srpska Institute of Statistics. On the south side, there are The Official Gazette of the Republic of Srpska and the Lanaco Information Technology Centre. These functions and the proximity of the Vrbanja, Česma and New Borik settlements require the public space to be tidy and green, which can be organised in the form of a greenway. At this moment, opportunities for the realization of the optimal system of urban greenery are not great. However, in the planning we should strive for the creation of

mutually connected entities, which is proposed by solution proposed by this text. The greenway connects the surrounding settlements and introduces parts of the protected park-forest into a city green matrix.

Therefore, the concept is developed on the basis of contextual conditions and influences, and the intervention is given on the level of buildings, open spaces and context of the communion (Figure 4).

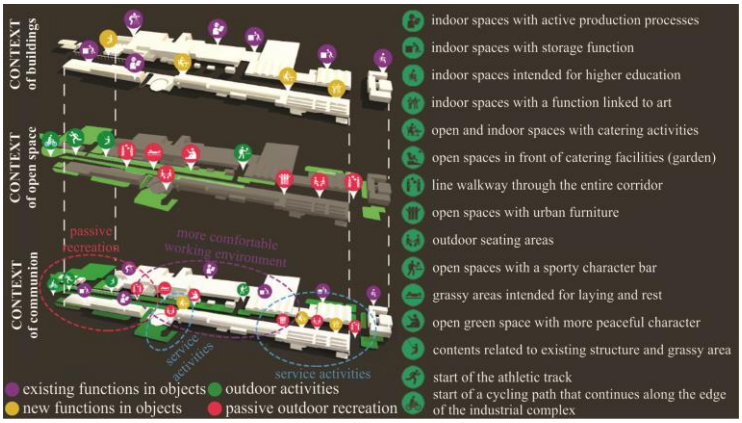

Fig. 4 Intervention in the selected polygon
(Source: Matić, 2017).

The aim is to provide the users of the space with a pleasant place for relaxation, socialising and entertainment. By retaining and 'coating' existing railways, rehabilitation and redesign of the surrounding buildings facades and transformation of the devastated canal for installation to a long waterway, created a space which testifies about the history of the industrial giants of the last century. At the same time, the space is further enriching with green structure giving the impression of space on a human scale and naturalness (Figure 5).

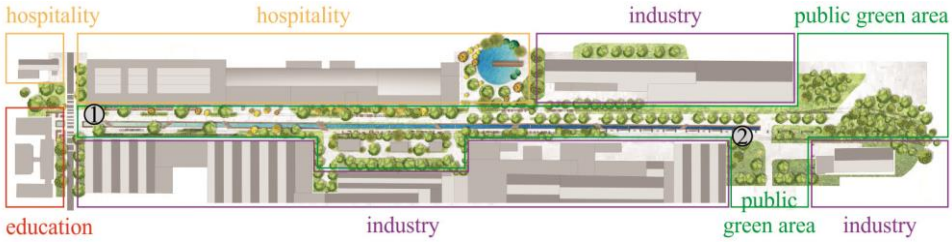

Fig. 5 Plan of the greenway, 1:6000
(Source: Matić, 2017)

The existing industrial artefacts, which testify the history and spirit of the place, are given the new functions that make them attractive and recognisable. The function of structures has changed, so the storage spaces have become home to art, work, recreation, relaxation and entertainment (Figure 6-1). This way, the space has been refurbished with new cultural and

hospitality contents complemented by the functions of the objects located on the west side of the greenway, especially education and administration. Thus, the greenway and its contents have been integrated into the environment and allow the adequate level of safety and comfort to the users of the space. The regeneration design has created an incentive space that can influence development of the site and increase in the value of land and real estate (Figure 6).

Fig. 6 Photomontages of the new design
(Source: Matić, 2017).

The regeneration project enriches the business area with new amenities. The former industrial plants and open spaces are enriched with cultural and hospitality amenities/finctions. Urbanisation of the area by improving the quality of the environment, the working conditions of the users of the space and the life of the inhabitants of the surrounding settlements can generate employment and construction works. Protection of existing biodiversity and interpolation of the new green structure, with a combination of nature, railways and art installations, provides safe, attractive and cost-effective places for work and active and passive recreation. Regeneration and preservation of industrial city giant keep the unique identity of space. Upgrading the ecological and aesthetic quality of environment will undoubtedly improve the quality of life of people living and working in this area.

5. CONCLUSION

The increase in the density of population in the centres of cities and their simultaneous expansion has become a threat to the existence of open and green spaces. In order to improve the condition of the green spaces and achieve the satisfactory efficiency of the endangered landscape elements, this paper re-examines their significance for the city as well as their ecological, social and aesthetic function, which has become an imperative in defining strategic goals of a sustainable city. There are opportunities to increase the greening and improve the

quality of green infrastructure in the built city tissue. One of them is the implementation of green structures at the brownfields.

The brownfields regeneration is an acceptable method in the function of comfort increasing in the narrow urban area of Banja Luka, and therefore provides the possibility of renewal of the green city identity. Forming greenways could mitigate or prevent environmental damage caused by intensive urban development. Exploring opportunities to improve the quality of the natural environment and life in the growing cities puts emphasis on expansion of green infrastructure by implementing greenways at the site of abandoned railways. Theoretical research emphasises the ecological, economic and health benefits of greenways. Furthermore, it points to the development flows and the condition of the existing green spaces of the urban matrix in Banja Luka, the possibilities of planning the new ones, as well as the tendency of regeneration and preservation of such vulnerable ambient units. In applied research, the emphasis was placed on the process of development of urban matrix of the city of Banja Luka and the spatial resources of the former Incel factory at the location of inactive industrial railways. Research has shown that the transformation of railways into greenway allows preservation of genius loci in the urban development process, and affects ecological, economic, social and aesthetic improvement of the area. The regeneration project initiates development of workout routine, leisure and work in the open, contributing to significant improvement of quality of life of the people living and working in this area.

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ZELENI KORIDORI KAO ELEMENT URBANOG PLANIRANJA: STUDIJA SLUČAJA BANJA LUKA

Kontinuirano prisustvo koncepta krajolika u planiranju i projektovanju područja grada Banja Luka do kraja XX vijeka uticalo je na formiranje identiteta Banjaluke kao zelenog grada. Međutim, u posljednjih dvadeset godina, prisutno je odsustvo koncepta zelenog grada u planiranju i projektovanju područja Banja Luke. U cilju poboljšanja stanja urbanog zelenila i postizanja zadovoljavajućeg stanja ugroženih elemenata pejzaža, ovaj rad ponovo razmatra njihov značaj za grad. Zelena infrastruktura ima ekološku, socijalnu i estetsku funkciju i postaje imperativ u definisanju strateških ciljeva održivog grada. Studija je pokazala da postoje mogućnosti povećanja zelenih prostora i poboljšanja njihovog kvaliteta u grđenom tkivu grada. Jedna od tih mogućnosti jeste transformacija postojećih braunfilda u zelene prostore. Iz perspektive urbanističkog planiranja, svrha ovog rada je da istakne mogućnost implementacije zelenih koridora u gradskoj strukturi za studiju slučaja u gradu Banja Luka. U tom kontekstu, istraživanje se fokusira na područje nekadašnje fabrike Incel i mogućnost transformacije napuštene željeznice u zeleni koridor. U ovom istraživanju, kontekst održivog prostornog razvoja Banja Luke se smatra trajnom kategorijom koja uključuje, između ostalog, ambijentalne vrijednosti, duh mjesta i karakteristike zelenog grada koji su važni za stanovnike grada.

Ključne reči: *urbano planiranje, braunfildi, zeleni grad, zeleni koridori, Banja Luka, nekadašnja fabrika Incel*

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THE CONCEPT OF FRAGMENTATION: BETWEEN FORM AND FORMLESS

UDC 72.01:004.946

Mila Mojsilović, Vladimir Milenković

University of Belgrade, Faculty of Architecture, Belgrade, Serbia

Abstract. *Drawing on the idea that abstraction of architectural design is repeatedly demonstrated by new concepts, and that the idea of the design contains a fragment of its internal laws, the paper raises the question of alteration of forms towards new time- space categories. In contrast to Euclidean geometry based on the continuity of geometric forms, fragmented forms draw upon deformations and variability, operating in the limit zones, for the design, zones of the greatest creativity and potentiality. A new understanding of reality shaped by digitization of all systems has created the basis for forms of self-organization, openness, contingency, and emergence. What we have before us is basically a new aesthetics that goes beyond the horizon of visible in a way that allows the whole world and all its parts to be seen in a completely new, immaterial way. This means that architectural forms appear in the visibility zones, together with the forms of their systemic dislocation.*

Key words: *Post-digitization, Fragmentation, Formless, Spatial flexibility*.

1. POTENTIALITY OF INCOMPLETENESS - THE CONCEPT OF FRAGMENTATION

Appreciation of fragments and fragmentation can be traced back to early German Romanticism, when the fragment was determined as the central philosophical notion, both as concept and idea of form, through the expression of a philosophical limit and its overcoming (Sandford, 2016, pp. 25-35). To the extent that the Romantic idea of the fragment has developed from a general fascination with ruins, it is also deeply linked to its origin via the cultural appreciation of archaeology, architecture, and ancient cultures. Thus, the cultural and intellectual context of the Romantic idea of the fragment has quickly spread from the concepts applied in literature and art to all other fields. The Romantic fragment can be seen as *an artistic solution to a philosophical problem* (Osborne, 2013, p. 58), and the problem of *the presentation of the unpresentable* (Manfred, 2004, p. 53).

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Corresponding author: Mila Mojsilović
Faculty of Architecture, University of Belgrade, Kralja Aleksandra Blvd. 73/II, 11000 Belgrade, Serbia
E-mail: milamojsilovic@yahoo.com

The contemporary concept of fragments and fragmentation diverges from romantic ideas of fractions, cracks, separated and broken pieces, ruins, regret for the past, and it conceptualizes the idea of incompleteness as the essential potentiality of form, imagination, and contingency, where the fragment is determinate, projected, and conscious intention to leave things, concepts and forms open to new interpretations and readings.

This view sees and interprets the fragment, although essentially unfinished and incomplete, as a well-rounded form and not its part or residue – *If a broken piece (part) did not qualify as a fragment, it nevertheless offered great potential if its accidental or involuntary character could be transfigured into a determinate and deliberate statement of fragmentation* (Brain, 2007, p. 227). The fragment in its full sense is the idea of *something complete in itself and yet essentially incomplete* (Schlegel, 1991, p. 45). It is a self-sufficient form that requires infinite work on eliminating its incompleteness – which is precisely why the fragment is the idea of presenting the unpresentable, it is essentially ambivalent and paradoxical. Complete in its incompleteness, the fragment indicates the plurality of potentials - *Each fragment stands for itself, as well as for the whole from which it is detached* (Lacoue-Labarthe, Nancy, 1988, p. 44).

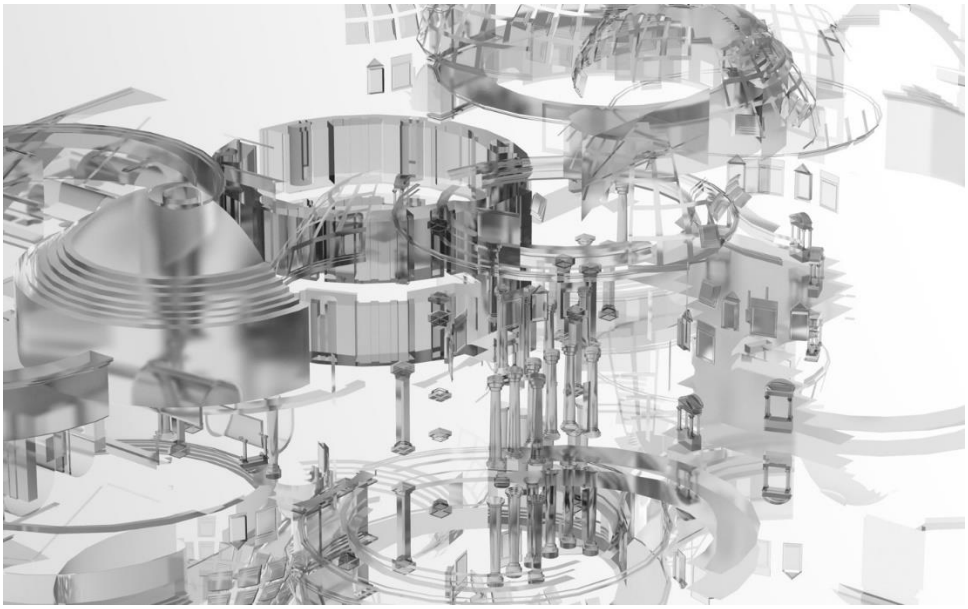

Fig. 1 Fragment 000389561 Presentation of the Unpresentable,
M. Mojsilovic & F. Prica, Digital model, 2018:19.11:14.56

However, the question is whether this formulation of fragmentation and fragments requires isolated observation so that the totality we speak of is visible? For the French philosophers Nancy and Lacoue-Labarthe, the existential obligation of the fragment, if not its existence as a totality, is formed by *the integrity and the wholeness of organic individual* (Lacoue-Labarthe, Nancy, 1988, p. 63), that is, specificity. If the fragment is simultaneously in the whole and in each part, it can be interpreted as an elementary particle (specificity) of each whole. The fragment, in order to be a fragment, and not just a detached broken piece,

carries in itself all the information of the whole, that is – *in its detachment or isolation, fragmentation corresponds to totality or the whole* (Lacoue-Labarthe, Nancy, 1988, p. 63). In other words, the fragment is essentially defined in terms of its natural and inherent multiplicity – it is always becoming and never complete (perfect).

Fragmentation is in this sense the presentation of being and/or of existence, in which the searching for, is the essence of its integrity. As a result of this search, what arises is erasing, fraying, blurring and overlapping of the edges of the trace of fragments –making the aesthetics itself fragmented (Nancy, 2008, p. 126). The individuality and specificity of the fragment becomes, at the same time, the plural whole through the projection (presence) of all its potentialities and possible scenarios. The presence of each of these parts is therefore, paradoxically, co-presence (Heikkilä, 2010). The fragment, in its singularity, always has the structure that is *more than one* (*plus d'un*), as a trace of the other or the whole (Lacoue-Labarthe, Nancy, 1988, p. 64), simultaneously grounded in essential detachment.

Under the conditions of such multiplicities, where things are never formally unities or totalities, but multiplicities that contain points of unification or centres of totalization (Deleuze, 2009), focus is not on the elements that make it, but on what there is between them in the void and on what separates them and distinguishes them. Thus, on what is sufficiently unknown to be contingent. Multiplicity is characterized by a specific type of complexity where it is not a matter of finding the unity of multiplicity but, on the contrary – of considering unity only as a temporary constellation or virtual dispersion. Therefore, the complexity does not consist in the one, but in the fact that each thing (each of its elements) can diverge and overlap with others, being in constant becoming and movement (Rajchman, 1998, pp. 12-36). In this context, unity is defined as a contingent operation that holds a potential divergence.[1]

2. Fragmentary Experience of Time in the Era of Post-Digitization

The issue of contemporary can be addressed as a temporal and ontological problem of space, that is, to be contemporary – is to exist at the same time with something else, in relation to which we position ourselves, as a relation-reflection, a temporal determinant rather than a historical position (Rabinow, 2009, pp. 355 - 364). On the other hand, setting the concept of time as a central one in relation to the dynamic continuity of architecture, in which time as the context becomes a condition for the contingency of architecture (Till, 2009), corresponds with the contemporary need for dynamic spatial interaction, enabling the reaction to changes, or to changeability itself, coupled with incompleteness.

Stabilization of classical physics in the nineteenth century, brought about by mathematical postulates, led to conceptualization of the image of the world in which temporal determinism prevails and in which time does not have a creative role. Consequently, the idea of the future is set as fixed, unchangeable and defined in the past. Such a stable and static image of the world and of time, future and reality, has been shaken by science, especially thermodynamics, which introduced the idea of the arrow of time that conflicted with the symmetric concept of classical mechanics, where the past and the future were interchangeable (DeLanda, 2000). If thermodynamics, a science that deals with concepts and phenomena guided by ideas about the

[1] Divergence – denotes gradual moving away, or opposites. In mathematics, it is a property of a sequence or a series not to be inclined to a finite, limit value.

fluidity of things and matter, their variability that maintains differences in the state of emergence, is translated into the concept of fragments, we can see that only in these dynamic conditions that are *far-from-equilibrium*, in this unique intensity zone, the morphogenesis that is directed at the difference (which arises from it) becomes visible, that is, what it essentially is, while matter itself becomes an active substance, which is generated in itself, and whose form does not emerge, does not arise from the outside (externally) (Nicolis, Prigogine, 1989). Matter seen in this way is an *inert*[2] material that does not come any more from Plato's *Heaven or the mind of God*, but from the minds of people or cultural conventions: the World is amorphous and shaped by language.

Open future, which arises from the concept of openness of the world, as changeable and dynamic, is closely linked to the theory of actualization, in which nothing has already emerged, nor it exists now, but everything is in constant becoming. DeLanda sees the core of this approach in a neo-Kantian theory of perception in which individual experience is completely structured by intertwining of concepts and representations, while Kant's transcendental concepts (of space and time) have been replaced by the conventional concepts of a given culture. This approach to reading and interpreting cultures in which they are independent and free can be observed in many contemporary theorists such as Margaret Mead, Franz Boas, Edward Sapir, Benjamin Worf, Thomas Khun. In fact, if every culture indeed develops in its own constructed reality, then we can speak of an open world, in which the future is never predefined in the past, but always unbound and open to multiple interpretations.

Measurable time, enabled by technological developments, in fact by the invention of the mechanical clock in the seventeenth century, is the basis of the modern concept of time, organizing its own cycle and separating from physical space (place as a reference to time) and virtual understanding of its flow. Expressed in hours, minutes and seconds, time has suddenly become representational in its own three-dimensional reality. This distinction is considered to have generated the process of modern time and the modern concept of space-time relations. The mechanical clock enabled to create the image of a numerically quantified universe. Time is measured not by its distinctiveness or personal experience, but by well-established abstract units that have gradually pervaded the sense of life (McLuhan, 1994, p.146). However, what we measure with abstract time are actually concrete and defined actions, events and intervals. Mass production of watches made time accessible to everyone, as an integral part of everyday life and a social category. The modern (social) construction of time and space not only transformed abstract understanding of cosmic time into measurable time, but also introduced speed as its new category.

The digitization of machines enabled access to the data anywhere and anytime, thus making information independent of space and time, accessible everywhere and at any time. Virilio calls this the "*Third Revolution"*, when speed becomes a key element for the perception of a new concept of space-time continuum. Abandoning the concept of *here and now*, as open possibilities for anywhere and anytime, as space and time instances, the concept of physical distance is replaced by psychological distance, while the screen becomes the space of interaction (Virilio, 2000). In this process of development of society and technology, space and time as we have known them lose their significance and seek redefinition and a new conceptualization in the conditions of digital and virtual.

[2] Inertia – a property of a body to resist any change in its state and position (rest or motion in a straight line), unless an external force acts to change that state.

The new social and spatial organizations that have been directly influenced by this concept of time and space led to the simultaneous presence of the past to the future in the present. The question of the nature of time is not and cannot be separated from our perception of time and its real transience.

Time conceived as a category of the modern age has become understandable, and therefore present in all its flows, changes, extensions and contractions. For Bergson, time is not an invisible whole and cannot be reduced to measurable units, it always remains internal and subjective in opposition to its technical representations, and whereas digital time is repeatable, reversible, and infinite, human time is irreversible, finite, and subjective (Deleuze, 2015).

What characterizes the new temporal digital paradigm is the fragmentation of the homogeneous linear (flow of) time, as we knew it, providing displacement and new mechanisms for (apparent) control and experience of time – that is, space and time become the contingencies that shape our experience (or are shaped by them). Digitization allows a shift from manipulation of static forms to geometry, flows and plans. On the other hand, operating in the field of virtual space (manipulation), the digital in architecture challenges the question of scale in the design, appearance and representation. The gap between modelling, reality, and representation, Frampton sees as a field of image seduction, emphasizing that this does not necessarily imply the dematerialization of architecture (Frampton, 1995).

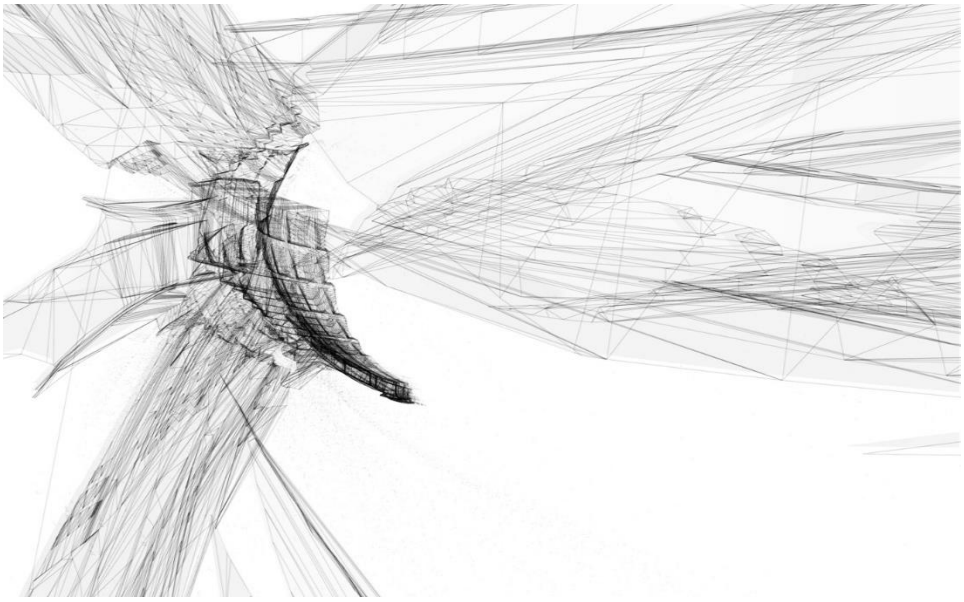

Fig. 2 Fragment 00038960 Potentiality of the Incompleteness,
M. Mojsilovic & F. Prica, Digital model, 2018.19:11.17:32

Thus, for example, zooming can be viewed as a consequence of the crisis of the traditional notion of scale, caused by digitization and globalization, which generates a specific form of perceptive instability. This instability blurs the distinction between the abstract and the concrete, since nothing is at the same time more abstract and more concrete

than the view (openness) of interpretation based on the ordinary categories of form and object (Berger, 1990). Generally speaking, in the age of the digital and digital manipulation, materiality becomes the intersection line (point/zone) of two opposed categories. On the one hand, pure abstractions, based on signs and codes, and on the other hand, full concreteness of perception of material phenomena and properties such as light and texture, are enabled through infinite *zoom in*. Hybridization of the abstract and the ultra-material represents a new world (a new paradigm) of sensations and movements (Picon, 1990).

Architecture as a discipline is in the phase of the post-digital era in which distinctions between the analogue and the digital are not so significant, and in which focus shifts to structural differences within each medium. While the transition from the production of form to the research of form (Kolarević, 2003) speaks of the transition to a continuous process, or a generic one, that does not imply finality of form even at the time of its materialization.

3. OPENNESS OF SYSTEM – FORMAL FORMLESS

Under the conditions of the universe viewed as a spider's web, always becoming, self-structuring, avoiding final definition or any kind of closure, the concept of formless (*informe*) is the idea of a search for form and a call to formation of characteristic points, specific intersection points of form. The French philosopher Bataille speaks of the fragment as something (that is) formless (*informe*) (Bataille, 1985), or whose form is always becoming, in motion, and as such elusive. Thus, the specific form of the fragment can be referred to only as a constant state of variability, which is always between form and formless.

The constant search for formation conceived in this way *does not produce meaning, but conceptualizes the purpose* (Bataille, *1985).* To think the formless, the unformed, is *to think being as becoming and as such to think the being of becoming* (Mellamphy, 1998). To become means to pass or surpass. To enable becoming is to come to terms with the idea of transience and incompleteness, as well as broken narratives. Thus fragmentation demands a distance, which allows it to break away from us, only to reappear, overcoming both the whole and its parts. Becoming (fragmentation) is, therefore, always defined both in the future and in the past in terms of the principles of the formless, unformed, and formlessness or shapelessness (Balmond, 2007).

The fragment can be compared with the present moment, that is, with the present - which is neither part of the past nor the future, but separated from them and *always yet to come* (Mellamphy, 1998). The present is unformed and as such always becoming – not becoming *something*, because the something that it *is* is becoming. The present is becoming, and it is not a part of anything, but something else beyond formulation – *it breaks with the concept of part or parts, it is a hole in the whole or wholes* (Mellamphy, 1998). The present is neither a part nor a whole, but separated from both (alienated), and for this reason fragmented (as a fragment of time). We can say that the fragment is always already abandoned, and as such and because of it, it calls for form, formation, definition, formulation, and conceptualization. But if the fragment is the call to form, is it at the same time the betrayal of the concept of formless (*informe*) (Deleuze and Guattari, 1987). To capture the fragment would mean to confine it, to frame it, which would be fatal for its variable nature - the fragment should not be inserted (formed) into a given (existing) system or structure (formulation), but it should neither be left out nor viewed as something separated from it, formless and undefined (Mellamphy, 1998). Thus, it could be said that

fragmentation and fragments demand the concept of a new field (discourse), new narratives, and a new concept of space, time and form, which do not attempt to define them in terms of the existing, but allow only some limit values to be defined, leaving the essential openness of the system and interpretation. To leave the fragment undefined (formless) would be as fatal as to form it. The fragment is somewhere between these two polarities, in the gap. The fragment never fills this gap, this void, it is this gap and its inevitable becoming. To fill the gap would mean to betray the fragment, to represent it and make it visible (Mellamphy, 1998). The fragment *never represents a certain (necessary) system or a synthesis of totality* (Nancy, 1993), but, as Heidegger said, it *aims to capture the guiding representation of continuous (perpetual) becoming* (Shahan and Mohanty, 1984).

If the virtual is understood, like Deleuze and Guattari do, as one of the states of reality characterized by openness to the emergence of (new) potentials, its reality becomes the reality of change (changeability) and event. If the virtual is change in itself, then it can figure only as a mode of abstraction (Massumi, 1998). It is not a representation of what it will be when it changes, but it is what is at a given moment, including all its potentials that evolve gradually. Massumi defines circumstances as self-abstraction to the extent to which they are realized through their potentiality. The virtual is not contained in any existing form of things or states, but it is in motion, in the transition from one state to another (formally and/or metaphorically).

Challenging abstraction and the virtual through the very process of form research that is in principle non-formal (for it is realized through the virtual), whose ultimate end is always form, Massumi offers the concept of topology and topological forms that have in themselves continuous transformation within their own variation. Topological forms operate in the zone in-between, between defined points (positions) of their beginning and their end, or within their limit values. Topological forms are variations that do not have the idea of separation and breaking in themselves, but they figure as an open but dependent system within the field in which deformations (changes) are possible. This is in fact the basis of their continuity. That is, the continuity of the zone in-between, as an environment for changes (and therefore the design process), is inseparable from the conceptualization (actualization) of form. Topological form is a sequence of still-standing and captured variation and a process of change at a given moment. In order to be topological, form must have a trace of the potential for otherness as evidence of its changeable nature and its variability. The variation captured by past and future in (broken) form is the virtuality of its form and appearance, as well as those that have not been realized (Massumi, 1998). The abstract field of variation, or a field of generative transformation (Massumi, 1998), becomes a condition for potentiality and the idea of form and its changeability (variability), while indeterminacy itself must be designed so that it emerges from the interaction of constraints.

Turning to topological forms leads to a shift in the focus of architectural design, from object to sequence, in which deformation and variability become the material to be used. Framed origin of form is translated into a movement that structures it. Finality of the idea of perfect form has been replaced by the process of emergence and invention of form that becomes the topic around which a topological paradigm is formed, because form is represented only as one in a sequence. Thus, imaginary digital space (in which the digital operates) is no longer a neutral screen for imagining (and/or representing) already imagined (conceptualized), but an active means of finding form that, as an environment, participates in structuring and conceptualizing. Such understanding of the digital is the idea of performativity of architecture that involves the design process itself through the digital

spatiality of the appearance of matter (its actualization), both the subject and the context in which it appears. Massumi sees digitization and the topological paradigm as a neo-modernism, characterized by Deleuze's *fold to infinity*, as well as an extended field of fluidity of form, identity, even the entire discourse. Transition to the virtual structures the form, although it is non-formal conceptually (but also formally), it is more a state within transition, a moment of transition and the intersection of change. Even though the virtual cannot be seen or felt, it cannot not be seen or felt as other than what it is (Massumi, 1998).

Fig. 3 Fragment 00038944 Complete in its incompleteness,
M. Mojsilovic & F. Prica, Digital model, 2018.12:11.19:45

The point of origin, of potentiality, changeability and anticipation can be understood as the primacy of forces upon the form, or a difference in potential, where the difference is the entropic arrow between tension and matter (Deleuze, 2004, pp. 86-89), and form is not a physical manifestation of matter, nor is it merely the result of a realized force, but a provisional state of equilibrium between forces, in a world shaped by the singularities and the differences (Deleuze and Guattari, 1994, pp. 222-223/241). That is, the idea of matter in form is replaced by the idea of material and force (Deleuze, 2006, p. 160). The algorithmic nature and programming, as a process of the emergence of form, refer to processes of morphogenesis as the idea of the visibility of change, variability and potential.

4. Systemic Dislocation of Fragmentary Particle

Drawing on the philosophical thought of Nietzsche, Heidegger, Bataille , Blanchot, Barthes, Deleuze, and Nancy, the fragment can be seen as a constant state of becoming, separated from the whole and its parts, as something broken and as such without form, or whose form is elusive due to the fact that it is always becoming (it strives to become, but it never becomes), while this striving, this call to form, is what makes it a fragment, as

unfulfilled desire to attain the state of form (striving for finality and integrity) (Mellamphy, 1998).

Always in search of form, in a state of becoming, conceptualizing the transition from one state to another, the fragment surpasses the idea of the whole and its parts, not belonging to either. The idea of constant (recurrent) appearance implied in the idea of the fragment, opens up possibilities (is a condition) for creating (reading) differences (*differance*) as a constituent element of fragmentation towards a new world of appearance and representation: *In the eternal recurrence (return of the same), it is not the same that returns, re-presents itself, in whole or in part, but precisely the difference – or fragmentation*. If the idea of recurrence is taken from Derrida, who argues that recurrence occurs due to unrepeatability, unlike Deleuze who sees recurrence as a flow, the fragment can be interpreted as the idea of specificity and essential lack of definition. It is realized through the concept of difference, the ferment of change, and the idea of the continuity of life. The difference is, in Deleuzian terms too, always a kind of specificity, but it also appears within a whole, a whole that is always becoming, a whole that is insufficiently defined.

It could be said that fragmentation (fragment) is a specific kind of survival and that, conceptually, it stands in opposition to the ideas of fulfilment, hierarchical organization, progress and progression. The fragment does not develop in a linear and continuous way, it does not grow, but always remains within its frames that are expected to be variable, defined in terms of the limit values of its beginning, but not the end.

The fragment is seen as something dislocated, as something that breaks away from the whole to which it belonged, which dissolves, dissipates, discontinues, and disappears, but viewed – not as a negation, but as what constitutes it. That is, *in this shattering, in this dislocation, we must recognize a value and not negation* (Blanchot, 1993, p. 308). If the concept of value is understood through the idea of formal qualities, as something that contributes to defining form, as its elementary particle that contains incompletion, then we can speak of coding the incompletion as the trigger for morphogenesis.

Although broken, the fragment persists and continues its life - *Fragments are unfinished separations, in a way destined to the gap (blank) that separates them, finding in this gap not what forms (ends) them, but what prolongs them or what makes them await their prolongation - what has already prolonged them, enabling them to persist in spite of their incompletion* (Blanchot, 1986, pp. 58-59).

Conceptually speaking, the idea of fragmentation has no end because both the beginning and the end are about the whole. It never ends, its end is broken, interrupted, or simply disabled, and that is precisely where its potential lies. Precisely because it has no end but persists despite everything and never disappears, the fragment can be seen as a kind of break – *Neither beginning nor the end are ever interesting, the beginning and the end are just points. What is interesting is the middle… one begins again in the middle* (Deleuze, Parnet, 2009).

The force of potentiality is beyond abstract concepts. For Deleuze, it is virtual in the sense that opposes Bergson's critique of abstraction, who argues that the possible cannot be betrayed, because it does not fulfil nor does it negate expectations, it always remains in the zone of potentiality (realizability), and thus there is more in the idea of the possible than in the idea of the real. It can be said that the virtual is – abstract in a different way than the possible. Unlike abstract mechanisms, abstract machines are real, though not concrete, actual although not effectuated, containing a specific reality of virtual in things. They have

the abstraction of immanent force, rather than transcendental form of abstract virtuality, of other possible worlds, beyond the world that we know (Rajchman, 1998, pp. 18-20).

The condition for the emergence of the formless (*informe*) is the intensification of space that breaks with the intervals of articulated elements of the limited space and the traditional place in which it occurs as free and exceeds the framing of place, plan and programme (Rajchman, 1998). It is a matter of shifting the centre of gravity with a constant movement, motion and disappearance, in folding and folds of forms that capture the void. Multiplicity is the idea of endless folding, or endless becoming and its elusive nature that is in constant motion.

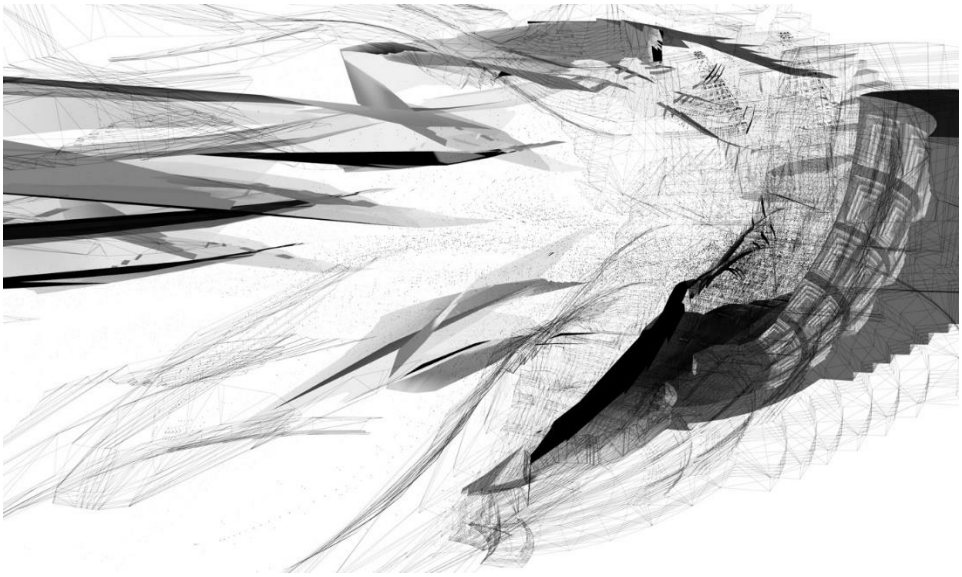

Fig. 4 Fragment 00038975 Neither Beginning nor the End,
M. Mojsilovic & F. Prica, Digital model, 2018.19:11.21:36

In fact, it is a matter of searching for a place of specificity as a condition for the production of the new, which enables constant becoming through movement (motion) and (morpho)genesis, producing differences in the conditions of openness of the system, in its own incompleteness that allows changes and (fulfilment) of potentiality.

5. CONCLUSION - SPATIAL FLEXIBILITY

The civilization trend supported by new technologies and changed perception of space and time has accepted the predominant influence of digitization, resulting in continuous questioning of the methodology of the design process. In search of new ways of designing, in the conditions of the production of generic forms, topological and fragmented forms emerge that open up other fields of possibilities and diversity, towards new concepts of space and time category.

In contrast to Euclidean geometry based on the continuity of geometric forms, fragmented forms rest on the idea of deformation and variability, in the limit zones of the greatest creativity and potentiality. A new understanding of reality shaped by digitization (of a system) has created new concepts such as self-organization, openness, contingency, emergence, and thus a new aesthetics that goes beyond the horizon of visible (Mosco, 2004). Aesthetics of the digital allows the world and all its parts to be seen in a completely new, immaterial way.

Challenging the influence of digital technologies on architectural practice, despite the introduction of new concepts and terms such as trans-architecture, generic architecture, digital morphogenesis and fluidity, can be read at the moment of its actualization, or when it is translated from the virtual (space) into a real context. The question of the flexibility of understanding these concepts concerns replacing physical form by digital design (Jeska, 2008). This concept of architectural object as a variable structure opens up the possibility of stretching architecture (Maxwell, 1996), which is no longer expected to be static, but in its actualization after the virtual. Spatial flexibility, as a concept, allows objects to be variable and to adapt to the spatial and temporal changes in the context.

Abstraction of the universal is not what explains, but what must be explained, and the aim is not to rediscover the eternal or the universal, but to create the conditions for producing the new. The world is logical in accordance with the possibilities given by abstraction, even if not all the possibilities (potentials) have been realized (Rajchman, 1998), and in a sense precisely because of it.

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KONCEPT FRAGMENTARNOSTI - IZMEĐU FORME I NEFORME

Polazeći od ideje da se apstrakrnost arhitektonskog projektovanja svaki put iznova dokazuje novim konceptima, i da je u ideji o projektu sadržan fragment njegovih internih zakonitosti, rad otvara pitanje alteracije oblika na putu ka novim prostorno vremenskim kategorijama. Nasuprot Euklidovoj geometriji koja počiva na stalnosti geometrijskih oblika, fragmentisane forme počivaju na deformacijama i promenljivosti, operišući u graničnim zonama, za projekat, zonama najveće kreativnosti i potencijalnosti. Novo razumevanje realnosti oblikovano digitalizacijom svih sistema stvorilo je osnov za oblike samoorganizacije, otvorenosti, kontigentnosti, emergentnosti. U suštini pred nama je nova estetika koja prevazilazi horizont vidljivosti na način koji otvara omogućava da se čitav svet i svi njegovi delovi, sagledaju na potpuno nov nematerijalan način. To znači da se u zonama vidljivosti naziru arhitektonski oblici zajedno sa oblicima svoje sistemske dislociranosti.

Ključne reči: *postdigitalizacija, fragmentarnost, besformnost, prostorna fleksibilnost*

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TRADITIONAL GATES IN THE PIROT AREA VILLAGES (RELATIONSHIP TO THE ARCHITECTONIC HERITAGE)

UDC 692.81(497.11)
728.6(497.11)

Branko AJ Turnšek, Isidora Đorđević

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

Abstract. *Gates represent the first architectonic element visually encountered in a rural household, and that, to a great extent, defines perception of a rural environment. Most often they are simply made, with or without decorative elements, made from the locally available materials, serving the elementary needs of a rural household. However, their position provides them with a multidimensional character, not only physical, but also symbolical. In this way, they become an important segment of architectonic heritage whose existence testifies the diversity of vernacular tradition and characteristics of an area.*
This paper analyses the appearance, function, materialization and structural design of old traditional gates in the Pirot area villages, in an attempt to emphasize the need to preserve them as testaments of cultural-historical identity of this area.

Key words: *gates, structure and materials, functionality, preservation, tradition.*

1. INTRODUCTION

„The man leaves his mark on every object he touches.“ Ivan Cankar

Architectonic space, as an ambient wherein people live, work and create is a result of human visions, wishes, understanding and time in which they live [1]. Gates, as architectonic forms, represent a recognizable element of heritage of an area. They are a product of local builders who, using the available materials and simple techniques, created works which nowadays illustrate the diversity of our vernacular tradition. Their multiple character reflects not only the functional requirements, but also esthetic needs of their creators and users.

With limited resources, with locally available building material, without aspirations of monumentality and unnecessary artsy appearance [2], structures subjected to satisfying basic human needs were made. This precisely is a recognizable criterion governing the people

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Corresponding author: Branko AJ Turnšek
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: ajbranko@yahoo.com

constructing their housing in rural areas, adapting them to their needs, terrain contours and climate conditions. According to Slobodan Maldini, the concept of vernacular architecture as: *„The term for architecture created on the foundations of a separate tradition inside a region which is separate in geographical or cultural-civilizational terms. Vernacular architecture is traditional architecture, but also architecture of a specific style which is characteristic for a certain area. Vernacular architecture is not pretentious, it is simple, homely, innate, those are traditional structures made of local materials constructed following the well-known forms and types."* [3].

The subject of the paper is an analysis of characteristics of old traditional gates in the Pirot area villages and emphasizing the need for their preservation. Even though they differ in terms of size, form, used materials, structure and way of construction, and time of construction, the gates should meet the basic requirements, primarily functional and esthetic. Time, insufficient durability of materials, negligence, disinterestedness, inexpert interventions and adaptations, and eventually physical demolition resulted in numerous examples of their devastation which destroyed or diminished their historical value and authenticity.

Pirot is specific for its location, because nearness of the roads connecting Europe and Asia determined its development. For that reason, vernacular architecture represented a resulting sum of numerous cultures, Old Slavic, Illyrian, Thracian, Roman, Byzantine and almost five centuries of Ottoman cultures. Also there are differences between the town which was on the very high road and remote villages where the impact (of oriental building style) was less intense in comparison to the original, indigenous one (e.g. the village of Gostuša).

The goals of research:

- Identify, describe and analyse appearance, function and structural designs of traditional gates from the Pirot area;
- Draw attention to the gates in the rural area of southeast Serbia, as a part of architectonic heritage which was not paid due attention until now;
- Indicate a need to preserve them and affirm them as an important segment of rural and architectonic heritage.

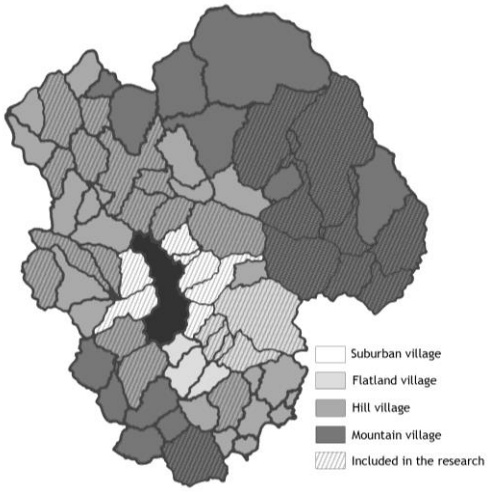

Fig. 1 Villages included in the research (Pirot, map of the area)

For the purposes of this research, a field data acquisition was performed, and on the occasion 36 villages in the Pirot are were visited (51% of the total number) and 151 gate was documented. The processed representative sample included the villages belonging to different categories, which facilitated making relevant conclusions after the performed analysis of the collected material (Fig. 1). Four types of settlements are classified on the basis of the land configuration and proximity to the town, so care was taken to balance their share in the sample. The research included 100% of suburban, 62.5% of flatland and 43% of hill and mountain villages, respectively (Table 1).

Table 1 Specifics of gates according to the settlement type (in terms of land configuration)

Settlement type	Suburban	Flatland	Hill	Mountain
Settlements included in the research / total number	7/7	5/8	15/35	9/21
Expressed in %	100	62.5	43	43
Share of old gates	Very small	very small	small	Largest (in comparison to other settlements)
Material of gates and fences	wood, adobe	Wood, adobe	wood, adobe, stone	Wood, stone
Canopy cover	S-tile, roof tile	S-tile, roof tile	S-tile, roof tile	Stone slates, roof tile

2. About Gates as an Architectonic Form in Traditional Architecture

2.1. Historical context of emergence of gates and their conceptual definition

As early as when the first shelters, shrines and other significant structures were constructed, a need to protect and enclose them arose [4]. The people closed the openings in their first habitats using branches, stones, skin and bones of animals, which provided only an elementary protection from the weather and wild animals. Formation of indoor spaces and more permanent dwellings also led to construction of sturdier and more durable barriers at their entrances, serving as protection [4]. For instance, huts made of twigs, as one of the first dwellings, had a door made of interwoven branches in a wooden frame. At a later date, the openings are shut using crudely hewn boards or planks, connected with wooden crosspieces [5].

The first door, although primitive in architectonic and formal senses, already had completely defined practical and symbolical function of a gate and entrance [4]. Later on the gate stands out as a separate element, when the enclosed curtilage started to form around the house. The basic function of the first enclosure was to mark the boundaries of a property, protect the household, and prevent the livestock going out or in. Initially, it was a *plot*, a fence made of stakes interwoven with twigs, mostly willow twigs for their natural flexibility. Later, there are fences made of more durable materials, such as *taraba* (picket fence). In some areas, depending on the availability of the material, the courtyards were enclosed with stone. Gates were built in agreement with the material of the fence, by interweaving of willow twigs or by nailing the upright pieces connected by a horizontal or diagonal wooden railing. The protective function was particularly prominent in the period of the Turkish rule. The remaining traces of that urban matrix and architectonic form can be found in some locations, especially on the Constantinople road, which were exposed to the passing armies.

The concepts of the door and gate have closely related meaning and in some places they are employed synonymously. In etymological terms, the word for a gate – *kapija* derives from

Turkish *kapi*, and it can be defined as a type of door or entrance into an enclosure as defined by D. Milovanović [4]. M. Mladenović talks about the gate as a showpiece of a house, and in his mind, the form of a gate contains an „inverted presentation of the house volume" intimating existence and characteristics of internal space [6].

In Serbian, the words *vratnice, dveri, portal and porta* are used, which also define the architectonic concept of an opening for passage which full determine its basic function [4]. The words *kapija or vrata* also define the geographical concepts meaning passage through some natural barrier or boundaries between various areas (Gvozdena vrata (Iron gate) in Đerdap, Demir kapija…). Gate as an engineering and architectonic form represents a boundary between the interior and exterior, a contact with the outside world, and simultaneously it is "a symbol of secure life and latent fear of dangers outside… a safe sanctuary or an illusion of one's own power" [6], it bars entrance and provides communication with the environment. In time, two forms have been established: doors and gates for wagon passage as separate elements, and doors as parts of gates.

A door as an architectonic concept determines those openings which provide communication between various spaces, i.e. block this communication between them. Miloš Matić mentions that their basic function is closing of entry openings in buildings or individual rooms [7]. In the traditional architecture, in addition to this definition, the concept of a door includes the threshold and lintel, door jamb, armature (hinges) used to mount the door panels, locks and handles. Depending on the structure of the building, certain parts can be omitted, or may have multiple roles. For instance, door jamb can be a column, i.e. a part of the roof structure. Vertical and horizontal posts forming frame of the door, create a strong bond between the gate wings and massive walls of the house, whereby the wings are the movable element closing and opening the space, establishing or interrupting connection with the exterior.

2.2. Traditional architecture and symbolical meaning of a gate

A. Deroko, speaking of rural architecture, claimed that every spontaneously developed architecture is influenced by three factors: way of life and needs of population, available building material and climate of the specific area. Vernacular architecture is a subtle fusion of spatial harmony, building inventiveness and artistic inspiration of an unknown builder [8]. Abundance of physical-geographical elements, particularly relief, water, foliage, landscape and ambient values, natural environment, development and way of life of people, lends a specific cultural matrix to any area [1]. Building heritage represents a collective interpretation of an intricate complex of social beliefs of a population which are expressed through the physical form of dwellings [9]. It can be said that the choice of gate form in one environment has the same genetic code. They can be very simple, but also decorated with fine plastics, so in their appearance, form and details on may observe the esthetic experience of a population in an area. Sometimes, they are devoid of any visual articulation, but the character, wealth and power are expressed by the size and primary form, coarse plastics or sculptural approach to construction of the gate itself.

The multidimensional perception of a physical partition, serving to compartmentalize space, create openings on the buildings or provide security within a property also has a symbolic importance in ritual practice. The fence around a curtilage represents a boundary between the external or public area and the courtyard which is an interior or private world of a family. Courtyard doors – gates represent a symbolical gateway between on world into another [9], and

the threshold is identified with an altar for communication with the ancestral spirits, for taking communion and sacrificing [6], [10]. A balanced relationship of symbolic values and material causes is an important factor in the creation of any, and so of this architectonic form. In all the cultures, irrespective of when they were created, the symbolism of the gate is expressed in a similar way. The symbolism of elementary forms, symbols, motifs, numbers, structural designs and used material testifies about their universal character. The specifics in the combinations of the mentioned elements express autochthonic culture, identity and originality of every individual expression of style [4].

3. AREA OF RESEARCH

3.1. Old gates as a part of architectonic heritage in the rural areas of the Pirot municipality nowadays

The aspect of affirmation of culture in vernacular heritage is in the document "Charter on the Built Vernacular Heritage" by ICOMOS (International Council on Monuments and Sites), is specially emphasized: *„The built vernacular heritage occupies a central place in the affection and pride of all peoples… It would be unworthy of the heritage of man if care were not taken to conserve these traditional harmonies which constitute the core of man's own existence",* stressing that *"the built vernacular heritage is the fundamental expression of the culture of a community, of its relationship with its territory and, at the same time, the expression of the world's cultural diversity"* [11].

Very small number of old traditional gates has been preserved in the rural area of the Pirot municipality in its original, authentic form. Most of old gates and fences were demolished by the owners themselves, to replace them with new ones, or they dilapidated and fell to ruins, due to neglect, time or material fatigue. It is interesting that the majority of gates preserved in their original form are found in the houses and curtilages which are deserted now, or which only occasionally have occupants. The oldest gates, as witnessed by the owners or neighbours are more than 100 years old, and they mostly date back to the first half of 20th century. They are mostly dilapidated and in poor condition, but even as such they represent an important document of architectonic heritage in the Pirot area villages. There are examples of successful restoration of old gates, but the number of those where the attempt to preserve their original form has been unsuccessful is higher by far.

3.2. Position of the houses and courtyard organization – precondition for positioning of the gates

Gates are positioned depending on the orientation of the house to the street. A large number of housing buildings in the villages is laid along the roads – streets, and not only those built in the recent decades, but also those from the end of 19th and beginning of 20th century. Such an orientation of the houses was characteristical for Pirot after the liberation from the Turks at the end of 19th century, when a considerable number of houses was built along the street and closer to it [12], [13]. On can also observe, a certain number of cases where the granary is located in front of the houses, near the road. The reason is both in the lack of space in the densely built villages (almost all the villages in the Pirot area), and in the fact that it is easier to transport crops to the storage in this way.

In some courtyards, the house is set back into the property, so as to provide intimacy and protection, which was especially characteristic for the construction in the period of the Turkish rule. A number of outbuildings is near the house in the courtyard (*dvor*, *avlija*), and a part in other areas of the household. The courtyard most often contains granary, maize storage, hay barn (*plevnja*), buildings for livestock and poultry, firewood shed (*drvnik*), bread baking ovens (*vurnja*)… There is no uniform arrangement of buildings, it is individual for each household [14].

3.3. Classification of fences and gates

There are no considerable differences in the appearance of gates and fences in the villages on the periphery of the Pirot valley and mountain villages, safe for the fact that those in the mountain villages are smaller in size. A traditional gate consists of two sections: first, larger used for letting wagons through and which is called the great gate (in the Pirot area, it is called „*golema kapija*") and the section for passage of people, so called the small gate. By their character, the entrances to the courtyards are to a great extent adapted to wagons, and there is only a small number of those with a separate gate for pedestrians – all pass through the great gate. The fences are made of wood or stone or adobe, with a gate having a canopy, otherwise, the buildings are placed on the alignment line, bordering the street, so there are no fences. Most of the entrances are in a housing building or an outbuilding in a form of a passage - "sajvan" (Turkish word, meaning tent, umbrella, used in the Pirot area as a canopy above an outbuilding).

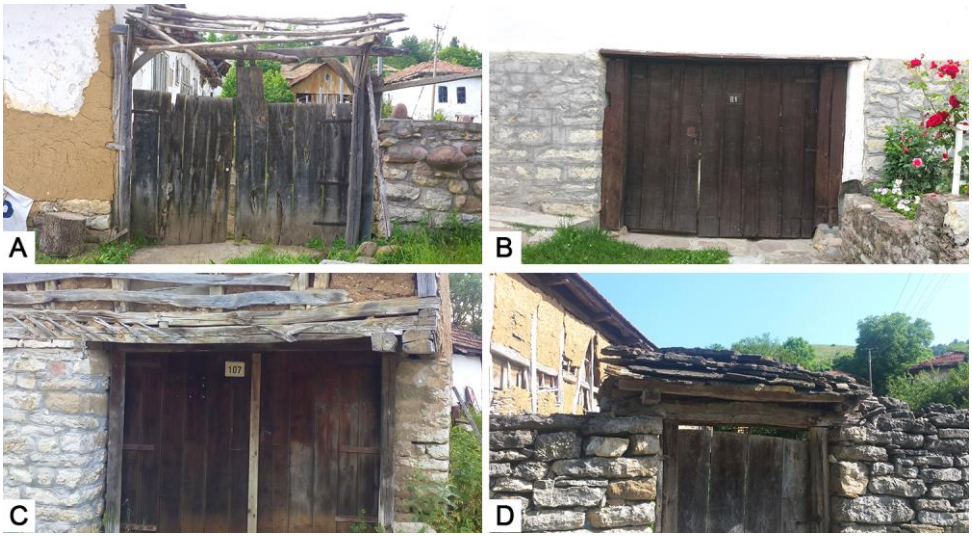

Fig. 2 Classification of gates based on the position of the house in respect to the access communication (photo I. Đorđević)

Based on the data obtained by the field research, the following classification has been developed, based on position of the house in respect to the access communication (Fig. 2):

- Gates of the houses placed next to the street line, whose courtyard has an entrance next to the residential building or an outbuilding (Fig. 2A, Visočka Ržana);
- Gates of the houses place next to the street line, whose courtyard is located behind the house, and which has a passageway though the house itself (Fig. 2B, Visočka Ržana);
- Gates of the houses set back in the courtyard, while an outbuilding with an entrance on it is placed next to the street line (Fig. 2C, Visočka Ržana);
- Gates of the houses set back into the courtyard (Fig. 2D, Pakleštica).

There is a certain number of houses where there are no gates, because the courtyards were not fenced at all, as is the case in the mountain villages, remote households, inaccessible terrain on steep gradient where there was no need for fencing. By analysing the structure and form, two types can be identified: covered and uncovered gates, which do not differ considerably in terms of form and used materials (Table 2).

Table 2 Classification of gats by structure and form

TYPES OF GATES					
	Covered gates				Uncovered
	With a roof		Passageway *sajvan*		/
	Gable	Hipped	Inside a residential house	Inside an outbuilding	/
Roof cover	Stone slates, S-tile, tile	Stone slates, S-tile, tile	/	/	/
Entrances	With separate wagon and pedestrian entrances, without separated pedestrian section				
Used materials: Gate wings	Wooden planks or combination of planks and laths (nonstandard dimensions)				
Used materials: Posts	Wooden posts: Driven into the ground, Resting on a stone footing				
Used materials: Hinges	Metal bolts: L shaped hinges, eye bolt hinges				
Used materials: Handles	Wooden or metal				
Used materials: bolts	Wooden or metal				
Size	Non-standardized				

3.4. Gates

3.4.1. Functional and formal design

In spatial and physical terms, the house is defined by the walls and the roof, which outline the house volume, while the fence in the same way defines a courtyard or curtilage [6].

A traditional gate has two entrances: for wagons and for pedestrians (Fig. 3A, Crnoklište), although there is a much greater proportion of those lacking the separate pedestrian section, so pedestrians also use the great gate (Fig. 3B, Slavinja). In the houses whose courtyard is not next to the street but behind the house, which is next to the street, there is a passageway with a gate. Its dimensions differ depending whether it is a wagon or pedestrian gate.

Left and right from the great gate (and of the small one, if it exists) are wooden posts driven into the ground or resting on stone footings. The posts are often stiffened by transverse beam and some with crosspieces, which can be set both on the interior and the exterior side. There are examples that a small gate is cut in one of the wings of the great gate, where small interventions on the structure provide a more practical door for pedestrians (Fig. 4, Temska). In the village of Gostuša there are entrance without a gate, more precise there is a passageway through the building – passageway *sajvan*, which leads to a house and it has side doors for a basement (*zevnik, zemnik*) (Fig. 5, Gostuša). In two cases, there is a frame of wooden beams on the entrance, in the third case there is none.

Fig. 3 Gates with a different number of entrances (photo I. Đorđević)

Fig. 4 Pedestran entrance obtained by cutting in the great gate wing (photo I. Đorđević)

Fig. 5 Passageway *sajvan* (photo I. Đorđević)

3.4.2. Materials of fences and gates

In the Pirot area villages the most readily accessible material is stone and wood. The simplest fences are made of roughly hewn wooden uprights and woven whips. When they are made of woven whips, they often do not have a gate – but only a passageway leading to the courtyard of the residential zone.

Picket fences, *tarabe*, can be encountered both in the villages near to the town and in the remote mountain villages. Since they were not coated by any protection, exposed to weathering, they rapidly rotted and dilapidated. Even though one may encounter examples several tens of years old, they are mainly in a very bad condition. Most frequently the upright boards are 2 to 3 cm thick, 10 to 15cm wide, 90 to 120cm high (Fig. 6A, Rsovci). The boards are rightly cut, pointed at the top, almost never of uniform dimensions. They are installed on the stakes driven into the ground, at a distance of around 3m, and they are connected by nailing them to two railings, which testifies that they are recent. Gates in such fences are made of the same elements, and for the purpose of stability and strength, the railings are additionally stiffened by one or two diagonal crosspieces.

Stone was used for construction of fences in mountain villages, where it was easily available. The fences made of stone can be seen more often, which is certainly due to the durability this material. Stone was broken or dressed and laid in an irregular course, without using any binder, resulting in the fences of very varied individual dimensions (Fig. 6B, Dojkinci). The stone fences covered on top by S-tile are rare (Fig. 6C, Vlasi). With such fences, different types of wooden gates can be observed (made of laths or boards, with or without canopy).

The third type of traditional fence is the made of adobe (bricks made of soil and baked in the sun) covered with S-tiles, and later with roof tiles (Fig. 6D, Prisjan). Such walls-fences are 1.5 to 2 blocks wide. Such fences are characteristic for the villages located on the periphery of the Pirot valley, while there are none in the mountain villages. The gates are the same, both in terms of material and form, as in the stone fences.

Fig. 6 Types of fences (photo I. Đorđević)

Irrespective of the fence material, wood used for construction of gates was the variety availably in the vicinity of villages themselves. It could be beech, ash, bitter oak, oak or hornbeam, but must often it was softwood, for its durability.

3.4.3. Structure of the fence and gate

In construction, one can particularly recognize the materialization principle (material availability principle), and mimicry-mimesis principle (relationship to the surroundings principle – "spirit of place") [15].

A number of traditional gates were covered with a canopy, which extended their service life and they were preserved in their original form. Most often they are covered with gable canopies

(lean to and hipped roofs are extremely rare), of wooden structure. Two or four wooden posts support the roof structure made of purlins, rafters and wall plates.

The cover is S-tile, and the mountain areas for this purpose are used stone slates of various sizes and thickness, roughly dressed. Unfortunately, most of the roof covers are replaced by the tiles nowadays, because of which they lost their authenticity. Dimensions of these roofs are in accordance with the size of the gates.

Fig. 7 Extended roofs near the gates with a storage space (photo I. Đorđević)

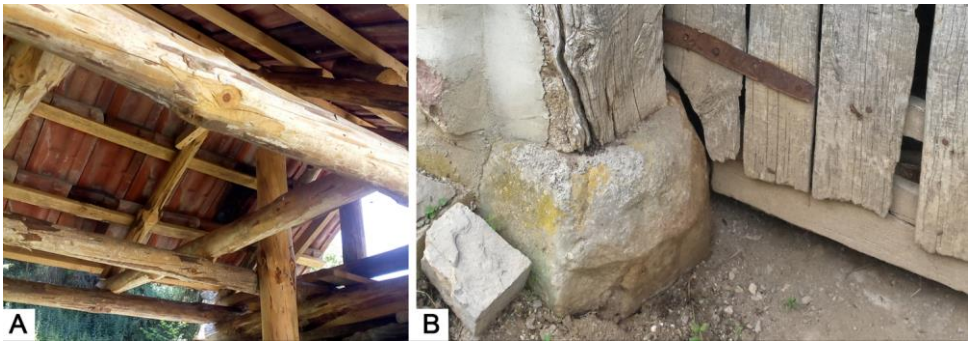

Fig. 8 Timber post resting on a stone footing (photo I. Đorđević)

The roofs can be extended as canopies which are used also for storage of tools, material or some other purpose (Fig. 7, Gostuša, Visočka Ržana). It is not rare that the roof extends to outbuildings of the village household. Such a construction (Fig. 8A, Sukovo) represents an evolution of the previous canopy. Gates are often simple structures without decorative details. The boards are either sawn or hewn, of various widths and nailed with nails to two transversal lathes. The posts are timber beams, driven into the ground or resting on a stone footing, on which the gate wings are mounted. (Fig. 8B, Brlog).

Due to the passage of time, and regarding that they have no protective coating, exposed to weather and insects, the structures quickly deteriorated, the boards warped and broke so numerous subsequent repairs on them are noticeable. In most cases those meant replacing rotted boards, reinforcing hinges, repairing or replacing the locking mechanism and handles, and subsequent paint coating or lacquering, so their authenticity is more or less compromised. There are also samples where no subsequent interventions are observable.

Gates are mainly mounted using “L” shaped iron bolts, with one pointed end driven into the post. The eye attached to the gate wing is then mounted onto the bolt (Fig. 9A, Krupac). There

are examples where the eye is fixed to the post, while the bolt is on the wing (Fig. 9B, Slavinja). Alternative method of mounting is with interlocked eyes, with long ends so as to be driven into the wing and post. The ends are bent, which provides additional strength (Fig. 9C, Visočka Ržana). The number of hinges depends on the mass of the wings, but the most common number is two. Older gates have wooden hinges, but there is few of them because they were replaced with metal, more durable ones.

Fig. 9 Gate wing mounting (photo I. Đorđević)

Considering the condition of gates themselves, a small number of them have other elements preserved, such as the locking mechanism. For locking the gates, locks and latches were used, mostly the metal ones, which became widely present in the second half of 19th century. They are simple, without any decorations. In a small number of gates, one may find wooden latches used to close the gate from the inside. The consist of two parts – one attached to the wing, with an opening along the middle, and the other, movable, which by sliding left and right goes in or out of the opening, blocking or freeing the other wing on the gate, that is, locking it and unlocking it (Fig. 10, Gostuša, Gostuša, Nišor).

Fig. 10 Door locking mechanisms (photo I. Đorđević)

Instead of a handle, for the purpose of easier opening and closing, there are knockers, having a double function. They are small, simple and without decorations. The original wooden handles are very rare because considering their dimensions they were easier to brake and they fell off the gates. In the mountain villages they have simple forms (Fig.11, Dojkinci, Crnokliště, Pakleštica).

Fig. 11 Gate handles (photo I. Đorđević)

3.4.4. Decorative elements on the gates

The artistic expression of the gates can be discussed only after the imperative of their functionality has been satisfied [6]. It is noticeable that they do not differ much mutually in form and size. Very often, some details contribution to the difference in their style can be observed. It is evident that functionality is in focus, while fine decorations are not present. The material status of their owners was expressed through the gate size.

There is only a few gates which have a sort of a decoration or attempts and stylization of details. Some of them have a number of thin laths in their upper sections, which are cut in different way on their tops, for esthetic purposes (Fig. 12, Slavinja, Crnoklište, Sukovo). Such examples are the most numerous in the villages nearby Pirot, so it can be assumed that the need for esthetic details was learnt from the urban environment, by copying the town gates of the time.

Fig. 12 Gate decorations in the form of thin laths in their upper parts (photo I. Đorđević)

In the mountain villages, there are almost no decorations but the gates of neighbouring villages of Rsovci, Visočka Ržana, and Slavinja, there is an almost identical way of decoration obtained by placing wooden panels cut in a form of an arch at the top of the gates, or vertical inserts made of lathes. This similarity in door decoration shows that, most likely, it is a work of one and the same craftsman, or a copy (Fig. 13).

Fig. 13 Similar way of decoration of gate wings (photo I. Đorđević)

Another form of decoration was observed, on the posts next to the gates, where horizontal grooves are made at the top and the bottom (Fig. 14A, Dojkinci), and only in Temska village, they are shaped in a different way. Namely, their builder retained the original dimensions of the post at the bottom and the top, while the middle section was rounded and thinned. The same principle was used for braces (Fig. 14B, Temska), except for rounding their middle section. In the same village, at several locations, an identical or similar way of post or braces decoration was implemented (Fig. 14C, Temska).

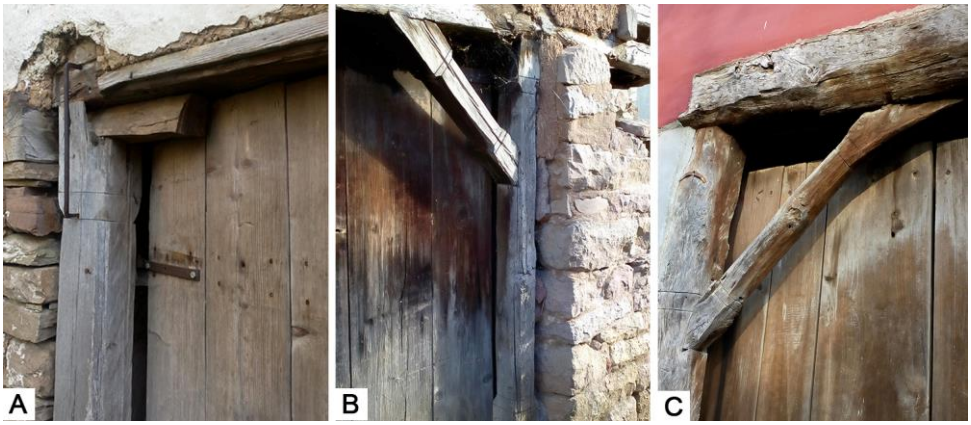

Fig. 14 Decoration of the posts and braces (photo I. Đorđević)

Impressive dimensions of gates and decorations are the result of the owners intention to demonstrate their status and financial standing, while the less well-off people only observed their function. But, considering that only wealthier households could provide covered gates, only such gates survived to this day, implying that the analysed examples are exactly those of the wealthy households.

3.4.5. Gates - keepers of privacy

Gates in the villages of the Pirot area, apart from their basic function, with their size keep the privacy of their owners by screening the property from the curious eyes of onlookers. Some are over three meters high. Next to them are stone or adobe walls and outbuildings. Counting as well those houses whose courtyards are accessed through the tunnels inside the housing buildings, a large number of households is protected in isolated so there is no visual contact with the inner yard. The fact that most of the gates dates back to the end of 19th and 20 century, suggests that the need to protect the property and family is the result of the long Turkish occupation.

3.5. New gates

In the villages of the Pirot area, the authentic wooden gates were replaced by more durable metal gates. It can be conclude that new generations, just as their ancestors, are not interested in the esthetics, but functionality, so the materials chose are those which will ensure durability. Of course, one can ignore those examples of gates and fences serving to advertise the status of the owner and unsuccessful attempts to imitate the traditional gates. The reason for that is in the economy and low standard of the population. The policy which caused desertion of villages and lack of understanding of importance of preservation of authentic architectonic values, also meant neglecting the heritage and tradition. A positive and the increasing trend, seen in a number of Stara Planina villages is the tendency to restore the old gates or build the new ones, in the traditional style. This is in part a result of development of rural tourism (gaining increasing popularity) or restoration of family houses used by the owners for leisure (Fig. 15, Gostuša, Pakleštica).

Fig. 15 New gates built after the traditional model (photo I. Đorđević)

4. CONCLUSION

Vernacular architecture is a materialized reflection of human spirit on the cultural distinction of a certain area. Being a product of a specific area under social and historical conditions, its preservation is invaluable, as it is a testament of cultural historical identity of a region.

Gates, as part of architectonic heritage in the Pirot area are a product of local craftsmen, and they are characterized by simplicity and functionality. Presence of decorative elements is negligible. They were built of locally available material, mostly coniferous wood, and they provided peace of mind and security to rural population. Their dimensions were varied but sufficient to let through the wagons and pedestrians. Owing to the canopies, a certain number is preserved in their authentic form. Uniformity of their form, materialization and construction are recognizable characteristics. Their shape and hermetical character, because they completely hide the inner yards, makes them similar to fortress gates, which is a logical consequence of almost five centuries of Turkish rule.

The primary issue is how to preserve all the gates from oblivion, because when they disappear the entire ambient value of architectonic matrix of the rural space is reduced, and a part of history is erased. A multidisciplinary approach of analysis of rural areas would allow preservation of this traditional architectonic element. The need to preserve the remaining facilities is imposed, as the answer to the basic question. The local community and individuals, the region and state institutions should take part in that process, simultaneously cooperating with the neighboring regions. Collaboration involves a wide range of joint activities and projects, as well as the use of others' experiences. Vernacular architecture, as important issue for the preservation of identity, is present in the area of Eastern Serbia, Macedonia and Bulgaria, and it is to a large extent matched. The approach should be systematic and systemic, through recording and listing all remaining architectural structures of this type, through their evaluation and classification, protection, researching and finding the role and places in the development of the cultural values of this and neighboring regions. An important role is played by education of the population, affirmative relations in the media and activation of higher education institutions, through adequate scientific and research programs and projects, in order to permanently develop awareness of the importance of tradition and cultural heritage and the need for its preservation. Thanks to the development of rural tourism, ethno villages and households, the awareness of the value and importance of preservation of traditional values is becoming more affirmed, so in the recent years a return to traditional architecture is noticed, where new gates can be observed next to the housing buildings, which take after the authentic ones both in the way they look and their materialization.

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TRADICIONALNE KAPIJE U SELIMA PIROTSKOG KRAJA (ODNOS PREMA ARHITEKTONSKOM NASLEĐU)

Kapije, predstavljaju prvi arhitektonski element sa kojim vizuelno dolazimo u kontakt sa seoskim domaćinstvom, i u velikoj meri definišu percepciju konkretne ruralne sredine. Najčešće jednostavne izrade, sa ili bez dekorativnih elemenata, sačinjene od dostupnog materijala služe zadovoljenju elementarnih potreba seoskog domaćinstva. Međutim, njihov položaj im daje višedimenzionalni karakter, ne samo fizički i funkcionalni, već i simbolički. Na taj način postaju bitan segment graditeljskog nasleđa koje svojim postojanjem dokumentuje bogatstvo narodne tradicije i osobenost nekog područja.

U ovom radu se analizira izgled, funkcija, materijalizacija i konstruktivno rešenje starih tradicionalnih kapija u selima pirotskog kraja, sa ciljem isticanja potrebe za njihovim očuvanjem kao svedočanstva kulturno-istorijskog identiteta ovog prostora.

Ključne reči*: kapije, konstrukcija i materijali, funkcionalnost, očuvanje, tradicija*

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