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Creation of architectural forms by combining additive and information technologies

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Abstract. This work is devoted to the integration of advanced technologies of the modern industry for the creation of construction objects and architectural forms, as well as the development trends of this direction in the construction industry. The aim of the work is to modernize building methods for the construction of building and architectural structures by combining additive and information technologies. An empirical analysis of the construction industry market identified the main intra-industry development priorities affecting the formation of the industry, and a comparative analysis of “traditional” and additive manufacturing showed the advantages of digital technologies. The study of foreign experience has confirmed the relevance of the introduction of additive technologies into production practice. This article presents a 3D project "Digital manufacturing 2030" aimed at obtaining a positive effect from the implementation of layer-by-layer growing of complex building forms using computerization. The data proving its economic feasibility and social significance for the development of urban infrastructure and improvement of the standard of living are presented. Moreover, the percentage of "classic" and additive construction shows the effectiveness of the proposed development. The article is supplied with graphic materials and tables, as well as a detailed description of each stage of the study.

1. Introduction

In the era of digitalization of modern industry, trends in the development of main and auxiliary production are aimed at implementing the combination of advanced additive (AM) and information technologies, where the layer-by-layer production of a three-dimensional object based on 3D modeling acts as a tool for the technological process, and management includes the integration of infrastructure into a single network [1]. Additive manufacturing based on information technology is in demand in various industrial areas, however, the construction industry adheres to traditional methods of constructing objects [2], focusing on standard GOSTs of construction equipment and excluding the range of technical and economic means that can not only facilitate a number of production stages, but also reduce internal construction costs.

Analyzing the market of the modern construction industry, it is possible to single out the main factors affecting the external formation of the industry, such as the dynamics of housing commissioning, the growth rate of the volume of general construction works and financial indicators, as well as to determine the intra-industry priorities for the development of construction [3], which are primarily prefer new technologies.

That is why; the project “Digital manufacturing 2030” was developed, aimed at the collaboration of digital technologies, the purpose of which is to modernize construction methods for the construction of building and architectural structures. To substantiate the relevance of this project, it is necessary to analyze the additive and “traditional” production in the creation of construction projects, to study the experience of foreign countries in the introduction of additive technologies in the construction industry, to determine the economic feasibility and social significance of the project.

2. Materials and methods

Today, construction is one of the most resource-intensive industries. In terms of economic indicators, it consumes about 45% of raw materials and, nevertheless, has low productivity [4]. As for the creation of complex architectural forms, they, in turn, require high precision, a combination of architectural and structural solutions and aesthetics of the exterior of buildings. Thus, the use of 3D technologies will reduce the technogenic load on the environment, save up to 90% of the source material, in contrast to the current “traditional” production, as well as create construction objects of complex geometric shapes and structures in the shortest possible time.

North America is the largest consumer of additive technologies in the construction industry (figure 1), in Texas presented a comfortable house with a total area of 68 square meters, printed on a 3D printer in 48 hours, the cost of which was only 4 thousand dollars [2]. In China, 10 concrete houses were created using 3D printing technology, each costing just over three thousand pounds [5].

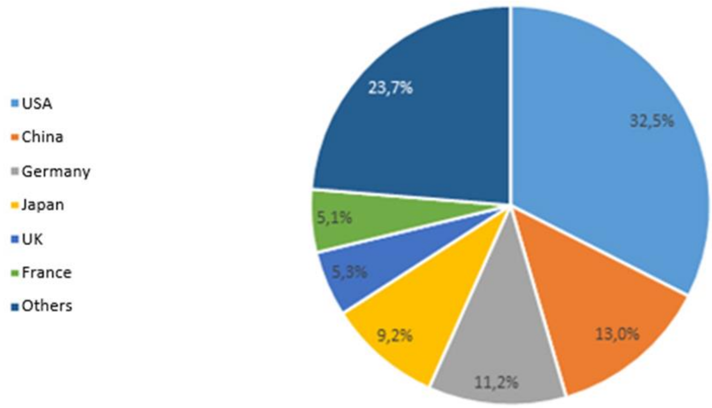

Figure 1. Consumption of additive technologies in the construction industry.

Others examples of successful use of additive technologies in the construction industry are "Office of the Future" (figure 2a) - a one-story building with an area of 250 square meters; this project was completed in 17 days [6]. A room in a hotel complex in the Philippines, 4 meters high and 120 square meters, was built in 100 hours (table 1). On its territory, there are two rooms and a Jacuzzi bath. House in Chicago with an area of 237 square meters - this project will force to redefine the traditional views of architects on aesthetics, ergonomics, design and construction methods. The sheer interior walls provide soft lighting, while the rolling arches exterior blends in naturally with its inhabitants [7]. The Volcano Pavilion in Beijing resembles clouds during a volcanic eruption. In 30 days, more than 1000 parts of the pavilion were manufactured on 20 printers (FDM) and then assembled together [7] (figure 2b).

(a) (b)

Figure 2. Innovative 3D projects in the construction industry:
a – "Office of the Future" in Dubai; b – Volcano Pavilion in Beijing.

Table 1. Economic potential for the regions of Russia, mln ton of fuel equivalent/year.

Country	Area, sq. m.	Time, hour	Cost, $
Philippines	120	100	60 000
USA	237	379	132 720
UAE	250	408	140 000
Chine	4305	1080	352 500

Comparative analysis revealed the following advantages of additive technologies in the construction of building structures [4]:

- low cost, which includes finishing and communications [8], and with the further spread of technology, a fall in prices for 3D construction is expected;
- reducing the construction time of objects due to the rapid erection of walls within a few days;
- absence of construction waste or their recycling as constituents of concrete mix, improvement of the ecological situation;
- reducing the cost of materials - no formwork, concrete slabs [8], 3D printing is carried out on the foundation;
- ease of construction of buildings with unique architecture, any geometric shape, compiled in the process of 3D-modeling;
- reduction of manual labor by automating the construction process and reducing man-hours by up to 80%;
- improving the quality of the construction site using G-code and increasing its service life - more than 130 years.

3. Results

Based on the data obtained during the study, it can be confirmed that this technology of layer-by-layer growing of building forms is relevant for many developed countries and is actively introduced into industrial practice as innovative projects (table 1), and projects printed on a 3D printer are about 50% cheaper than “traditional” construction, is similar in area and complexity of buildings.

The Digital manufacturing 2030 project represents the development of an improved model of a robotic construction robot with 3D printing functionality for the construction of buildings and the creation of architectural structures of complex geometric shapes. The versatility of this invention lies in the fact that it can work both with brick blocks that outwardly resemble a children's Lego designer [4], connecting them together using a special mixture, and with the help of a replaceable nozzle, turn into a 3D construction handle for spatial construction of structures.

A mobile construction 3D printer consists of a body on a self-propelled chassis, an on-board computer built into it and a 3D printer, where two extruders are located on the lower parts of the arrows [4] The printing process is as follows: according to the data in the g-code on the location of the building object, the percentage filling of the layer and the constructed 3D model of the future building object, the on-board computer independently determines the coordinates of building blocks using the method of static data processing [10], their height and depth, and the extruders apply the finished building mixture on the base, and subsequently on each layer, building up the object. To eliminate the appearance of cracks and increase the strength of the construction object, glass, steel, Portland cement and fiberglass are added to the fine-grained concrete used by this construction robot.

Unlike the traditional construction method, the presented project with the implementation of cultivation technology has tremendous advantages: financing is 20-30%, technogenic load - 25-35%, construction - 45-60% [11], building materials - 70%. Thus, the given data show the economic significance of the project “Digital manufacturing 2030”: the percentage of additive and “traditional” production (table 2).

Table 2. Practical significance of the project "Digital manufacturing 2030".

Cost in % of traditional construction	Main contribution	Using the project "Digital manufacturing 2030"
20-30%	Financing	Project duration with fast time to market, dramatically reduces project cost
25-35%	Technogenic load	No construction waste
45-60%	Construction	Significant reduction in manual labor as physical work is replaced by digital technology
70%	Building materials	The building mixture required by the customer is used, no additional buildings are required

The social significance of the Digital manufacturing 2030 project lies in solving housing issues related to renting housing, in cities with a population of over 5 million people do not have a permanent place of residence, so the project will allow them to acquire decent housing. Also, the pandemic and remote work have intensified the trend of population outflow to country houses, and the Digital manufacturing 2030 project is able to meet the emerging demand, which will help solve the problem of overcrowding in the center and undeveloped suburbs, and low-rise buildings and cottages will provide air circulation and the "ventilation effect", solving environmental problems.

4. Discussion

The economic effect from the implementation of such innovative 3D projects in foreign countries (table 1) proves the practical significance of the Digital manufacturing 2030 project for the country's economy, in which 3D construction will be implemented. Moreover, the revealed advantages of combining additive and information technologies open up new development trends for this direction, emphasizing its relevance.

The percentage ratio of "classical" and additive construction (table 2) shows the efficiency, consisting taken together of the addition of economy and efficiency, as well as the feasibility of the proposed development. With regard to the social significance of the project, it is aimed at positive changes in the urban environment [9] and improvement of the life of citizens as a whole by solving the housing issue.

Summing up the results of the work done, it can be noted that the project "Digital manufacturing 2030" is a construction integration of advanced technologies, in which the positive effect is achieved much faster and better with minimal losses of investment and time.

5. Conclusion

In conclusion, I would like to add that the 3D printing market is far from oversaturated with innovative projects, which is why collaborations of various technologies with additive technologies have great prospects for dynamic development in any industry in order to create a sustainable competitive advantage.

References

[1] Logachev M S, Voronin I V, Britvina V V, Tichtchenko S A and Altoukhov A V 2020 Local Area Network Monitoring: The Issue of Broadcast Storm. *International Journal of Advanced Trends in Computer Science and Engineering* 9 4216-4222 10.30534/ijatcse/2020/07942020

[2] Bogodukhova E S 2019 Additive manufacturing in the construction industry. *Modern technologies of metal processing and means of their automation* (Tula: TulSU) 61

[3] *Construction industry market analysis* Retrieved from: http://id-marketing.ru/about/uslugi/obzori-rinka-id-marketing/analiz-stroitelnogo-rinka

[4] Bogodukhova E S, Kashapova R F and Konyukhova G P 2019 Additive technologies in the construction production sphere. *Theory and practice of project education* **2(10)** 44-46

[5] *Construction 3D printers* Retrieved from: http://3dtoday.ru

[6] *Printed office building in Dubai* Retrieved from: https://www.rbc.ru/technology_and_media

[7] *Additive technologies in construction* Retrieved from: https://www.3dpulse.ru/news/zhurnal-additivnye-tehnologii/

[8] *Pros and cons of 3D printing in construction* Retrieved from: https://top3dshop.ru/blog/3d-printing-houses-in-russia-china-europe-price-video.html

[9] *Social significance of projects* Retrieved from: https://te-st.ru/2018/04/05/socially-significant-project-what-is-it/

[10] Konyukhova G P and Britvina V V 2013 Mathematical statistics in physical culture 19. *Teoriya i Praktika Fizicheskoy Kultury* **11** 60

[11] *Additive technologies in construction: equipment and materials* Retrieved from: https://additiv-tech.ru/publications/additivnye-tehnologii-v-stroitelstve-oborudovanie-i-materialy.html