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The use of BIM technology in the design and construction of modular houses

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ABSTRACT:
The article presents a new trend in sustainable construction through the building of small, cheap and energy--efficient modular houses. The use of BIM technology in developing a model of a prefabricated modular building structure equipped with installations and necessary household appliances was discussed. The benefits resulting from the use of BIM (Building Information Modeling) and VR (Virtual Reality) technologies in the process of designing modular buildings were indicated.

KEYWORDS:
modular houses; small houses; BIM technology

1. Introduction

One of the best sustainable construction solutions to mitigate harm to the environment during the operational life of the building its construction process are modular houses. More and more investors are leaning towards building small houses, captivated by their simplicity, low costs and quick assembly. For people leading an active lifestyle, who often change their place of work and living, modular houses may be an interesting housing option that ensure an easy relocation without the hassle of selling and buying real estate. Portable modular houses are available to people on a limited budget and due to the current construction law regulations allowing the construction of houses with a building area of up to 70 m^2 without a building permit, they may soon dominate the landscape of many suburban areas.

The construction of a mobile home should be carried out in such a way as to shorten the investment process to the necessary minimum. This involves the need to employ only professional teams using modern technology and high-quality construction materials and products. Both the material production process and the construction processes must be based on dynamically developing automation and robotization. In publication [1], the authors presented several examples of how automation increases efficiency and reduces the number of complex design aspects. The development of computer hardware and software has enabled the computerization of the design process, which is now faster and more accurate, and the entire investment process has been improved by the available BIM technology. In the case of modular construction technology, design automation may also be related to the robotization of the production and assembly processes of houses made of large-scale prefabricated elements. Designing, using BIM technology and automation of the prefabrication production process, will enable the implementation of more complex, creative and ingenious constructions.

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2. Development of modular house technology

The first projects related to the use of standard objects prepared on the factory line, easy to transport and adapted to any combination of construction in order to shape any residential buildings, were associated with the use of sea transport containers [2]. Temporary service, commercial and residential buildings were designed in this way. In the 19th and 20th centuries, the construction of houses using modularized and prefabricated elements was developed on a massive scale [3]. Construction systems for building houses using industrialized methods were intensively implemented, in which the so-called modular coordination was used. It was a set of rules defining the interdependence of the dimensions of a building, its elements, components and technological devices used to construct them. Dimensional coordination based on the use of modules, i.e. conventional units of linear measurement, was called modular coordination [2]. The widespread use of the building module resulted in the dynamic development of the industry of prefabricated elements produced in roofed production halls, which allowed for independence from weather conditions and the production of products of much better quality.

Currently, modular construction includes frame houses and the construction of flat prefabricated buildings, the so-called SIP panels (Structural Insulated Panels) [2, 4] as well as spatial modules. The frame system is a post and beam structure designed in wood, steel or aluminum. Prefabricated beams and columns can be freely combined vertically and horizontally in a 5 x 5 m modular grid. The frame is filled with prefabricated walls composed of internal and external cladding and insulation, and the individual panels also contain windows or doors. The panel system is a type based on the construction of prefabricated flat wall and ceiling elements. They can be wooden, steel, reinforced concrete, layered or mixed. SIP wall panels are structural boards composed of wood-based cover boards, e.g. OSB boards filled with insulation made of polyurethane foam, styrofoam or mineral wool.

Spatial modules usually have a frame structure with light sandwich walls; reinforced concrete or expanded clay concrete modules are less frequently used. The process of designing a modular building includes its division into prefabricated elements manufactured in production plants, preparing their structure for transport by one or more means of transport, and developing assembly technology. In the case of spatial modules, they are appropriately equipped with basic devices, installations and window and door joinery. The publication [5] discusses the design of a multi-family building in which a library of modules was used for the functions of the hall, bedroom, bathroom, kitchen and living room, designed for two types of apartments: for single people or a young couple – type A, and for a family – two-generational – type B (Fig. 1a). Appropriate prefabricated spatial modules were developed for the functional division of apartments (Fig. 1b).

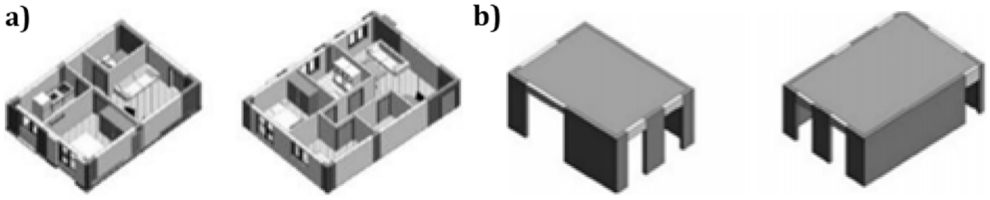

Fig. 1. Multi-family modular house: a) typical apartment designs, b) prefabricated modules [5]

In the article [5] it was pointed out that due to the specificity of designing prefabricated modules, cooperation of engineers of particular specialties via the BIM platform is impossible in real time, therefore coordination concerns the optimization of the model and its implementation. The collision detection function between designed elements from different industries allows you to prevent construction delays and minimize production costs. After obtaining a model that meets the design requirements, it is divided into prefabricated and cast-in-place parts. For example, a type B house is divided into internal and external wall panels, ceiling elements, lintel beams and other parts. The prefabricates, separated in this way, create a library of components for further implementation and production.

The publication [6] proposed a method for designing floor plans of prefabricated houses, which is based on designing a new floor plan of a multi-family building by selecting modules from a BIM object library, modifying it, combining and re-saving module libraries. In this way, an extensive library of modules in accordance with the principles of combinatorial logic allows you to systematically increase the effectiveness and efficiency of design.

In recent years, with the emergence of the idea of sustainable development and eco-logical construction, a new approach to the design of living space has appeared, referring to minimalism, savings and anti-consumerism. The article [7] discusses the architectural trend called Tiny Houses, consisting of residential buildings with a very limited living space, but functional and meeting all physical and mental needs. In European and North American countries, i.e. in highly developed regions where residents experience all the privileges and inconveniences of living in a highly urbanized space, it is preferable to locate small houses in direct contact with nature (Fig. 2) [8].

Fig. 2. Tiny house (source: https://insteading.com/building/tiny-house-builders/)

The publication [9] indicates mini container houses, i.e. modular houses, as one of the forms of Tiny Houses, defining them as very practical and economical. Ready-made solutions are used to build modular houses, which can be combined into larger projects, tailored to the investor's portfolio and needs. They have a simple, rectangular form, limited to the dimensions of the containers (approx. 2.4 m × 12 m and 2.4 m × 6 m) and their quantitative variations. A "mini house on wheels", also known as mobile homes, was considered a similar but separate category. The publication [10] also confirmed the need to distinguish the concepts of modular houses and mobile houses. Mobile homes are built in a factory and then placed on a trailer chassis to allow them to be moved at will. The owner of a mobile home rents or leases land on which he can build a house on temporary foundations. An example of such a solution is the "Casita" house, made of prefabricated elements by the start-up Boxabl, with an area of 35 m^2. Commonly known as "Elon Musk's mobile home", it has a foldable structure in such a way that its complete assembly in a new place takes only one day. The interior is arranged like an ordinary apartment – there is a kitchen, a bathroom and a room divided into a living room and a bedroom (Fig. 2) [11]. A mobile home, despite the lack of a permanent connection to the land, is subject to construction law. In the case of mobile homes, it is possible to register them as temporary buildings intended for temporary use. However, this time is limited to 120 days only. Before this period expires, you must obtain a building permit or move the mobile home to another location.

Fig. 3. Photos from the movie <<Elon Musk's mobile home>> (YouTube · FutureUnity PL 24 September 2022)

3. Design of modular houses

Technological progress has opened up the possibility of using computer software in the openBIM standard, enabling cooperation between various design and construction management programs. Thanks to this standard, designers and companies producing prefabricated modules can share information and data effectively and accurately. Designing, or rather modeling, a building using BIM technology also offers enormous opportunities when it comes to analyzing the building, adapting it to the cardinal directions, checking sunlight, and preparing architectural visualization.

In prefabricated modular buildings, it is necessary to ensure the consistency of components in terms of not only dimensions, cross-sectional features and type of materials, but also properties such as thermal resistance, tightness and fire resistance. The task is accomplished through BIM building information modeling technology, which combines structured, multidisciplinary data to create a digital representation of a given component at every stage of the modular building process, from design to construction and operation. The created building model allows you to effectively manage project costs and production and assembly operations.

At the design stage, BIM technology enables the development of a three-dimensional model of standard elements of a modular house, ensuring its precise reproduction in the prefabrication process in the factory. Creating libraries of ready-made prefabricated elements speeds up the design process when creating new modular house designs. Digital technology allows you to create a simulation of the assembly of a modular house, which eliminates the possibility of delays resulting from the need for modifications and allows you to select the optimal assembly technique of prefabricated components. The created 3D model of a modular house constitutes input data for automated prefabrication equipment (or 3D printing) and enables quality control of the component by comparing it with the model obtained by 3D scanning of the prefabricated element. Eliminating errors during prefabrication and optimizing the assembly process obviously reduce design and construction costs and ensure the proper quality of components.

BIM technology is an effective tool for multi-disciplinary coordination in the exchange of information and interaction at the design stage between model creators: architects, constructors and installation engineers. This technology not only enables the removal of collisions between the created architecture, structure and installation models, but also allows the definition of information exchange sheets (BIM Execution Plan), which define the requirements for the organization of production, assembly and effective management of the building during its operation.

The effective transmission of this information promotes continuous innovation in modular building technologies.

It is advisable to implement BIM models of modular houses in combination with VR (Virtual Reality) technology in order to visualize and recreate the building structures (Fig. 4) [12].

Fig. 4. Visualization of the BIM model of a modular house structure

VR technology enables the development of a digital animation of the assembly process of a modular house with visualization of the connections of individual elements of prefabricated structures. This process is an important tool in determining the best construction scheme, as well as ensuring resource efficiency in the construction process. By entering data on the terrain layout, staff can simulate the assembly of specific components at the construction site of a modular building and plan the construction process in such a way as to save resources as much as possible and ensure proper environmental protection. Preparing interior views of a modular building based on a 3D model allows future users to familiarize themselves with the project and adapt it to their individual needs through IT interaction functions. For example, at the simulation stage you can see the effect of changing finishing materials, furniture and equipment arrangement. Using BIM+VR technology, designers and future users can enter the spatial model of the house and from any perspective see the practical effects of using various design ideas related to e.g. changing lighting, furniture arrangement, etc.

4. Conclusions

The use of BIM technology allows you to collect all information regarding the designed facility, e.g. structural solutions, sanitary and electrical installations in one model, which opens up new opportunities to meet various needs and operations during the entire life cycle of the building. This technology, which allows collecting information from each of the three main phases of a building's life, is appreciated by developers who value a comprehensive understanding of the needs of the investor, current and future users. The BIM building information modeling concept helps to plan and visualize buildings that are much more energy efficient, use less water and provide better air quality. Thanks to this, architects and constructors are able to specify not only the architecture, structure and interior layout, but also the behavior of the facility in the future. BIM allows you to quickly make changes that are automatically visible throughout the project. At the same time, you can see what the proposed solutions look like in three-dimensional space, thus avoiding collisions and other design errors.

The use of BIM technology in the construction process has enormous benefits and can play a key role in the future of construction automation. BIM models of modular houses provide the possibility of implementing robotization and 3D printing in the prefabrication production

process, which will in turn enable the creation of more complex and precise structures, as well as reduce the costs and time of their production.

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Zastosowanie technologii BIM w projektowaniu i budowie domów modułowych

STRESZCZENIE:
Przedstawiono nowy trend budownictwa zrównoważonego w zakresie wznoszenia małych, tanich i energooszczędnych domów modułowych. Omówiono zastosowanie technologii BIM w opracowywaniu modelu prefabrykowanej konstrukcji budynku modułowego wyposażonej w instalacje oraz niezbędne urządzenia gospodarstwa domowego. Wskazano na korzyści, jakie wynikają z zastosowania technologii BIM (Building Information Modeling) i VR (Virtual Reality) w procesie projektowania budynków modułowych.

SŁOWA KLUCZOWE:
domy modułowe; mały dom; technologia BIM