Environmental benefits of additive technologies

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\textbf{Abstract.} The environmental movement, which began at the end of the 20th century and is now gaining more and more momentum, covers all spheres of society. Construction requires a large amount of natural resources, this is due to the increase in population and the acceleration of urbanization processes. Therefore, the problem of introducing environmentally friendly materials, energy-saving technologies, and “green standards” seems to be extremely important and relevant for the entire construction complex. The purpose of this article is to analyze and evaluate the world and national experience of introducing additive technologies into the construction process as the most environmentally friendly method for construction and operation. Based on the purpose of the scientific research, it is possible to identify the solution of the following tasks: analysis of research and development in the field of additive technologies to ensure the preservation of the environment, the use of statistical quality management tools to summarize the results. The article describes in detail the projects related to the construction of buildings and structures using additive technologies, analyzes the impact of this construction process on the environment. Environmental factors affecting 3D printing at each stage of the life cycle of the construction object are highlighted. The main environmental advantages of additive technologies and the problems of their implementation are identified.

\textbf{Keywords:} construction, digitalization, additive manufacturing, 3D printing, 3D-technology, 3D-additive technologies, environmental aspects, eco-friendly materials, energy-saving technologies.

1 Introduction

Today, one of the main trends in the development of mankind is urbanization, which has a significant impact on the environmental situation around the world. According to Rosstat, 74.8\% of the country's population lives in cities in Russia [1]. By 2053, the world's population will reach 10 billion inhabitants and the number of city dwellers living in cities will increase [2]. Rapidly growing and developing cities and towns have a significant environmental impact on the environment. Consuming more and more natural resources every year, they enormously increase the load on the Earth's shells. In view of this, the main goal of designers, builders, as well as enterprises and consumers are to create favorable and high-quality conditions for production and construction in order to reduce and minimize the threat of a negative impact on the environment in order to slow down the development of

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global problems. With traditional construction methods, the main problems are low labor productivity, high statistics of accidents at construction sites, difficulty in controlling construction processes, lack of skilled workers, environmental pollution [3-4]. According to Rosprirodnadzor, in Russia in 2020 only 22% of construction waste (about 15.5 million tons) was sent for recycling, often the materials used are toxic and pose a great danger to the environment [5]. Over the past 10 years in Russia, the volume of construction waste has increased 8 times. However, by 2030, the volume of construction waste to be disposed of and recycled should be at least 85%.

There are a number of global environmental problems in the construction industry: excessive energy consumption, irrational use of materials and resources, which generates a large amount of waste, as well as toxic substances that are formed during production and construction, adversely affect the state of the environment (air, water, soil) [6-7]. The above disadvantages of traditional construction are partially or completely eliminated with the use of additive 3D printing technology. Post-industrial society requires fresh approaches to the organization and safety of work, reducing the human factor, reducing the duration of construction and the impact on the environment. Thus, in connection with modern trends, it is necessary to propose and develop new types of buildings that will meet the following components: comfort, environmental friendliness and efficiency in their operation, as well as provide favorable living conditions and bear minimal load on the natural frame.

In this article, the author considers the use of 3D printing in construction as an innovative way in the environmental sphere. The key problem today is the environmental situation in the industry. We must devote all our efforts to improving the quality of life and work with respect for nature. The question of how additive 3D printing technologies help to reduce the destruction of the external environment is relevant today for the construction and manufacturing sectors. As part of the research, it is planned to develop recommendations that ensure environmentally friendly construction with the use of additive technologies in the conditions of urbanization. To begin with, it is necessary to identify a complex of environmental factors that affect 3D printing, providing a modern approach to construction and a high level of safety and health of people.

The scientific and technical hypothesis consists in the assumption of the possibility of reducing the adverse impact on the state of the environment during construction through the use of additive technologies.

2 Materials and Methods

To further study the impact of additive technologies on the environment, we will resort to the methods of structural analysis of objects built using 3D printing. When drawing parallels between traditional and additive construction, it is important to rely on the opinions of experts and specialists, as well as scientific universities directly related to this field of study, since when studying this topic, it is advisable to understand the potential component of 3D printing of various structures for the environment. In order to assess the possibility of reducing the aggressive impact on the environment, when choosing one or another method, it is necessary to study all stages of the life cycle of a building or structure. Starting from the idea of the project and the environmental justification for choosing the location of the facility and ending with its operation, which provides modern comfortable living conditions. It is also necessary to take into account such aspects as the preparation of materials, the production of additional equipment, transportation, waste disposal, working conditions.

Let's look at some examples of the environmental impact of 3D printing. A special role in the construction of structures is occupied by the choice and use of building material, which directly affects the environmental background. In 2018, the progressive Italian
company Crane Wasp [8], when creating a house project, developed an innovative composition for printing based on waste from rice cultivation, the main components of which are clay and sand of local soil, straw, rice hulls and hydraulic lime. The project is environmentally friendly not only due to the use of natural components for construction, but also due to the fact that it does not require the installation of a heating or ventilation system, since it is possible to maintain a constant temperature inside the building all year round. The house uses passive solar heating technology and natural ventilation.

A similar achievement can be seen in the development of Massimo Moreti [9], who seeks to produce affordable, affordable and environmentally friendly housing. Its main feature is the choice of working with modified clay and clay excavated directly at the place of production. This development will help build houses for a huge number of people, with minimal income. And due to the negligible impact on the environment, this method of construction is quite interesting and attractive to developers.

Scientists from China [10] are also proposing to use construction waste as a new environmental material for 3D printing. This development is more likely to be used for construction with a minimum level of risk, however, the benefits of recycling 50% of waste is a big contribution to the environmental component. Construction using, as raw materials, waste, local soil, recycled materials is especially relevant in the modern world. This confirms the interest in preserving the environment.

Currently, research is underway on materials used in additive manufacturing, which are subject to very strict requirements for safety, resistance to aggressive environments and climatic conditions, strength, etc. For example, powder materials have strict requirements for the shape and size of particles. The quality requirements of the raw materials used for 3D printing processes in most countries are less well documented in terms of their environmental characteristics. Therefore, in parallel with the development of the production of materials for 3D printing, the development of international standards regulating environmental factors in construction using a 3D printer is also underway.

Quite interesting developments are underway in the field of additive technologies, in particular, technologies based on the process of agglomeration of inert materials, such as sand. With the help of a special binding fluid, and this possibility is of interest to the space community in connection with its potential application for space. This means that thanks to the development of additive technologies, space exploration, construction in particularly harsh spatial conditions, will potentially be possible with minimal environmental pollution, which is also an important plus.

One of the main advantages of additive technologies relative to traditional ones is that when implementing a project, you can do with minimal production waste.

According to research by the Michigan Technological University, a significant reduction in CO2 emissions can be noted, which is one of the significant advantages of this type of construction, since many countries, in the development of the Paris Climate Agreement, are trying to keep the global average temperature rising and plan to reduce greenhouse gas emissions by 2050. Similarly, Russia has developed a plan to reduce greenhouse gas emissions by 2050, according to which CO2 emissions should be reduced by 36% [11].

An important subject for study is the impact on human health during the construction of structures using 3D printing. Analyzing construction methods, it can be noted that a decrease in the number of workers, and additive construction requires much fewer of them than traditional construction, leads to a significant reduction in injuries on the construction site. Also, this type of construction does not cause much discomfort in the quality of noise for the surrounding life, which also positively affects the health of both people and animals.

At the same time, after analyzing scientific articles, it is possible to note ambiguous statements about the consumption of electricity. For example, the Atkins project showed that energy consumption in additive manufacturing is much higher than in traditional
production (13.1 kg of CO2 per product versus 1.9 kg). With more electricity consumption, the work of hydroelectric power plants (HPP) and thermal power plants (TPP) increases, the concentration of emissions of harmful substances into the atmosphere during the operation of thermal power plants is high. But there are other estimates of technological energy flows and costs arising from 3D printing. The authors of the articles [7, 12-14] study the impact of the full use of the available system power on the overall efficiency of the process and the corresponding energy consumption. Scientists have developed a modeling method for calculating the total energy consumption when printing using inkjet printing technology on a binder, correlating the energy consumed with the geometry of the part, the thickness of the layer and the orientation of the part. However, the model estimates energy consumption only at the printing stage and needs to be updated to include energy consumption at the curing and sintering stages, as well as resource requirements and process emissions to quantify the overall environmental footprint of the entire process chain. The conclusion of the study was that minimizing costs in additive manufacturing leads to minimizing energy consumption. From an environmental point of view, 3D-printed parts can be particularly advantageous for very small batches or in cases where significant functional advantages are offered at the stage of product use (for example, lightweight part designs and restoration of parts).

Of particular interest, according to the results of the analysis of literature and developments in the field of additive technologies, is the zone of priority measures, which includes the most influential environmental factors. It is in their relation that it is necessary to plan corrective measures to reduce the negative impact on the environment. However, planning should be preceded by a detailed analysis of the causes and areas of occurrence of environmental factors. To present the results, we will use the method of causal analysis, which illustrates the list of causes of one effect in the form of a structured Ishikawa diagram. The method is used to display the most significant factors (causes) influencing the final result (consequence), which can be further verified empirically or based on available data. The reasons are divided into four key categories: personnel (people), technology (method), materials, equipment.

The resulting diagram is shown in Figure 1. Analysis and identification of the most significant aspects that affect the environment during 3D printing and the operation of such objects will allow developing a set of measures to ensure environmentally friendly construction using additive technologies.

As part of the cause-and-effect analysis, all factors were ranked with the most significant highlighted. Structuring environmental aspects increases the potential effectiveness of the developed corrective measures.
The work of hydroelectric power plants (HPP) and thermal power plants (TPP) increases, the significant aspects that affect the environment during 3D printing and the operation of such production (13.1 kg of CO₂ per product versus 1.9 kg). With more electricity consumption, planning should be preceded by a detailed analysis of the causes and areas of occurrence of curing and sintering stages, as well as resource requirements and process emissions to parts.

Offered at the stage of product use (for example, lightweight part designs and restoration of developments in the field of additive technologies, is the zone of priority measures, which highlighted. Structuring environmental aspects increases the potential effectiveness of the analysis and identification of the most significant factors (causes) influencing the final result (consequence), which can be further verified empirically or based on available data. The method is used to display the most significant factors (causes) influencing the impact on the external environment. Firstly, it helps to reduce a significant amount of construction waste. Since, unlike the traditional method, in which the loss of raw materials can be up to 80%, additive technologies use almost the amount of materials that is necessary to manufacture the product. Secondly, additive manufacturing improves production and technological processes through the use of new and non-traditional materials (polyactide (PLA) and other environmentally friendly biodegradable materials). Thirdly, the use of additive manufacturing can contribute to the restoration of nature. An example of this is 3D printed, i.e., artificial, reefs [7, 15-16]. Thus, the use and development of additive technologies provides the potential to save and preserve the environment.

But manufacturing with additive technologies has its drawbacks and limitations. At the moment, one of the global problems in the implementation of 3D printing on a large scale is the high-power consumption of machinery and equipment [8]. Based on this, three main categories of measures to improve the parameters of energy flows in a given production process to the environment can be distinguished:

1. Appropriate choice of process technology and 3D printer that will help reduce the negative impact on the environment
2. 3D printer optimization
3. Optimization of process parameters

Therefore, when introducing this technology directly into the construction process, it is necessary to take into account the imperfections and the expediency of using this technology in order to benefit. The main environmental benefits of additive technologies are presented in Figure 2.

Fig. 1. Ishikawa Diagram - Environmental Impact of 3D Printing. Source: Compiled by the author.

3 Results

The practical significance of the study lies in the possibility of using additive technologies at capital construction projects to solve a certain range of environmental problems. The article is devoted to the theoretical search and explanation of the environmental aspects of the use of additive technologies in construction and their development in the world. The environmental factors that affect 3D printing at each stage of the life cycle of a construction object are identified.

Additive manufacturing, like any technology, even the most harmless and safe, has an impact on the external environment. Firstly, it helps to reduce a significant amount of construction waste. Since, unlike the traditional method, in which the loss of raw materials can be up to 80%, additive technologies use almost the amount of materials that is necessary to manufacture the product. Secondly, additive manufacturing improves production and technological processes through the use of new and non-traditional materials (polyactide (PLA) and other environmentally friendly biodegradable materials). Thirdly, the use of additive manufacturing can contribute to the restoration of nature. An example of this is 3D printed, i.e., artificial, reefs [7, 15-16]. Thus, the use and development of additive technologies provides the potential to save and preserve the environment.

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Discussion

Based on the research of scientists, we can dwell on the most important points, namely why 3D printing is seen as a technology that can change the construction market.

Since the majority of errors and violations in construction in one way or another depend on the person, it is an urgent task to reduce the human factor. Additive technologies can partially, and at some sites even to a high extent, replace physical labor at a construction site with intellectual labor, reducing errors.

The next indisputable fact is a significant reduction in the construction time of the structure compared to a number of traditional solutions.

And the most important from the point of view of ecology is the provision of recycling, as well as the recycling of materials, which leads to positive impacts on the environmental component of both individual regions and the entire area of application of these technologies.

Due to these positive properties, it can be assumed that additive technologies are especially promising for the development of new territories in terms of environmental impact and the speed of building and structures formation.

It should be noted that at present the social and environmental component of the formation of the architectural environment of cities is of great importance. To date, the technologies under consideration meet the objectives of "green" construction and are actively developing in all areas of activity.

Conclusion

This article provides an overview of the available data on developments and current implementations in the field of 3D printing, an appropriate environmental analysis of
additive technologies, material raw materials, as well as technological processes and post-processing processes.

Thus, if assessed from an environmental point of view, the higher environmental impact created at the production stage by the method of additive technologies should be compensated by functional improvements at the stage of product use [12]. For a holistic assessment of the impact of these technologies on the environment, more general and in-depth studies are needed, covering all stages of the life cycle of buildings and structures erected by the additive construction method.

3D printing in construction can become an energy-efficient and environmentally friendly way of production. Since the use of this technology allows you to abandon the use of stationary equipment, reduce the amount of waste from production processes and reduce costs. It also helps to develop parts and products with optimal characteristics, including reduced weight, good mechanical properties and unique geometry.

Based on these facts, it can be concluded that today, using additive manufacturing as the main technological process in the construction sector, it is possible to significantly reduce the negative impact on the environment.

Due to the growing environmental problems of production processes, it is necessary to analyze in detail the potential impact of AT on the environment during the construction of entire industrial centers by understanding, comparing and determining the characteristics of additive manufacturing processes to ensure their sustainability. As promising areas of research, there is an urgent need for the development and creation of domestic devices for 3D printing, as well as mixtures with the necessary characteristics and allowing to provide the necessary physical and technological characteristics of the final product.

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