Pregledni rad/Review paper
Primljen/Received: 11. 1. 2019.
Prihvaćen/Accepted: 2. 5. 2019.

PREFABRICATED BUILDING IN THE CONTEXT OF PAST AND PRESENT

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Abstract: The prefabricated construction method is considered the most advanced form of industrial construction. In prefabricated construction, elements are usually produced in a stationary plant according to industrial principles and then transported to the construction site, where they are assembled and finalized into a finished structure. Lack of builders' interest and understanding, poor public perception, insufficient investment in research and development of prefabricated construction have been identified as the main reasons for the insufficient application of such type of construction. However, prefabricated construction is nevertheless increasingly applied throughout the world.

Keywords: prefabricated building, prefabricated construction systems, prefabricated elements, assembly tools

MONTAŽNO GRAĐENJE U KONTEKSTU PROŠLOSTI I SADAŠNJOSTI

Sažetak: Montažni način gradnje smatra se najrazvijenijim oblikom industrijskog građenja. Kod montažnog građenja elementi se najčešće proizvode u stacionarnom pogonu po industrijskim načelima i zatim se transportiraju na gradilište gdje se montiraju i finaliziraju u gotov objekt. Nezainteresiranost ili nerazumijevanje graditelja, loša društvena percepcija, nedovoljna ulaganja u istraživanja i razvoj montažnog građenja identificirani su kao najveći razlozi nedovoljne primjene takve gradnje, međutim, unatoč navedenom, montažno građenje sve se više primjenjuje u cijelom svijetu.

Ključne riječi: montažno građenje, montažni sustavi građenja, montažni elementi, sredstva za montažu

1. Introduction

The prefabricated construction method means the construction of building structures using prefabricated elements that are previously produced and are assembled on a desired site [1]. Prefabricated construction is the most advanced form of industrial construction [2]. Although present in all construction industries, it is still most common in building construction [1]. In prefabricated construction, structures are made by assembling previously produced large construction elements [1], i.e., elements are usually produced in a stationary plant according to industrial principles and transported to the construction site where they are assembled and finalized forming the finished product by production methods and means [2]. A less common case is that production is organized on the construction site in order to make savings in transport, but then quality and industrial technology deteriorate [1]. Material resources, environmentally-friendly production and state-of-the-art technological equipment and materials facilitate modernization of prefabricated structures, and prefabricated construction is increasingly widespread throughout the world and is increasingly applied [3]. Lack of builders' interest and understanding, inadequate bank policies, poor public perception, insufficient investment in research and development of prefabricated construction have been identified as the main reasons for the insufficient application of such type of construction [4].

2. History of prefabricated construction

Construction with finished elements is not new, i.e., in ancient times construction elements were prepared in the field (stone blocks in quarries), then transported and placed in pyramids and temples [5] (Figure 1).

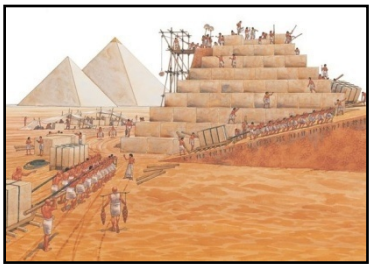

Figure 1. Construction of a pyramid [6]

Around 43 BC, the Romans used prefabricated elements for quick and efficient construction of their fortresses in newly-conquered Britain. In the 16th century, wooden parts of Nonsuch House were produced and painted in the Netherlands and later assembled in London. They were painted because the intention was to achieve the effect of brick and stone (Figure 2).

Figure 2. Nonsuch House [7]

From 1624, simple prefabricated houses were shipped to new settlements in British colonies. In 1851, Crystal Palace was completed in less than six months by the prefabricated construction method. Crystal Palace was assembled in Hyde Park in London from prefabricated cast iron elements [8] (Figure 3).

Figure 3. Crystal Palace [9]

From the 18th to the 19th century, prefabricated wooden buildings were built to accommodate soldiers in England, Germany and Austria and colonial administration in British colonies. Industrial production of cement elements was organized for the first time in 1838, and industrial production of reinforced-concrete elements in 1849, when French gardener J. Monier (1823-1906) made variously shaped flower pots (Figure 4).

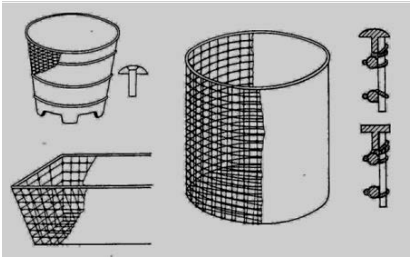

Figure 4. J. Monier's reinforced concrete flower pots [10]

The first prefabricated T-shaped girder for a rolling plant was produced in Germany in 1852. For the 1889 world exposition, Gustave Eiffel designed a temporary tower assembled from prefabricated iron elements to represent the exposition exit. Today, it is one of the most recognizable structures in the world [8] (Figure 5).

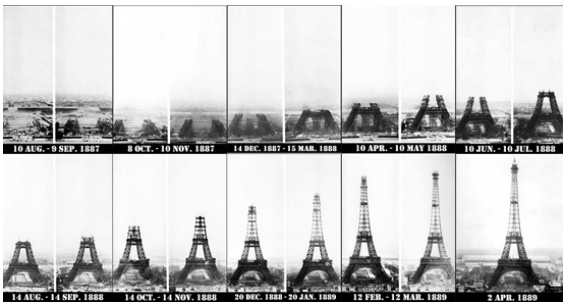

Figure 5. Eiffel Tower [11]

In late 19th and early 20th century, prefabricated elements were increasingly used: the load-bearing structure of the casino in Biarritz (1891), the first large-surface concrete roof elements (Brooklyn, USA, 1900), prestressed concrete roofs and floors (Lund system, 1905), reinforced concrete truss structure (Visintini system, 1906), first glued wooden structure

(1910), first prefabricated residential buildings in Europe (1918), serial production of prestressed reinforced concrete girders for floors and roofs (Hoyer system, 1937), prefabricated reinforced concrete girders for a bridge (span 33 m, 1938) and a hangar near Rome (span 36 m, 1939), prefabricated bridge over the Marne River (span 78 m, 1942) [5]. In 1950s, Buckminster Fuller [12] (Figure 6) described the idea of an industrial method of building entire multi-story buildings that can be transported from a factory to a construction site using large zeppelins. Namely, modern society and consequentially modern requirements in the construction industry imposed a need to introduce industrial methods in construction processes and to use prefabricated construction methods when building structures [2].

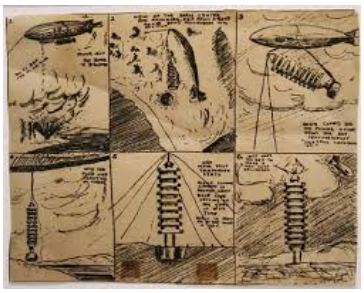

Figure 6. The idea of transporting buildings using zeppelins [13]

In France, R. Camus (1953) realized the idea of constructing residential buildings from prefabricated elements that are only assembled on the construction site [5].

3. Prefabricated construction systems

The concept of prefabricated system means structures created as a result of prefabricated construction. Considering different authors, there are many classifications of prefabricated construction systems, related to: structure, materials used, weights of prefabricated elements, percentage of prefabrication, production site, purpose of the structure and "openness" of the system [1].

In terms of structure, prefabricated systems are large-surface systems with transverse and longitudinal load-bearing walls (Figure 7), skeleton systems with frame column-beam or column-slab structures (Figure 8), spatial box-element systems (Figure 9) and mixed systems - combinations of the previously mentioned systems.

Large-surface systems are made of prefabricated plate elements one story in height andone room in length, but can also be strip-like, which is common in light systems or in industrial hall walls and roofs [1]. Large-surface systems with transverse and longitudinal load-bearing walls have a high degree of productivity and prefabrication [2] and therefore they are most common [1]. Their disadvantage is that they provide uniform building exterior solutions and spaces are defined by the load-bearing wall elements [2].

In contrast to large-surface systems, skeleton systems are highly flexible because the space is limited only by the floor slab supported by columns. The structural system is column and slab, or column and beam as a frame and floor slab. Considering that walls are not load-bearing, they can be light and made of any material available and the skeletal system is highly flexible. Seismic stability of these structures is also very good [14].

Spatial prefabricated systems consist of cores that give a final shape to the structure by putting together into a whole. They are characterized by a high degree of prefabrication (95%) because most of the work is done in a factory production plant. The assembly time on the construction site is very short, but the system requires expensive and heavy machinery in the production and assembly processes.

Mixed systems are a combination of large-surface, skeleton and spatial systems, so they can be skeletons carrying spatial cores, then large-surface systems combined with skeleton in some places, spatial systems whose cores are skeletal or skeleton systems closed by large-surface face wall elements, etc.

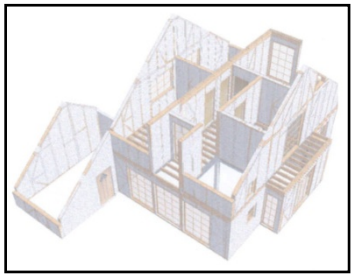

Figure 8. A skeleton house [14]

Figure 9. Prefabricated spatial system [16]

In respect of materials used, systems can be made of: heavy concretes, lightweight concretes, brick products, timber and wood products, metal and artificial materials. Most prefabricated systems are produced from concrete due to the wide range of characteristics of concrete, which is suitable for shaping, prefabrication and has a very good compatibility with other materials (Figure 10).

Figure 10. Prefabricated concrete system [17]

Prefabricated systems of clay brick products (Figure 11) with all its advantages assume a leading role in residential construction.

Figure 11. Prefabricated system of brick products [18]

Prefabricated wood systems (Figure 12) are the oldest method of prefabricated construction. As a material, wood is easily processed, easily transported and joined, is a good load-bearing element and thermal insulator, but is inferior for thermal accumulation and is not fire-resistant [1].

Figure 12. Prefabricated wood system [19]

In the prefabricated construction method, metal is most commonly used as a load-bearing skeleton of residential and industrial buildings (Figure 13). A case study conducted on an eight-story residential building showed that the prefabricated steel system has up to 78% lower mass compared to a conventional concrete structure [20]. Disadvantages such as the lack of corrosion resistance and the influence of high temperatures, or fire, can be minimized by applying appropriate protection measures [14].

Figure 13. Prefabricated metal system [21]

In a prefabricated construction system, different artificial materials find their place, and these are panels made of wood chipboards and other products, plasterboards reinforced with glass fibers, plastics (Figure 14).

Figure 14. Prefabricated house made of recycled plastics in Great Britain [22]

In terms of weight, prefabricated systems can be classified into: lightweight, with elements up to 3 t in weight, medium heavy, with elements weighing from 3 to 7 t, and heavy, with elements over 7 t in weight [2]. Weight limits have changed with the development of mechanical lifting and transport means. Besides, the classification of prefabricated systems

by weight is not precise considering small elements made of heavy materials and large elements made of lightweight materials [1].

In terms of percentage of prefabrication [2], prefabricated systems can be classified into the groups: semi-prefabricated construction systems, where less than 50% is made on the construction site from finished prefabricated elements (different semi-prefabricated floors), and the rest is performed using conventional methods; prefabricated systems where prefabrication is 50 to 90% involved; these are usual prefabricated systems, where other than assembly, only a small part of the works is carried out on the construction site; total prefabrication, where more than 90% of works on the structure is made from finished prefabricated elements, and only a negligible part is carried out by conventional technology on the site.

With respect to production site of prefabricated elements, systems can be divided into: site systems, where production is organized on the construction site, within reach of a tower crane for transport savings [2], but there is a loss in quality and industrial technology [1], stationed systems, where prefabricated elements are produced in permanent highlyequipped production plants (factories) and are completely finished in an industrial manner[2]. In these systems there are costs of transporting finished construction elements, but much more is achieved by industrial production technology [1]. Which of these two systems will have an advantage in a particular situation depends on economic and other reasons [1].

With regard to purpose, prefabricated residential systems are the most widely spread, becoming increasingly similar to each other in the world as they take over each other's improvements manifested in design, technology and solutions of individual details. These days, business buildings and halls are rarely built using conventional methods because such structures fall within the scope of larger buildings by their scale. Prefabricated bridges are economically more cost-effective because scaffolding and formwork are avoided, which is a significant cost item. Also, superstructure is made in the factory and substructure is made on the construction site at the same time. As for the prefabricated systems for civil engineering structures, these are usually individual applications or serial production of particular elements only (concrete railway sleepers, power poles, construction pit fencing elements, curbs, sewers, manholes, etc.) [1].

With regard to "openness", prefabricated systems are open and closed. Open systems mean construction of different structures of the same purpose with serially produced prefabricated elements and they are therefore more convenient and their external appearance is different. Closed systems mean application of prefabricated elements for structures that are designed according to that system only [1].

4. Advantages and disadvantages of prefabricated construction

Prefabricated construction method has its advantages, but also disadvantages. The advantages are the following:

- prefabricated construction elements can be produced under optimal conditions of technique, technology, climate and productivity
- achieves better usage of materials, reducing losses and waste
- allows continuous operation during the year, lower temperature effect on the construction work
- elements are usually assembled through a dry process, so the structure can be used immediately
- reduces the heavy physical work, staff is permanent, worker acquires the qualification fast
- faster building, lower costs, i.e. cheaper construction [1].

The advantages of prefabrication observed through the characteristics of the industrial method of construction:

- accelerated production process, i.e., shorter total construction time
- increased productivity, cheaper production and improved quality
- reduced worker strain
- continued production throughout the year
- reduction in living human work by introducing higher degree of mechanization andautomation and thus achieving greater speed and efficiency of production
- transfer of works from construction to production plants with considerablymore favorable work conditions than on the construction site
- production organization in larger batches, allowing the useof state-of-the-art work facilities and thus achieving higher productivity, betterquality, lower production costs [2].

In addition, research shows that prefabricated construction brings environmental, economic and social benefits, i.e. prefabricated construction could contribute to sustainable construction in densely populated urban areas [23]. Also, prefabricated construction is considered to be most efficient for reducing waste in the context of construction [24] and for achieving productivity, reducing work demands and improving working conditions [25]. As advantages of prefabricated construction over conventional construction, it is emphasized that this type of construction is faster, requires less investor activity, and insulation of external walls is better, which leads to lower consumption of thermal energy [26]. A study aimed at establishing energy efficiency (cooling, heating, lighting) of individual prefabricated units found a significant influence of artificial lighting on the total energy consumption in the units where daylight was not well utilized [27]. Covering prefabricated buildings with retroreflecting materials (especially southern and eastern wall) can reduce internal temperature up to 7°C. Often only one of these advantages can be sufficient to apply prefabricated construction [28]. Thus, e.g. in industrially developed countries lack of skilled construction workers, and in countries with cold climate better use of short construction season can be in favor of prefabricated construction [5].

Disadvantages of the prefabricated construction method are high initial investments, costs of transport of construction elements, large number of connections, and uniformity, or standardization of structures [1]. However, it should be borne in mind that design of a prefabricated structure has a significant role in customer's decision [4].

Some other disadvantages of prefabricated construction are limited product selection and flexibility, high initial investments in equipment and physical facilities, the necessity of organizing large batches, specialized workforce and the need for organized preparation of work, which must take into account all activities and physical facilities because production does not tolerate improvisation [5].

Regardless of these disadvantages, industrialization of construction has pervaded the building trade, and prefabricated construction as its most productive part is becoming something without which modern construction cannot be imagined [1]. Namely, construction time of a project is reduced by as much as 40% compared to conventional construction, according to some sources. In addition, results of research conducted in Great Britain and Brazil show that the progress in prefabricated construction also contributes to the conventional construction method [29]. Taking an overall view, prefabricated construction has many advantages over traditional construction methods.

5. Conclusion

Before making a decision on construction of a house or other structure, it should be considered whether to build in a prefabricated or conventional manner. Namely, there are many advantages, but also disadvantages, of both construction methods. We will focus on the advantages of this construction method, which are:

- industrial production

- organization of production in larger batches
- components are highly serial, ready for installation
- material quality control is better
- accelerated production process, i.e., shorter construction time
- increased productivity
- cheaper production
- improved quality
- reduced use of scaffolding and formwork on the construction site
- reduced worker strain and improved working conditions
- reduced workforce engagement on the construction site
- the structure can be used immediately
- continued production throughout the year
- less material waste and savings in thermal energy consumption.

Only one of the above advantages can be sufficient for application of prefabricated construction. Although advantages of prefabricated construction are numerous, prefabricated construction is still not as popular as conventional construction due to limitations in design and it is often used for temporary housing after natural disasters or for temporary housing for workers. However, prefabricated buildings can now be designed at the same quality level as the traditional ones and represent a luxurious place to live [31]. Selection of prefabricated finished houses used to be relatively modest and the shape of the house was such that it was evident at first sight that it was a prefabricated house. Today, it is no longer the case because manufacturers of prefabricated houses have numerous standard and model houses whose projects can be modified and customized in agreement with the manufacturer [26]. It is not negligible that such construction is faster and cheaper and these reasons will certainly contribute to a greater use of such construction method that is already largely present in the world.

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