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NEW HORIZONS AND OPPORTUNITIES OF MODULAR CONSTRUCTIONS AND THEIR TECHNOLOGY

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Abstract **–** The use of modular construction technology has emerged as a promising solution to the challenges of the construction industry all over the world. This paper examines the new horizons and opportunities that modular construction technology offers not only in the Albanian context but also in some European countries. The paper provides an overview of the status of Albania's construction market and emphasizes the advantages of modular construction technology, including quicker construction, lower costs, and better quality control. Unfortunately, prefabricated constructions are not very present Albanian construction industry, and it is not given the proper attention due to lack of infrastructure, organizational purposes, and lack of proper experience. The paper also examines the challenges associated with the implementation of modular construction technology in Albania, exploring the history of prefabricated constructions, also including regulatory barriers, lack of awareness, and the need for skilled labor. Finally, the paper concludes by suggesting strategies to overcome these challenges and promote the adoption of modular construction technology in Albania, such as targeted government policies, education and training programs, and partnerships between industry stakeholders.

Keywords – Modular Constructions, Prefabricated, Constructions, Technology, Building Materials

I. INTRODUCTION

Modular constructions are advanced that generally are built in a couple of days or weeks. Nowadays, investors, stakeholders, and inhabitance are showing increasing interest in modular and prefabricated buildings compared to traditional constructions. In addition, modular constructions compared to traditional constructions have many benefits including higher quality, shorter construction period, the possibility of saving money, shorter work schedules, and workers and materials cost reduction in the construction site [1].

Smith (2016) describes the benefits of such construction instead of traditional ones and the different possibilities of their implementations. [2] Meanwhile, Generalova et al (2016) emphasize that modular construction can reduce costs, can improve building quality, and shorten project time mostly in the Russian market. He explains their importance in the building of multi-story and high-rise structures as well as at low elevations [3].
Zhang et al (2016) focus on the Chinese construction business industrialization timeline taking advantage of the use of BIM in modular, and prefabricated industrial constructions. The study discussed the use of specialized equipment such as

3D laser scanners in order to collect data. The use of a tacheometer was very useful for quick installation [4].
In addition, Lopez and Froese (2016), on the other hand, describe the costs associated with the two major types of prefabricated buildings, such as panel and modular. They establish which choice was more economical [5].
Mohsen et al 2008 in their study analyze the design and construction works before and after project implementation. The prediction of construction efficiency and duration were the aims of the study. Alternative construction situations were determined [6].
Using a matrix of dependency structure, Lee et al. (2017) optimized the construction process step. Construction information flow at work served as the basis for this procedure. [7].
Kamali and Hewage (2016) also discussed the methods for choosing the right Life Cycle Indicators that consider the sustainability of traditional buildings and modular homes [8].
In the meantime, Kamali and Hewage (2016) provide an explanation of how various kinds of modules are produced at factories and assembled on construction sites. These modules provided enormous advantages in terms of life expectancy, cost, and environmental preservation.
According to Sevenson (2015), a modular home that was 3D printed and built can survive an earthquake with a Richter scale magnitude of 9.0. [9].
Three Swedish timber construction methods are the subject of an innovative architectural methodology presented by Larsson et al. (2012). Up to 20 levels can be produced by each system [10].
According to Aaron Morby (2017), Tide Construction intends to erect a modular structure with two towers 44 and 38 stories high on the site of the old Essex House, which is close to East Croydon station in Greater London [11].
At the beginning of the 21-th century, new significant modular constructions arose also in Russia. The very first modular buildings were built at the beginning of the 20-th century. It was observed rapid development of implementation and learning ability, due to modern materials and manufacturing technologies equipped with relevant precisions. Many designers noted the importance of modular constructions considering their advantages. The Russian designers were most focused on the benefits of this technology but there is no classification of them yet [12].
It was needed classification of them based on their foreign experience in order to highlight their main design features and their most relevant solutions in the Russian Federation.
The modular buildings were erected from unified bulk modules. Three-dimensional modules (block box or block container) were special structures manufactured in a factory having load-bearing and enclosing structures, considering thermal parameters and their physical and mechanical properties. Was also taken into consideration their stability, strength, and consistency of geometric measurements during transportation and installation. The primary characteristic of modular construction is the use of prefabricated building parts to create the building framework. Each of the blocks must meet the requirements for strength, stability, and rigidity as independent elements and as part of the whole structure. The modules must be suitable for transportation. The ability to transport them from the factory to the construction location depends on their dimensions. Considering the rules of the road in the Russian Federation the length of the oversized cargo should not exceed 12m, the width 2.55m, and high no more than 4m from the roadway. Furthermore, taking into account the dimensions of the vehicles the maximum dimensions of the modular blocks were: width 2.5m; length 12m, and height 3.4m (sometimes the height was 3.9m).
The main feature that distinguishes modular construction from onsite constructions (volume block buildings) made of reinforced concrete, is that their main structural elements are steel and wood. Generally, steel is the most preferred material because it has the highest bearing capacity [13].

II. WHAT ARE THE MATERIALS USED FOR MODULAR CONSTRUCTION?

Generally, prefabricated buildings, use any material that a building can be made. Furthermore, they use one or two typical materials related to their structure. These materials are steel, aluminum, timber, and precast concrete.

a. Steel is the most used material for such types of constructions. Generally, it is used to make house frames. There are some advantages such as lightness, and strength, as well as resistance to fire, termites, fungus, wrapping or shrinking. Steel is one of the materials that have the highest strength-to-weight ratio. It can be manufactured with a tolerance of less than one millimeter. These structures when compared to timber frame structures take a shorter time to assemble and create almost no waste.

b. Sometimes high-grade aluminum is used for prefabricated house frames. This material is lightweight one and can be recycled relatively easily at the end of its life.

c. Meanwhile timber is highly qualified because of its aesthetic qualities. Prefab timber is often called engineered timber. Timber is a renewable material, carbon naturally, a natural insulator, flexible, and lightweight material. Some timber proprieties make it simple to work with simple equipment, which can lead to the reduction of energy consumption during construction. There are two types of prefab timber such as glued laminated timber (Glulam), and Cross-laminated timber (CLT). CLT is composed of two-way-spanning solid wood panels. Such panels can be used for walls, roofs, and floor panels. These layers are stuck to each other and each layer is placed at a 90° angle in relation to the other panel. This technology is similar to the common plywood, except that the layers are generally thicker. On the other hand, Glulam is also a structurally engineered wood. Its layers are dimensional lumber bonded together with adhesives. Glulam has high load-bearing capabilities, and dimensional stability, and can be manufactured to high or width lengths. Generally, it is used for beams and trusses. The grains of its layers run along the length of the material. This is the main difference between Glulam compared to CLT.

d. Concrete is cast and dried in a regulated atmosphere to create precast concrete. This material can be used for columns, beams, walls, floors, and stairs. It can be cast with a variety of textures, colors, or finishes. Concrete is characterized as a material with a high thermal mass (the capacity of energy storage). Furthermore, it creates a time lag for it, in order to travel into the material. Hence, the reduction of indoor temperature fluctuations is one of the biggest benefits of such structures [41].

Fig 1. A.B.C. Modular structures; source: Chris Neylon/CarbonLite; D.E.F. Prefab methods; source: Bilanol/iStockPhoto, brizmaker/iStockPhoto, brizmaker/iStockPhoto

III. Classification of Modular construction

There are some classifications of modular buildings according to their structural scheme, frame modules, and nodal connections [14], [15], [16].
On the other hand, according to their construction schemes they can be divided into:

a. Scheme of the compiled modules (Figure 2. A)
b. Scheme with a stiffening core (Figure 2. B)
c. Scheme with an external steel frame (Figure 2. C)

Structural schemes have the responsibility to arrange the modules in space transferring loads. The scheme of compiled modules forms a direct connection of the modules with each other horizontally and vertically along the height of the building. Vertical and horizontal loads are absorbed by each module. The strength and deformation of the building are determined by each frame module and the nodal connection between them. There is a transfer and accumulation of loads from one module to another in the compiled modules scheme in order to assess the strength and stability of the building as a whole, taking into account only one module especially with horizontal influences: wind and seismic. This type of scheme is the most widely used in the Russian Federation.

Figure 2. A Composite module [17]. B. Steel core modules C. Schemes with outer frame

For high-rise, modular buildings generally are used a scheme with steel or reinforced concrete core. The stiffness core perceives all horizontal impacts and the frame of the modules is only vertical. All vertical and horizontal loads are perceived by an exterior carrier skeleton (external steel frame). In such schemes, the modules operate separately from each other and are non-bearing once. Considering such schemes and according to the frame of the modules can be distinguished modules with supporting corner columns; load-bearing walls; and non-bearing modules.

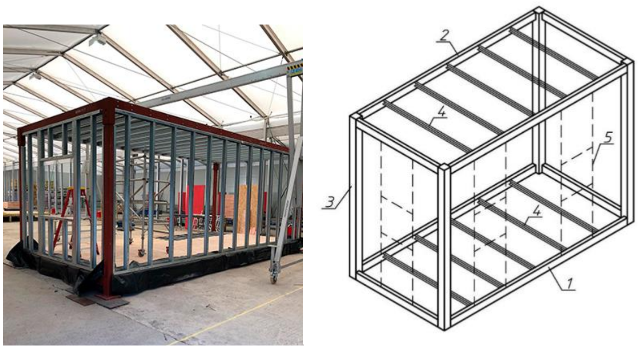

Fig. 3. A. Frame system of modules [18]. B. Typical module frame with supporting columns 1 – lower horizontal frame; 2 - upper horizontal frame; 3 - column; 4 - flooring beams; 5 - wall fencing (if necessary) [19].

The load-bearing wall modules are formed by a diagonal or cross lattice, located in the plan of the wall, and all the loads are perceived by this lattice insuring strength and immutability of the module. The connection of the frame elements sometimes in a system with retaining walls can be done by hinges according to the principle of farm formation. These kinds of systems have the advantage of using smaller sections and creating modules of large dimensions. The main disadvantage of the load-bearing systems is the limitation of the areas by the size of the module.

Meanwhile, the support columns consist of the implementation of the support legs as seen in Figure 3. B, located in the corners of the modules. Loads are transferred to these columns such as vertical or horizontal. One of the main disadvantages of this system is the need of using more powerful sections of beams and columns as well. The designing and implementation of the nodal connections of the frame elements are also complex. These connections are in charge and provide immutability to the structure. The creation of a free layout is one of the main advantages of the system.

The columns are generally made of square or rectangular sections [20], [21]. These sections have a low bearing capacity for bending. Furthermore, the use of tubular sections is preferable. Generally, the dimensions of the sections vary from 100x100mm to 150x150mm [22]. Meanwhile, the horizontal elements work mainly in bending. The most used are I-beams, [23] C-shape elements [24] as well as square and rectangular sections [25].

The process of choosing the correct type of column and beam consists in choosing also the correct type of nodal connection. There is a classification of nodal connections of modular buildings, considering the location of the building [26].

a. Intramodular connections
b. Intermodular connections
c. Connections to the foundation
d. Connections with stiffening core (if available)

The connections to the foundation consist of three main types: Embedding the post into concrete; through anchor bolts; and welding to a steel grillage or foundation embedded part. The foundation should provide perception and load transferring during installation. The nodal modes to the foundations, though the base plates on welding are widely used in the Russian Federation and not only. These types of nodes are easy to install.

Inter-module connections are used to connect modules to each other. They are constructed: on bolts, welding, and on connectors [27].

The main advantage of inter-module connections on connectors is the simplicity and reliability of mountain connections [28], [29]. The connectors often have a complex design and they are developed by a technological process of the different enterprises. In the Russian Federation, the most famous ones are Vector Praxis connectors, composed of cast steel parts and have a complex shape with threaded holes for making intermodular connections, using high-strength bolts. These bolted inter-module connections are easy to install and provide the ability to quickly disassemble modular buildings [30], [31]. For their montage is required additional plates or flanges. These additional elements increase the size of the assembly and complicate the installation of the structure. Such kinds of joints in welding are relatively labor-intensive and are not separable [32]. On the other hand, these nodes in welding are compact and have a greater bearing capacity compared to bolts. In domestic construction, the most widespread nodes are welded intermodular connections through docking plates. These types of nodes have high shear stiffness and reliability, which avoid connection deformations in the design of modular buildings.

Intramodular connections provide a significant impact on the strength works and immutability of modular buildings through the intramodular beam-to-column connections, which are performed on bolts or in welding [33].

These connections are made through gussets [34]; flanges [35] or connectors [36]. One of the main advantages of bolted connections is the easy assembly and disassembly of the structures. Meanwhile, the main disadvantages are malleability, low bearing capacity, and low stiffness of the connection. Weld connections are generally made with direct welding of the beam to the column [37]. These connections ensure the constancy of the module geometry and have higher load-bearing ability and toughness, but consist of a higher labor intensity. Meanwhile, the ability to disassemble modules is not a mandatory requirement. Due to their advantages, they are one of the most used structures.

According to a study in Lithuania, through a comparison between three types of different constructions, some important conclusions were drawn. The first building was equipped with calcium silicate bricks masonry. One of the most common structure types in Lithuania and its surrounding nations is this one. The load-bearing and not wall-bearing walls are masonry of calcium silicate bricks or ceramic. The second one is built with wooden frame modules. These types of buildings are made of wooden frames and can be built as one or multiple stories. These units are constructed from high-quality timber that complies with national standards and specifications. The third one is built with metal frame modules. These metal-framed components can support future loads and are intended for single- or multi-story structures. The coupling of the elements can be done by screws or by welding.

Fig. 4. A. Building with calcium silicate bricks [38]. B. Wooden-frame modular construction [39]. C. Metal-framed modular construction [40].

According to the research, three potential variants were created in order to satisfy the criteria of thermal resistance A++. Paroc mineral wool was used as thermal insulation in all construction iterations. The Autodesk Revit software counted the estimated costs for each building. Taking into account the calculations, the metal frame module installation cost per sqm, construction time, machine hours, and man hours, are lower than the wooden frame module and calcium silicate brick masonry. Work safety during construction, environmental protection and quality of work performed for wooden frame modules and metal frame modules are higher than in calcium brick masonry buildings. The comparison of the degree of utility of alternatives showed that wooden frame modules and metal frame modules are higher respectively 99.68% and 98.48% compared to the calcium silicate brick masonry building (68.76%) [1].

Steel is one of the most preferable materials for modular buildings. And the most widespread system of modular constructions is the one equipped with supported columns, because of the creation of free space planning solutions compare to modules with load-bearing walls. The most common welded intermodular connections are through docking plates, because of their high shear stiffness and are quite simple to install. They ensure geometry consistency and have a higher load-bearing capacity and rigidity.

IV. MODULAR CONSTRUCTION (PREFABRICATED BUILDINGS) IN ALBANIA

Albanian experience in modular construction or in prefabricated buildings is not new. Immediately after the Second World War, during the socialist period, the Albanian construction market was flourishing due to the high demand for new buildings for residential purposes. The motto of the era was to build quickly and with affordable prices. Standardization and typification were highlighted to fulfill the market demand and the need to accommodate the inhabitants. During 1950-1970 the new buildings were mostly built with retaining walls using red-coated or silicate bricks [42]. There were introduced the prefabricated structures in order to develop faster. These structures generally were equipped with a concrete core (staircase) and coated with prefabricated panels of reinforced concrete which were welded to each other. The construction of the panels was made in the fabrics and the reinforced concrete of the staircase was poured directly into the site of the construction. The construction of them was quick and efficient but do not guarantee indoor thermal comfort due to thermal bridges in their contact points and air infiltration. Also, concrete panels show poor thermal performance due to the very high U-value (coefficient of thermal transmittance) parameter. Thus, nowadays has begun the implementation of external thermal insulation in the building envelope to improve them according to the standards of the time [44].

Fig. 5. Prefabricated residential buildings, Manhattan Street, Kamez, Tirana, Albania [44].

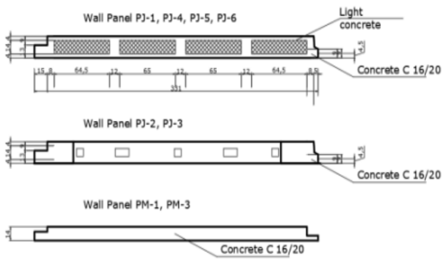

Fig. 6. Section of the prefabricated panels, Manhattan Street building, Kamez, Tirana, Albania [44].

Such experience, regarding residential buildings, nowadays is unfortunately almost stopped due to lack of infrastructure and organizational purposes. However, there are still some companies that work with precast reinforced concrete components for industrial silo structures. According to their position they are divided into categories such as columns, beams, structural panels, covering elements, and facades, based on their location and their static role in the building. Some of the elements such as beams, or other covering elements incorporate prestressed cables. It is necessary that the concrete of the beams or other structural elements must have achieved the necessary mark in order to be able to resist the stresses coming from the cables on the first day if possible. Different additives or accelerators are used to archive these criteria [43].

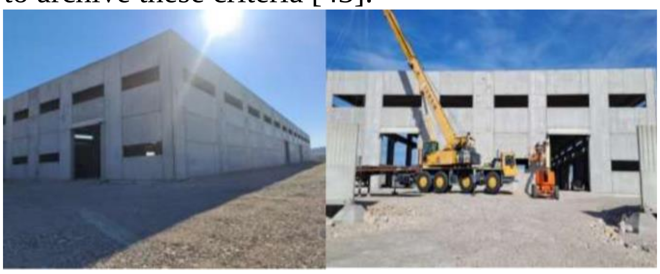

Fig. 7. Prefabricated concrete buildings IXHEM SHPK factory (ltd), Durres, Albania [43]

Prefabricated metallic structures are most recently commonly used in Albania. Generally, they are not used for residential purposes. Mostly their usage covers the industrial sector such as warehouses or metallic bridges.

Fig. 8. A. Prefabricated metal building, Tirana, Albania [45]. B. Prefabricated metallic bridges, Tirana, Albania [46].

V. CONCLUSION

Prefabricated buildings must achieve two primary criteria, including high quality and quick manufacturing assembly. These two criteria create the possibility of fast building operation. The European experience and Albanian ones show that these typologies of buildings play a significant role in the construction market, and thus cannot be neglected. Albania must promote the adaption of modular and prefabricated construction technology in order to overcome the challenges of the time, as a result of a partnership between government policies, education and training programs, and industry stakeholders.

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