

FOLDED STRUCTURES IN MODERN ARCHITECTURE

UDC 72:624=111

Nenad Šekularac, Jelena Ivanović Šekularac, Jasna Čikić Tovarović

University of Belgrade, Faculty of Architecture, Serbia
jelenais@sezampro.rs

Abstract. *Folded structures are three-dimensional structures - spatial structures and they belong to the structural systems. The term folded structure defines a folded form of construction, including structures derived from elements which form a folded structure by their mutual relationship in space.*

For very long time this type of construction has been realized in practice only in of reinforced concrete and made on site, which conditioned the use of a very complicated shell. Development of prefabricated building led to improvements of this type of construction so that the folded structures could be derived by assembly of prefabricated elements and their relationship – monolithization on site.

Development of the research of folded structures, starting from their earliest days to today, followed the innovations and latest developments in terms of applied materials and methods of connection. The tendency for the cost effective and quicker construction pushed the folded structures made in reinforced concrete, and led to the construction realized in wood, steel and other modern materials that eventually experienced expansion.

Key words: *folded construction, spatial structure, forming folded structures, the formation of folded structures in modern architecture.*

1. INTRODUCTION

There are different ways of constructing folded structure in terms of their forms and the application of different materials they are made of. Based on the research and analysis of the formal potential of the folded constructions the systematization of folded structures was done in terms of shape and geometry. The term folded structure defines a folded form of construction, including structures made of plates and structures made of sticks which make a folded form by their mutual relationship in space. Some authors [5] also call a folded structure the origami construction.

2. THE EMERGENCE AND DEVELOPMENT OF FOLDED STRUCTURES IN CIVIL ENGINEERING

Design and construction of folded structures occurs at the beginning of the twentieth century, and is associated with the development of reinforced concrete [13]. The basic idea of creating this type of construction is striving to achieve more constructive height and greater rigidity and reduce the net weight of the structural element. The strength and stiffness of folded construction is achieved primarily by proper design of the structure, and to a lesser extent, by thickness and dimension of the elements that form it. This solution was possible to realize due to the development of structural systems and the use of reinforced concrete.

Engineer Eudene Freyssinet performed the first roof with the folded structure in 1923 as an aircraft hangar at Orly Airport in Paris. In technological terms this folded construction is made of prefabricated elements, with pre-stressed structure, which is a remarkable engineering undertaking of the time [16]. Based on the application of this pre-stressed structure Eudene Freyssinet has been called "the father of pre-stressed concrete."

Folded structures have emerged as a counterbalance to heavy frame structures, in which the net weight is very great and that are cost-effective only for ranges up to 25 m [12].

Folded structures are among the most cost-effective constructions, they use less material because of their high stiffness in the plane of maximum bending in the direction of the range [12].

The bearing capacity of full-flat panels depends on its thickness and quality of the material from which it was made. The large range of full plate becomes too thick and heavy, and as such is not economical. If we form the folded structure of the inclined panels, their vertical projection becomes the height of the folded construction, and thus enables the smaller thickness of the structural element. By the use of folded structures far greater ranges can be overcome than by the application of a full flat plate.

Folded structures are spatial structures formed by the elements in the plane, different in form and materialization. Folded structures differ in: geometric form, the form of a base over which they are performed, the manner of performance, methods of forming stiffness, function and position in the building, and the material they are made of.

By using folded structures different spatial forms can be made. The straight elements forming a folded construction can be of various shapes: rectangular, trapezoidal or triangular. By combining these elements we get different forms resulting in a variety of shapes and remarkable architectural expression.

Based on geometric shape folded structures can be divided into (Fig. 1):

- folded plate surfaces,
- folded plate frames,
- spatial folded plate structures.

Folded structures in the plane are the structures in which all the highest points of the elements and all the elements of the lowest points of the folded structure belong to two parallel planes.

Frame folded structures represent constructional set in which the elements of each segment of the folds mutually occupy a frame spatial form. This type of folded structure is spatial organization of two or more folds in the plane.

Spatial folded structures are the type of a structure in which a spatial constructive set is formed by combining mutually the elements of a folded structure.

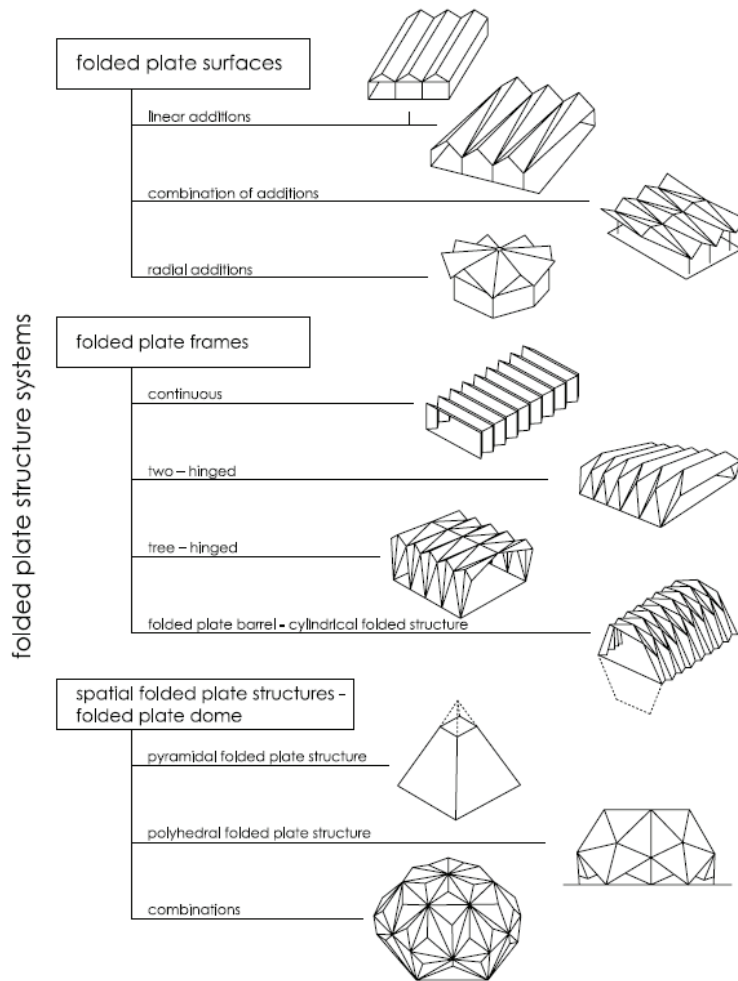


Fig. 1. Forms of folded structures [17]

The shape of folded structures affects the transmission of load and direction of relying of folded structures. Based on these parameters we can do the division in (Fig. 2):

- linear folded plate structure,
- radial folded plate structure,
- spatial folded plate structure.

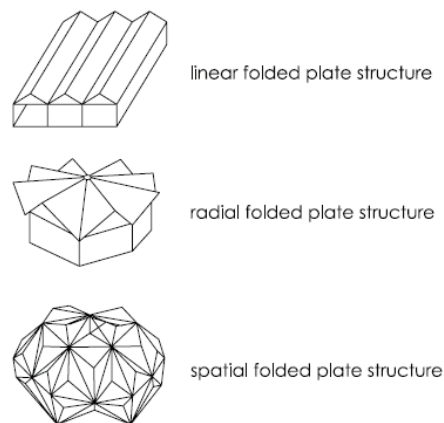


Fig. 2. Division of folded structures according to the direction of relying (Šekularac, 2010)

Combined folded constructions are carried out over the complex geometric basis, formed by the combination of simple geometric figures, rectangles and semicircles on one side or both sides. This type of folded structure can be derived in the plane or as a frame (cylindrical) structure, and represents a combination of folded structure above the rectangular base and $\frac{1}{2}$ of the radial construction (Fig. 3).

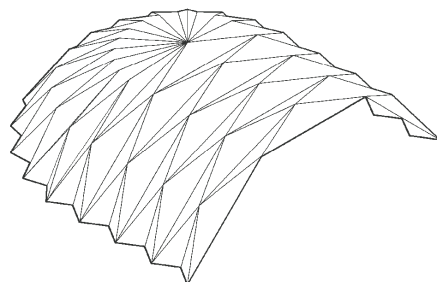


Fig. 3. Example of a combined folded structure formed by a cylindrical folded structure and $\frac{1}{2}$ of a dome structure [17]

Folded structure performed over an irregular basis is a complex spatial form. What characterizes this type of folded construction is the change of a range of the folded structure accompanying the base width. During the formation of such folded structures each triangular element of a fold has a different shape (size). This type of folded structure is formed by adjusting cylindrical folded structure to the irregular shape of the base.

By the method of execution folded structures can be divided into structures that are performed on site and prefabricated structures, which are produced in factories and

assembled on site. If it is a large span structure, the elements are not fully performed in the factory, but it is imposed as a solution the performance of elements in the form of smaller segments for easier transport and installation on site.

3. THE APPLICATION OF FOLDED STRUCTURES

Folded structures have found the application in architectural buildings and engineering structures. Based on the position in the architectural structure, this type of construction can be divided into: roof, floor and wall folded constructions. In engineering structures, bridges and retaining walls, various structural elements can be constructed on the principle of folded structures. The principle of greater stiffness of individual constructive element, by the introduction of folded form, has found application in many consumer products.

The largest number of examples of folded structures are roof structures. The need for acquiring the larger range and more cost effective structure led to the emergence of this type of structure. The development of spatial structures led to the exceptional formal solutions which directly influenced the aesthetics and visual identity of the building.

One of the most significant buildings constructed as folded form is the Chapel at the Air Force Academy in Colorado Springs, in the USA (Fig. 4). The author is the architect Walter Netsch. The basic construction of this facility consists of triangular plates - metal panels forming folded construction. The structure consists of 100 tetrahedral elements brought from the workshop and assembled on site. At the time when the facility was built it was disputed by the professional community, but later became an example of modern architecture in the USA.



Fig. 4. Air Force Academy Chapel, Colorado Springs, USA, architect Walter Netsch, year 1962 [28]

Folds of the roof structure can also be executed in wood.

Floor structures can be performed by using folded structures. This type of construction is carried out by using different materials: reinforced concrete, steel sheets, wood.

Mezzanine ceiling structure constructed as a wooden folded structure represents a trapezoidal crease with elements of veneer (plywood), and horizontal parts of the folded structure are made of solid wood. This type of ceiling called "Trofdek", patented in England, is a miniature version of the folded structure [3].

Mezzanine ceiling can be executed as a wooden folded construction and it represents a parallel "V" crease with elements of veneer or OSB composite, placed between the horizontal elements of cut solid wood. This type of ceiling is called "Kielsteg" and it has been patented in Austria (Fig. 5).



Fig. 5. Mezzanine ceiling called "Kielsteg"[26]

Mezzanine ceilings can be made from trapezoidal steel sheet [6]. This type of ceiling represents folded construction made of steel sheets. Trapezoidal sheet can independently receive and transmit the load, and together with concrete represents coupled structure.

In the design of bridges with large spans, it is important to design the construction that will meet all the defined conditions of stability and deformation. Folded form of construction has found its application in cases where the space among the supports of bridge structures is very large and it is necessary to transfer great load on the bridge support. The formation of "V" or trapezoid folded over which is executed the floor pavement, represents a remarkable engineering undertaking [9].

Walls can be designed and carried out as folded structures, since by folding we get a solid construction that can accept large vertical and horizontal impacts, which enables exceptional height of the wall fabric. This type of folded structures, due to their geometry, provides an economical solution and the rational use of material when compared to the height of the building.

Walls made as folded structures can be materialized in reinforced concrete. Facility constructed with this structure is the church of Notre Dame, the city of Royan, France, 1958, with the walls built in the form of folded in "V" shape of reinforced concrete. Viable galleries, which have a constructive role of the diaphragm, are built on them (Fig. 6).



Fig. 6. Appearance of Notre Dame, Royan, France, the architect Guillaume Gillet, 1958. [24]

Construction of a warehouse, built in 1968., is an example of a simple, yet practical, wall folded structure [15]. The complete construction is made of semi-transparent polyester resin, so it is not necessary to form any holes, and the light that passes through the body is sufficient for lighting during the day. The facility conceived in this way is very light, simple to maintain, and built by the system of prefabrication.

Retaining walls serve to receive a horizontal force of the impact of the ground. Great stiffness that vertical folded structures have influenced their use in retaining walls made of reinforced concrete. Performing of a folded wall leads to a more economical solution for a retaining wall and a lower consumption of materials - reinforced concrete.

Securing of foundation pits, especially if the ground is under water, is more frequently performed by using profiled steel sheet piles and this way of security also represents the application of folded. By using this piles the foundation pits of great depth can be secured. Joints are constructed to allow certain rotation, and thus the opportunity to carry out the walls of steel sheet piles in the bends as well. This type of security of the foundation pits represents a vertical folded structure of steel and this type of pile is called Larsen planks (Fig. 7).



Fig. 7. Securing the foundation pit with Larsen planks [29]

The application of profiled sheet is also present when performing light wall partitions. If the partition wall of plaster cardboard has great height, the classical form of substructure in CW or UA profile cannot satisfy the condition of necessary rigidity and therefore it is introduced as a substructure another kind of a substructure in the form of plates of trapezoidal sheet on the total height of the projected wall. These plates of the trapezoidal sheet represent vertical folded construction made of steel sheet. Covering with plaster slabs is done over this substructure. Within such wall there is still room for thermal and sound insulation as well as space to run the installation. This wall can be run up to 10.0m of height, even as a fire wall.

The largest application of folded structures is in the formation of trapezoidal sheet. This type of folded structure can absorb and receive the load without introducing additional structure. Application of trapezoidal sheet, except as roofing, is in making the thermal insulation of roof and wall sandwich panels.

4. DIVISION OF FOLDED STRUCTURES ACCORDING TO THE MATERIAL THEY ARE MADE OF

Depending on the material they are made of, folded structures can be divided into the constructions of: reinforced concrete, wood, metal, glass and plastic materials (polycarbonate, synthetic resin reinforced with glass fibers, polyester resin, etc.). Their capacity, the possible form and application depend on the material they are made of.

4.1. Folded structures made of reinforced concrete

Concrete is the most commonly applied material for creases. A large number of authors define folded construction as the construction made only from reinforced concrete. The reason for this statement is the fact that most of the folded structures are made of this material.

Most commonly applied form of the crease is a "V" shape whose static height depends on the range and load. Folded structures of boards, cast on site, which require casing, are generally made of wood. In cases where the slope of the plate is greater than 30° a double plating is required. In this case the dimensions of folded plates are not limited. We can get a great variety of types in this way.

The installation of reinforced concrete folded structures made of composite slabs enables to form different shapes of folds in reinforced concrete [23]. When creating elements in plants, plating that is used is very simple.

On site during the formation of folded it is necessary to connect joints of plates. Thickness affects the way of monolithization in such a way that thin plates have more complicated monolithization of the joints as a result of a lack of space for their mutual connection. Folded structures can also be formed if we get one plane of the folds by joining several smaller elements, including a larger number of compounds by monolithization. In some cases, in addition to monolithization of the compounds, it is also necessary to pre-stress.

4.1.1. Truss folded structures of reinforced concrete

The reinforced concrete can form a truss folded structures. An example of a folded structure formed in such a way is a folded construction of a hangar at Gatwick airport in London. This structure was formed as a trapezoidal folded construction, i.e. as a structure with three-band bars that are not placed next to each other, but at the distance from each other, and their mutual distance is roofed by purlins. Such structure, formed by rods connected to a whole by pre-stressing, represents a trapezoidal crease in the cross section. It looks very elegant, with very small dimensions of the cross section of rods and gives the impression of a steel construction [9]. This type of construction is not common for folded structures of reinforced concrete.

4.1.2. Reinforced concrete folded structure performed in combination of full-wall and lattice bearers

Example of folded construction that is a combination of corrugated board and lattice structure has been carried out at Delft University in the building above the amphitheater, which was designed by Van den Broek [4]. Folded structure is made from cantilevered overhang, length of 32 m. This design has enabled a flexible space. It was performed as a full-wall folded structure that changes into the lattice structure above the supports.

4.2. Metal folded structures

Metal folded structures can be derived from trapezoidal sheet or truss. Folded constructions made of metal, steel or aluminum, consist of belts and diagonal bars of infilling. The construction of such folded structures does not require formwork or powerful pumps. Deformation and stability in the design of metal truss structures are of great importance. Height of trapezoidal plate affects the size of a range that can also handle its load capacity.

4.2.1. Floor folded construction of steel sheet

Bridges made of steel structures have relatively small own weight, so we tend to form their floor structure of light weight. In this case, a trapezoidal sheet, as trapezoidal fold, is one of the possible bearings of a floor construction of the bridge. As a flat pavement over the trapezoidal are installed flat sheet panels, and a wearing course runs through them [18].

4.2.2. Lattice folded structures of steel trusses

Folded structures can be made of steel trusses, over the various forms of base. Besides the roof folded construction, the construction of boundary walls is performed as lattice folded structure. This type of constructions can handle a wide range. They are used in the design of large halls, sports facilities and exhibition pavilions, since their artistic expression contributes to the visual identity of the object (Fig. 8).



Fig. 8. International Convention and Exposition Centre, Nanning, China, architects Meinhard von Gerkan and Nikolaus Goetze, construction Schlaich Bergermann und Partner, Stuttgart, 2003 [25]

4.3. Folded structures of wood

Due to limitations of the possibility of overcoming the large ranges, as well as the reduction of world reserves of wood, wood was constrained by other materials (steel, reinforced concrete) early in the second half of the nineteenth century [10]. By the application of modern technological solutions weaknesses of wood as a material were eliminated and a great use of wood and wood products in a contemporary building was enabled [8].

Folded structures made of wood are easy to transport, handle and assembly. This type of prefabricated folds on the basis of the primary supporting structure of a fold segment can be divided into: panel and truss.

4.3.1. Panel folded constructions of wood

Folded constructions of wood are usually formed as a panel. Wooden panel folded constructions based on their primary structure can be divided into:

- full wall panels,
- panels with grid supporting structure,
- panels with framework (panel) supporting structure,
- panels with arch supporting structure.

Joints between the wooden panels are articulated, therefore it is necessary to install additional stiffening elements - the diaphragms, which can be set as full-wall wooden elements or sticks (wooden or metal).

4.3.2. Full-wall panel folded constructions of wood

The elements of full-wall panel folded structure are constructed as compact elements of solid timber or laminated elements - plywood and the panel frame structure covered with veneer sheets [21].

Full wall element consists of cross-laminated wood panels. On the basis of the laboratory testing and research; by using newly derived knowledge has been constructed the prototype of the church, which is formed by 110 mm thick panels. Chapel St. Loup, Waadtland, Switzerland, was designed by Danilo Mondada, in 2007. [1]. Connections between the panels are established with the node plates and screws for wood.

Elements of wooden folded construction can also be formed of the panels consisting of a wooden box lined on both sides with veneer sheets. The role of the plywood is to receive the shear force in folded construction, while the elements of the frame structure in the deflections and hip receive the force of tensile and pressure. One possible way of establishing connections between the panels as the elements of folds is done with "L" metal profiles and screws [13].

"Trofdek" is a wooden folded structure with a small height of folds. This folded structure is a trapezoidal crease with sides of plywood (ribs) and the upper and lower band is made of solid wood and is used for connection between the elements of folds. "Trodek" is the commercial name of this design patented in England [3]. This type of construction has found application as a mezzanine and the roof structure, but is also used for panelling in the preparation of reinforced concrete ribbed construction.

"Kielsteg" - mezzanine construction represents a mezzanine folded structure. "Kielsteg" - element consists of upper and lower bands of solid wood and the ribs with "V" folds of plywood or OSB composite (Fig. 9). By using "Kielsteg" elements the ranges up to 30 m can be bridged. This type of structure can be implemented as a mezzanine construction of family houses and a roof construction for industrial buildings.

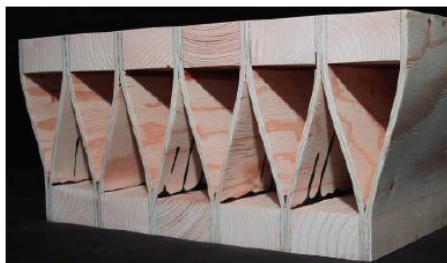


Fig. 9. Element of "Kielsteg" construction [26]

4.3.3 Panel folded construction with lattice, frame and arched supporting structure of wood

Element of panel folded structure can have a lattice, frame and arched structure, as a supporting structure. This type of panel elements means that both sides must always have set a full covering over the supporting structure.

Interconnections between full-wall panels as structural elements of the folded structure can be achieved by joining two panels: with bolts, screws indirectly over the wooden element, screws indirectly through the metal fittings.

4.3.4 *Folded construction of wooden trusses*

Elements of folded structure could be formed of wooden trusses. By combining the trusses we can get different forms of folded structures. Connection of trusses is done on site. Band sticks in the deflections and hips of folded structure and infilling bars are made from solid timber or glued laminated wood.

The choice of dimensions of the cross-section of the rod of wooden truss is affected by: the range, load, shape and dimensions of the element of a fold. Static calculation determines the precise dimensions of each rod in the lattice of a wooden element. When installing, the packages are formed on the ground. One package consisted of two lattice girders, each connected by rods along the bottom flange (Fig. 10).



Fig. 10. Installation of packages of folded bearers, Sports Hall in Medveđa, the designer of the construction LKV Center, 2001. [27]

Lattice folded structures can be made from the rods of glued laminated wood. They are used for large spans, even over 30 m. For such structures it is necessary to design and prepare a special shackle for interconnection of wooden elements in the formation of roof folded structure. The specificity of this type of lattice structure is that in places of the deflections and hip there is no duplication of rods, as elements of adjacent planes of folds which contain the grids. Characteristics of such folded structures are large cross-sections of the band sticks (hip and the deflection). This type of construction is mounted from individual elements and on site.

Formation of folded structures using wooden trusses is a modern technical and technological solution that overcomes the shortcomings of spatial structures made of concrete. Folded structures formed by using timber trusses can satisfy the high aesthetic requirements [7]. Wood as a natural material meets the high environmental requirements that any modern design must meet, and in view of obtaining natural materials as an

energy-cheap products and its possible recycling, which fits in with current trends in sustainable development.

Roofs formed in this way, as three-dimensional roof structures, are performed by the installation of pre-produced elements - wooden trusses, with unified compounds, and that enables industrial production of wooden trusses as the elements of folded structure (Fig. 11). The pursuit of such economic and more rational construction resulted in the selection of wood as a building material with excellent physical, mechanical and aesthetic properties. Installation of structures with these light elements provides convenient working on building sites and efficient installation.



Fig. 11. Mounted prototype of cylindrical folded structure formed by using wooden trusses as the elements of folded structure, Fair in Budva, author architect Nenad Šekularac, Budva, Montenegro, 2005. [17]

4.4. Folded structures of glass

Glass as a building material has intensively been applied as a structural element. By using glass alone or in combination with other materials, wall, roof and floor constructions can be made. Independent glass plate under the force of pressure is deformed - it flares up, and therefore, in order to prevent the deformation of a glass plate we associate it with another element. If we want to prevent this deformation with another glass plate, then this new feature is set at an angle relative to the base glass plate, thus forming a folds shape and achieve a spatial rigidity of the glass element. The possibility of making constructions of glass for a cylindrical folded structure is up to range 12 m [22]. This construction is designed with glass triangular elements with links realized with metal brace. This type of joint connection allows mutual stiffening of adjacent panels.

Nowadays the production of folded structures of glass does not have wider application in practice, however, there are research and development of experimental models that deal with this issue [20].

4.5. Folded structures of plastic materials

Products made of polyester resin had been widely used in the second half of the twentieth century. This material has also found its application and in production of folded structures. There are examples in practice where folded constructions have been derived from individual flat plate elements or in combination of spatial elements of "V" or "Λ" shape folds with a flat plate elements. This type of folded structures is made of polyester resin has found application in the construction of garden center facilities [19].

4.6. Folded constructions made in combination of different materials

Development of folded constructions led to application of several materials combined in a single folded structure.

During the 60s of the twentieth century, Renzo Piano had made a number of projects of temporary facilities with the construction derived in combination of steel and orthorhombic folded spatial elements of polyester resin [11]. With these projects he was trying to produce certain parts of the building at the factory and realize more economical design by selecting the type of material and reducing the weight of the elements, and thus rationalize the construction on site [2]. He experimented with use of different materials in the realization of dismantling structure for a storage of ore in the mine in Pomezí, Italy [14]. This structure consists of broken rhomboid plates made of polyester resin and reinforced with steel construction. All the interconnections between the elements were achieved with screws. Thanks to the type of material from which it was made - polyester resin, this folded construction is semi-transparent and allows a natural brightness and energy savings.

An example of making of the folded structure in combination of two materials (metal and glass) represents a test model of folded construction made of trapezoidal sheet metal and glass as a horizontal surface [22]. Coupling of these two materials is achieved by special screws. Perforations of the sheet allow the penetration of light and contribute to the artistic and aesthetic experience of space.

5. CONCLUSION

Spatial system of constructions consisting of flat elements mutually set at an angle represents a folded construction. First folded structures are related to reinforced concrete structures and for long time there has been present a prejudice that this type of construction can be performed only in that material. In the second half of the twentieth century folded structures were made of other materials: steel, wood, polyester resin and glass, and in their combination.

Applying the principles of unification and systematization as basic elements of the structural system, with a few different elements you get a flexible system of building folded structures in terms of technology and facilitate the process of production, transport and installation of folded structures.

In terms of design and visual effect forming folded structures by using different materials interesting forms and design solutions can be obtained. That makes the structures obtained in this way different and special compared to other, less complex, spatial forms.

REFERENCES

1. Buri H., Weinand Y., (2008), "Die provisorische kapelle von St. Loup", *Holzforchung schweiz*, No. 2008/2, pp. 18-19.
2. Davies R.M., (1967), "Space Structures", Blackwell Scientific Publication Oxford and Edinburgh, pp. 759
3. Fischerm R., (1964.) "Architectural Engineering, New Structure", McGraw-Hill, New York, pp. 170-171
4. García R., (2006), "Concrete folded plate in the Netherland", *The Proceeding of the Second International Congress on Construction History*, The Construction History Society, Cambridge, pp. 1202.
5. Hani B., and Yves W., (2008), "Origami - Folded Plate Structures, Architecture", *The Proceeding of 10th World Conference of Timber Engineering*, Miyazaki, Japan, IBOIS-CONF-2008-021
6. Hart F., Henn W., Sontag H., (1987), "Atlas čeličnih konstrukcija – visokogradnja", IRO Građevinska knjiga, Beograd, pp. 356
7. Herzog, Natterer, Schweitzer, Volz, Winter, (2004), "Timber Construction Manual", Birkhäuser – Publisher for Architecture, Basel · Boston · Berlin, pp. 243
8. Ivanović - Šekularac J., Šekularac N., (2011), "Impact of traditional architecture on use of wood as an element of fasade covering in Serbian contemporary architecture", *SPATIUM International Review*, No. 24, pp. 57 - 62
9. Mikelis P., (1973), "Estetika arhitekture armiranog betona", *Građevinska knjiga*, Beograd, pp. 145, pp.76, 141
10. Petrović M., (1978), "Arhitektonske konstrukcije II", *Izdavačko-informativni centar studenata (ICS)* Beograd, pp. 5
11. Piano R., (2008), "Architectural record", The McGraw-Hill Companies, New York, pp. 125
12. Romić S., (1980), "Ljuskaste konstrukcije", *Naučna knjiga*, Beograd, pp. 1, pp. 100
13. Rosman R., Nonveiller E., 1984, "Tehnička enciklopedija", *Jugoslavenski leksikografski zavod – Miroslav Krleža*, Zagreb, pp. 173, 190
14. Schierle G., (2005), "Folded Plate and Cylindrical Shell", *University of Southern California*, pp. 5
15. Scott Bader Services Ltd., (2002), *Northamptonshire*, Great Britain, 1968. year, Publication, *Composites in Construction News*, The Newsletter of the NGCC (The Network Group for Composites in Construction), Issue Number 06, pp. 1
16. Sennott S., (2004), "Encyclopedia of 20th century Architecture", Fitzroy Dearborn of the Taylor & Francis Group, New York London, pp. 486
17. Šekularac N. (2010), "Shaping of the Folded Structures by Using Wood trusses", *doctoral dissertation*, Faculty of Architecture, University of Belgrade, pp. 25, 26, 32, 119
18. Tonia D., Zhao J., (2006), "Bridge Engineering: Rehabilitation, and Maintenance of Modern Highway Bridges", McGraw-Hill Professional, USA, pp. 86
19. "Tragwerke aus platten", *VEB Verlag für Bauwesen*, (1972), Berlin, pp.30.
20. Trometer S., Krupna M., (2006), "Development and Design of Glass Folded Plate Structures", *Journal of the International Association for Shell Structures and Spatial Structures IASS*, Madrid, pp. 253-254
21. Weinand Y., (2009), "Innovative Timber Constructions", *Journal of the International Association for Shell Structures and Spatial Structures IASS*, Madrid, vol 50, pp. 115.
22. Wurm J. (2007), "Glass Structures, Design and Construction of Self-Supporting Skins", *Birkhäuser Verlag AG*, Basel, Boston, Berlin, pp. 158, 181-183
23. Zhenqiang L., (1992), "Precast Prestressed Concrete Folded Plate Industrial Building System", *PCI Journal*, Chicago, USA, pp. 41

REFERENCE WEBSITES

24. <http://en.structurae.de>, accessed 12th Oct 2009.
25. <http://www.gmp-architekten.de>, accessed 12th Oct 2009.
26. <http://www.kielsteg.at>, accessed 12th Oct 2009.
27. <http://www.lkvcentar.com>, accessed 12th Oct 2009.
28. <http://www.skyscrapercity.com>, Eglises et monuments religieux en beton, accessed 12th Oct 2009.
29. <http://www.spundwand.de>, accessed 12th Oct 2009.

NABORASTE STRUKTURE U SAVREMENOJ ARHITEKTURI

Nenad Šekularac, Jelena Ivanović Šekularac, Jasna Čikić Tovarović

Naboraste konstrukcije predstavljaju trodimenzionalne konstrukcije – prostorne strukture i pripadaju oblasti konstruktivnih sistema. Pojam naborasta konstrukcija definiše naborasti oblik konstrukcije, što podrazumeva konstrukcije izvedene od elemenata koji svojim međusobnim odnosom u prostoru formiraju naborasti oblik.

Ovaj tip konstrukcija veoma se dugo realizovao u praksi isključivo u armiranom betonu izvođenjem na licu mesta, što je uslovljavalo primenu veoma komplikovane oplata. Razvojem prefabrikovane gradnje došlo je do unapređenja ovog tipa konstrukcija tako da su naboraste konstrukcije mogle biti izvedene montažom prefabrikovanih elemenata i njihovom vezom – monolitizacijom na licu mesta.

Istraživanje razvoja naborastih konstrukcija počevši od njihovog nastanka pa do danas pratilo je inovacije i savremena dostignuća u pogledu primenjenih materijala i načina veza. Težnja za što ekonomičnijom i bržom gradnjom potisnula je naboraste konstrukcije izvedene u armiranom betonu, i dovelo je do konstrukcija realizovanih u drvetu, čeliku i drugim savremenim materijalima koji vremenom doživljavaju ekspanziju.

Ključne reči: naborasta konstrukcija, prostorna struktura, oblikovanje naboraste konstrukcije, formiranje naboraste strukture u savremenoj arhitekturi