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Modular buildings in modern construction

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Abstract

The article considers temporary methods of using modular units in construction. The advanced world experience in the construction of modular buildings is analyzed. It is emphasized that modular construction has the potential to shorten project design and engineering time, reduce costs and improve construction productivity. The installation of modular buildings is cost-efficient, safe and eco-friendly. Modern modular systems are based on using not only large elements such as «block rooms» but various small 3D building elements. The analysis result of Russian developments in the construction of modular buildings proves that Russia has great experience in the development of 3D reinforced concrete modules. As the research results the article shows promise for developing of modern modular construction systems in order to provide the population with affordable, comfortable and eco-friendly housing. The paper describes the prospects and relevance of introducing modular prefabricated units not only into low-rise but into multi-storey and high-rise construction as well.

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1. Introduction

In a number of studies and reports of «Habitat's UN» it is emphasized that rapid urbanization is accompanied by aggravated housing problem. The cities are growing disproportionately to the rates of economic development thus increasing the gap between the poor and the rich. The megacities with the over 10 million population are the symbols of our time, but, unfortunately, they mostly do not mean such concepts as comfortable living environment,

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equal opportunities for all population groups, healthy micro-climate, etc. The world community is worried by the fact that 26 out of 34 existing megacities are in developing countries. These cities face such problems as urban sprawl, slums and spontaneous development. According to statistics in 2005 every third habitant of a city lived in unfavorable conditions. To satisfy the world needs in urban housing it is required to build about 35 million apartments a year (approximately 95 thousand apartments a day) [1, 2].

The development of mass affordable housing construction is relevant for many countries. Economically it can be justified only as the result of applying modern industrial construction methods that are based on standardization, unification and typification. Modern materials and construction systems are introduced under the condition of extensive use of energy saving technologies [3-11]. The efforts of specialists are aimed at searching the ways of reducing the construction costs. It should be noted that nowadays the construction from offsite fabricated modules, in other words, modular construction is one of the most promising and high-tech directions of architectural and construction development in the world.

Modular technologies are widely used in low-rise buildings of different functional purposes: office and household, warehouses, sanitary and special purpose premises, etc. However, in recent years, they have been introduced in multi-storey and even in high-rise construction. Modular construction combines various technologies based on rapid construction principles. The concept «modular building» should be focused on. In modern understanding, talking about the modular components of the system, two main directions in the construction of modular buildings can be distinguished: the use of separate elements of a frame system (beams, columns, floorings, wall panels, etc.) that are produced offsite and assembled onsite; the use of 3D elements (block containers) including necessary internal engineering facilities, interior and exterior finishing and built-in furniture and equipment. It is proposed to consider these directions in detail on the examples of advanced world experience in modular construction.

2. Prefabricated building construction systems

Prefabrication, pre-assembly, modularization, a system building and industrialized buildings are the terms which are used in the correlation and individually for describing the advanced technologies in rapid construction of buildings when structural components are produced at a plant and the construction site is used only for assembling. In this section special attention is paid to systems based on separate structural elements produced at a plant.

The first example is the unique technology developed in China by the BROAD Group founded in 1988. Its production complex is based in Changsha. In 2008 its subsidiary company Broad Sustainable Building (BSB) was established with the production (BSB Central Factory) in Xiangyin, Hunan. 7 principles of sustainable development are in BSB construction technology: 1 – it is the only enterprise in the world where 90 % of modular system components are offsite prefabricated elements (production wastes – 1 %); 2- energy consumption efficiency is 5 times higher than in traditional buildings; 3 – unique microclimate inside buildings with specially purified air; 4- seismic resistance (withstands the earthquake of magnitude 9); 5 – land saving (focuses on high-rise construction); 6 – saving of materials (metal structures from recycled steel); 7- durability.

The structural system is based on type-design practice of all elements: steel columns, beams (crossbeam), floorings and curtain wall panels. The most interesting module is the floor section of approximately 12.5m x 4.1m (see Fig. 1a). They are produced and equipped with necessary engineering facilities and finishing at a plant: electrical cables, concealed air outlet ports of central air conditioning and ventilation systems, heat and sound insulation, finishing details, etc. The standard height is 3.0 m. The produced modules are delivered to a construction site and assembled by bolted and welded joints. Typification of elements, high quality offsite fabrication and perfect logistics (production, storage, delivery, assembly) allow reaching amazing construction rate [12, 13].

The corporation has constructed over 30 buildings since its establishment. The following buildings are among them: a 15-storey hotel built in 6 days; a 30-storey hotel «T30 Hotel» (2012, 99.9 m) in Changsha (China) built in 15 days. Not stopping on the achieved results, BROAD Group has started an ambitious project: the construction of a building «Sky City» (838m) using their modular system (see Fig. 1b). This skyscraper is presented as a real «vertical city» of 202 floors. 83% of the building area must be used as residential apartments for about 17000 habitants. Besides, offices, a hotel, 5 schools, a hospital, stores, restaurants, 17 helipads, 6 basketball courts, 10 tennis courts and other things are provided. But the height of the skyscraper is not the most important component of the construction revolution. The unique fact is that it is planned to be built in an enormously short period of 90 days.



Fig. 1. (a) BSB Central Factory, floor section. Photo: © CEN [https://ad-i-tiv.com/2015/07/13/speed-of-construction-measured-in-floors-per-day/], (b) «Sky City» [12, 13].

Today the project is under negotiation. In order not to waste time, BROAD Group has decided to test the idea on a miniature of «Sky City», i.e. «Mini Sky City», official name – «J57 SkyTown» (57 floors, 207.8m) completed in 2015 (see Fig. 2a). It is a multifunctional building with offices, different service facilities, 800 apartments and 19 atriums of 10m height. The project feature of «J57 SkyTown» is the inner street (Sky Street) of about 5.5m width constructed inside the building with 11 % slope. The construction rate was 3 floors a day. The building was constructed in 19 working days. It is to be noted that before the construction started, 2736 modules had been produced at the plant within four months and a half.



Fig. 2. (a) «J57 SkyTown». Photo: © BROAD Group via CTBUH [http://www.skyscrapercenter.com/building/j57-skytown/19743], (b) Public housing in Hong Kong. Photo: © Generalova Elena.

One more example of introducing prefabricated structures in the construction of affordable public housing is in Hong Kong (see Fig. 2b). Prefabricated large-size elements are used in the construction of 40-storey residential buildings. Thus, mechanization, quality and construction safety increase; construction wastes are minimized; the level

of noise and air pollution at construction sites decrease. Prefabricated elements of different complexity are produced: modular facade panels, semi-fabricated plates, three-dimensional fabricated elements (kitchen units, bathrooms, garbage chutes, elevator shafts etc.). Standard zones are designed for engineering systems (gas supply, water supply and drainage) that are laid outside the house along the facade [14-17]. To optimize the number of typical structural elements Modular Flat Design has been applied in the latest decade. There have been developed 4 types of planning concepts for apartments. Modular approach provides the design development for residential houses under particular urban planning conditions.

3. Modular buildings of 3D blocks

3D modular house construction is the type of prefabricated construction based on applying 3D blocks produced offsite in advance. Their use has a number of advantages: assembling speed; high quality control at a plant; work safety as the time of high-altitude works shortens; testing and rapid introduction of new technologies at the plant; decrease of noise level and the amount of construction waste at a construction site that has a good impact on the environment, etc. The material for the constructive framework is reinforced concrete or a metal frame.

This type of construction has a long history in Russia. In Soviet times 3D block house construction was successfully introduced. It was one of the most promising methods providing high construction rate of residential buildings. In 1974 the production of reinforced concrete 3D block structures was launched in Krasnodar region for the construction of residential houses of BKR-2 type developed by Institute of Complex Design of Residential and Public Buildings in Moscow. The plant «OBD» operates and develops up to nowadays. The production line is designed to produce over 50 blocks per day. The size of the base member is 3.4m x 2.5m x 6.0 m. The area of a standard «block room» is 19.6m². Depending on the functional purposes there can be installed additional partitions, ventilation units, stairways, etc. Since 2005 almost all the residential buildings built from the blocks that are produced at the plant have 16 floors. The construction of a three-section residential house takes one month [18]. Although the achievements of this plant in the field of 3D block production are based on long-term experience in construction, design and operation, it should be noted that visually the final product has changed little. The facades are unvaried and do not correspond to the current trends in architecture. One more negative point about this technology is that 3D blocks require considerable costs for interior finishing and equipment installation after assembling.

There are some other examples illustrating the development of Russian 3D block house construction. In the industrial park «Maslovsky» in Voronezh region a factory for the production of 3D blocks «VYBOR-OBD» was founded in May 2015. The technology makes it possible to erect 17-storey buildings. It takes only 4 days to assemble one floor of a 4-porch residential house [19]. After assembling the building requires external coating. For this purpose a ventilated facade with metallic panels made from galvanized steel with polymer coating is used. It gives a building a modern look (see Fig. 3). As in the example given above the interior finishing and the equipment installation are made after a building's erection.



Fig. 3. (a) production of 3D blocks at «VYBOR-OBD» plant [19], (b) residential complex in Voronezh [19].

Having analyzed the construction experience of residential buildings made from 3D blocks in other countries it can be said that the production of modular blocks on the basis of a metal frame has got extensive development. Modular high-rise buildings require a central structural core where vertical and horizontal communications (stairs, elevators, passageways) are located. 3D modular structures are attached to the core as well. As a rule three main types of structural solutions are used for it: 1-a fabricated modular structure similar to ordinary modulus; 2-fabricated reinforced concrete; 3-a composite system from steel frame and monolithic reinforced concrete.

An interesting and illustrative example of using modular systems in construction is a high-rise residential building «461 Dean Street» being built in Brooklyn district, New York. After the completion it will be the highest modular building in the world (32 floors, 109.4m). This building is a part of a great complex «Pacific Park» and has 363 apartments (studio apartments, one-bedroom and two-bedroom apartments). At that 50 % of all accommodation units will be leased to families with low and middle income in the framework of a program aimed at providing such families with affordable housing.

In total 930 modular blocks will be required for the construction of the building. 225 types of modulus have been developed for this project design. They are produced at «FCModular» plant which was specially built for this purpose. To be more precise, at the plant the modulus become completely ready. Steel frames for modular units are brought to New York from Virginia and facade panels are supplied by the other plant. The size of a modular unit is: up to 4.57m width, from 6.10m up to 15.24m length (9.10m on average), 3m height. The production line that makes the modular units fully ready depends on their functional purpose and includes the installation of all engineering systems (electricity supply, water supply and drainage, ventilation and conditioning), equipment (bathroom equipment, kitchen equipment, etc.) and finishing elements (lamps, switches, floorings, ceramic tiles, etc.). The average production speed is 4 modules a day, approximately 1 floor a week (see Fig. 4). The most laborious and the longest process is the assembling of bathroom modular units. Therefore bathroom modular units are equipped with sub-components first and then they are built in into the main module. The ready modules are delivered to the construction site by special trucks and installed «just-in-time» at night. All parts of the building are fixed on steel columns with additional transverse crossbars to strengthen the structure. The architectural solution was developed by «SHoP Architects». Architectural engineering was done by the world famous company Arup [20-24]. It is to be noted that the production speed is not very high, but at the same time it makes it possible to achieve perfect quality, full equipment completeness and do interior finishing works.



Fig. 4. «461 Dean Street». Production of modules at "FCModular" plant. Photo: © Generalova Elena.

4. Conclusions

Summing up it should be noted that modular construction technologies are becoming widely used all over the world finding more and more applications. Modular construction is beyond the limits of low-rise construction and is extensively introduced into multi-storey and high-rise construction. In this direction energy saving construction technology is used. Material resources, eco-friendly production and the latest engineering equipment and materials are developed. It allows modernizing modular systems and introducing them in construction on a larger scale. It is very important that the use of modular units makes the construction cheaper including the construction of high-rise buildings. A myth that high-rise residential houses are only for the rich is being destroyed. This is one of the promising trends where the interested experts should find the ways of solving the problem of building affordable residential housing for different population groups under the conditions of hyperdense urban environment.

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