Architectural design of residential modules using additive technologies

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Abstract. The study focuses on the use of additive technologies in the field of architecture and design. The relationship between 3D printing technology and the main factors influencing the formation of the structural architectural typology is revealed. The main principle of the whole variety architectural forms systematization with a set of applied technologies and materials is traced. The impact of additive technologies on materials as well as on the concept of an architectural object and its function is analyzed in detail. The work developed and supplemented the features of the architectural objects’ formation using 3D-printing. The analysis and systematization of its practical implementation in Russia and abroad, taking into account the structural and functional features, is undertaken.

Introduction

The additive technologies have entered the daily life of a man today. The possibilities of applying 3D printing are endless. The objects of any complexity can be printed in an extremely short time in the nearest future with minimal resources’ expenses and the greatest possible detailing, inaccessible by the nowadays means of production.

In the field of architecture and design the additive technologies play the role of the continuous creation of structures and products technology in a fundamental change in the generative methods of forming the spatial structure and design of products [1].

Design and construction technologies in the context of the modern world development involve a large number of options for the development of technical ideas and their adaptation to the specific design tasks. This is the so-called “green building”, and the development and use of modern materials and 3D technologies in construction, the design of the new forms in architectural environment arises as a result of the new technological capabilities and aesthetic images of the time combination [1-17].

The use of 3D printing technology in the field of construction and design of the architectural environment allows to create any form, even the most unusual one in the shortest possible time with minimal cost [2].

Domestic and foreign experience in the use of additive-digital technologies in architecture and construction

Concrete printing technology, the so-called “contour printing technology” is very young. It first came into the operation in 2014 in China. The introduction of 3D-additive technology in the construction is implemented in many countries around the world. The national associations on additive technologies
have been created in 22 countries of the world, united in the GARPA - Global Alliance of Rapid Prototyping Associations, in which the participants exchange the technologies, developing, replicating, selling the rights to use them and engaging the 3D model developers. But they are widely used so far only in the USA, Japan, Germany and China. The world leader of the industry is the American company 3D-Systems (Figure 1) [2, 7, 8].

![Figure 1. Modern construction practice using a 3D printer (Compiled by M.Yu. Drebezgova)](image)

In Russia (according to “Industrial Review” No. 990 of March 24, 2015) the introduction of the developments in the field of additive technologies is less than 1% (globally). One of the limiting factors is the use of imported equipment (mainly from manufacturers from Europe and the USA), dependence on its stable supply in sufficient volume, as well as fluctuations in foreign currency exchange rates [6].

With the new materials and innovative technologies’ invention, the new opportunities appear to optimize the geometry and create architectural spaces that can be adapted to suit the specific users for their tasks. In addition, technology has always changed the architecture. New technologies, in particular construction robotics, will change it even more: a qualitatively different level will be reached. This technology offers flexibility, aesthetics, adaptability, and regenerative architectural structure. The rational approach is due to the resources’ saving - a clear definition of the required number of consumables [10, 12-14].

**Features shaping architectural objects using additive technologies**

Additive technologies make it possible to facilitate the modeling of architectural spaces and create the new generative methods of shaping spatial structures.

The potential of 3D printing is much higher than simply repeating the forms that had been made before. To develop this potential, a large number of the research projects are being carried out using the new methods and ways to develop this area [15].

The most practical value in the study of the additive technologies application was made by the architectural company “Branch Technology”, which implemented a demonstration project of a free-form
3D printing house (Figure 2) aimed at developing the 3D printing industry in architecture. Branch Technology offers a 3D printing patent process called Cellular Fabrication or C-Fab™. This process allows the material to harden in the open space, creating a triangular matrix of ABS fiber reinforced with carbon fiber using robotic manipulators, which gives unlimited formation.

![Figure 2. The world's first free-form 3D printing house to be built using Branch Technology in Chattanooga, Tennessee](image)

At the International Association of hull and spatial structures 2018 exhibition a printed pavilion structure is demonstrated. The design has impressive dimensions of 6 meters high and almost 13 meters wide, which currently surpasses the all known printed pavilions in the world (Figure 3).

![Figure 3. Printed OneCITY bandhell pavilion in New York](image)

The initial design of the pavilion of the OneCITY bandhell was created and analyzed digitally, but it turned out that creating a large gap that would increase the cost of the project would require a steel substructure. The team, led by industry technology designers Melodia Rees and Jason Vereshchak together with engineering and construction firm Thornton Tomasetti from the Indian University Corn Studio in New York, redesigned the structure and created an optimal structure that does not require a steel structure to make large spans, except fixing base plates on the foundation.

The Kuka KR 90 robotic arm operating according to the C-Fab technology was used for printing. Its peculiarity is in the seal of the inner “skeleton” of the future construction, i.e. the construction is similar to the cellular matrix. 40 panels were printed for 10 days from carbon fiber-reinforced ABS plastic. The finished product was covered with protective UV paint. Pavilion OneCITY, which by the way, can be used in conjunction with traditional building materials such as concrete, can withstand a load of 25 mm ice layer, up to 300 mm of snow and resist at a wind speed of 145 km / h [13].
However, the development of 3D printing of buildings is constrained by scale now. To build a large house at least two or three floors high, a truly gigantic printer will be needed, the costs of which will be enormous. There is one more possibility to “teach” a three-dimensional printer to navigate by means of the special scaffolding, erecting walls according to a given program. That is why the printed buildings today are either very small or consisting of separate modules, by copying which various versions can be created [1, 18, 19].

The modularity of a residential house will provide further architectural planning organization and development of a residential house over time, depending on the possible needs of its inhabitants and the number of people in the family [16–19]. The processes of further evolution of the human environment are inconceivable without symbiosis of the people’s adaptability and the adaptability of architectural objects. The symbiosis, which is mainly achieved through the application of the principle of modularity, variability and growth, the means of which are the flexible layout and transformability of a residential house.

When increasing the volume of the dwelling it is necessary to consider:
- a rational budgetary approach;
- energy efficiency;
- unification of products with the re-using possibility;
- the system should form logical functional layouts;
- the complete architectural image at all stages of growth;
- modular design with the possibility of delivery on public roads.

The basic idea of the proposed concept is in the form of a module. The profile of enclosing structures is a closed loop, providing high energy efficiency, as well as design simplicity and unification. The modules are connected to each other with an offset, thereby ensuring free movement within the space. The house grows with the additional modules attachment.

Summary
Thus, the improvement of the architectural and planning organization of a modular building, adapted to the needs of the family, goes from a conceptual aspect to actual solutions.

The principles of adaptability of modular residential buildings use makes it possible to:
- dynamically change the architectural objects and their adaptation to various conditions, which opens up the prospects for the new spaces and territories development;
- economically use the territorial resources due to the multiple changes in space;
- reconstruct the buildings having lost their previous functional purpose;
- create the comfortable individual housing meeting the changing needs, as well as saving the investments at the public and private levels.

The use of additive technologies at the present stage determines the beginning of the fundamentally new approaches formation to the creation of residential cells and is associated with the tasks of ensuring maximum functionality, comfort, resources and time saving. The further development of additive technologies in the construction and design of the architectural environment might be more focused on the development of architectural and design trends, since this approach makes it possible to create complex forms and structures. The materials science base will also be expanded by creating the new generation materials [20–22].

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