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Analysis of modern approaches to the application of 3D technologies in architecture and design

Análisis de los enfoques modernos de la aplicación de las tecnologías 3D en la arquitectura y el diseño

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Abstract

Relevance. The dynamic development of modern architecture and design implies continuous improvement of processes aimed at optimizing not only the design, but also the construction of various objects directly. Today, the most effective method of this optimization is the active use of advanced 3D technologies that allow you to bring visual, structural, engineering and technical solutions to a qualitatively new level. The purpose of the article is to analyze modern approaches to the application of 3D technologies in architecture and design. The objectives of the article are to analyze key trends, study the disadvantages and advantages of selected 3D printing technologies, as well as identify areas with high potential for implementing various types of architectural objects created on new-generation three-dimensional printers. Research methods include generalization, classification, systematization and analysis of the theory of formation of new architectural trends..Results. The article discusses various technologies and technical means, their advantages and

Resumen

Relevancia. El desarrollo dinámico de la arquitectura y el diseño modernos implica la mejora continua de los procesos destinados a optimizar no sólo el diseño, sino también la construcción de diversos objetos directamente. Hoy en día, el método más eficaz de esta optimización es el uso activo de tecnologías 3D avanzadas que permiten llevar las soluciones visuales, estructurales, de ingeniería y técnicas a un nivel cualitativamente nuevo. El propósito del artículo es analizar los enfoques modernos de la aplicación de las tecnologías 3D en la arquitectura y el diseño. Los objetivos delartículo son analizar las tendencias clave,estudiar las desventajas y ventajas de las tecnologías de impresión 3D seleccionadas, así como identificar las áreas con alto potencial para la aplicación de varios tipos de objetos arquitectónicos creados en impresoras tridimensionales de nueva generación. Los métodos de investigación incluyen la generalización, la clasificación, la sistematización y el análisis de la teoría de la formación de las nuevas tendencias arquitectónicas. En la

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disadvantages, as well as analyzes the key areas of application of 3D printers in the implementation of various architectural structures. Prospects for the development of highly efficient technology for the construction of buildings and structures are determined. The principles of operation of 3D printers are described. Conclusions. Three-dimensional printing technologies are used in global architectural practice for various functions of buildings, from public housing to restoration work, for modern and future architectural needs. Analysis of the international practice of creating architectural objects using 3D printers leads to the following conclusions: the technology of manufacturing buildings and structures has critical advantages, but also certain disadvantages. The prospects for further research are to conduct an empirical analysis of the use of 3D technologies in architecture and design.

Keywords: Architecture, Design, 3D technologies, 3D printer, 3D printing.

resolución de las tareas planteadas se utiliza el método de las generalizaciones, la síntesis de los resultados obtenidos y un enfoque sistemático. Resultados. El artículo discute diversas tecnologías y medios técnicos, sus ventajas y desventajas, así como analiza las áreas clave de aplicación de las impresoras 3D en la realización de diversas estructuras arquitectónicas. Se determinan las perspectivas de desarrollo de una tecnología altamente eficiente para la construcción de edificios y estructuras. Se describen los principios de funcionamiento de las impresoras 3D. Conclusiones. Las tecnologías de impresión tridimensional se utilizan en la práctica arquitectónica mundial para diversas funciones de los edificios, desde las viviendas públicas hasta los trabajos de restauración, para las necesidades arquitectónicas modernas y futuras. El análisis de la práctica internacional de creación de objetos arquitectónicos mediante impresoras 3D permite llegar a las siguientes conclusiones: la tecnología de fabricación de edificios y estructuras tiene ventajas críticas, pero también ciertos inconvenientes. Las perspectivas de investigación futura consisten en realizar un análisis empírico del uso de las tecnologías 3D en la arquitectura y el diseño.

Palabras clave: Arquitectura, Diseño, Tecnologías 3D, Impresora 3D, Impresión 3D.

Introduction

Dynamic development of modern architecture and design implies constant improvement of processes aimed at optimizing not only the design but also directly the construction of various objects. Today the most effective method of this optimization is the active use of advanced 3D technologies, allowing to bring visual, structural, engineering, and technical solutions to a new level.

Traditional architectural design is the creation of text and graphic documentation. The use of three-dimensional modeling and volume printing in the design process significantly simplifies and accelerates the creation of functional prototypes - as a result, the architect and the customer receive a functional prototype, the finalization of which takes a minimum of time and has maximum efficiency.

Architectural prototyping is associated with great responsibility - the quality of the model determines the functional and operational characteristics of the future object and, therefore, is an integral part of customer or client satisfaction (De la Torre et al., 2016). To a greater extent, 3D modeling is in demand today in suburban and commercial house buildings, but many large-scale projects are almost impossible to imagine without the use of 3D technology (Zeltmannet al., 2016).

The aim of the article is to analyze current approaches to the use of 3D technology in architecture and design. The aim of the article is to analyze the key trends, to study the disadvantages and advantages of the selected 3D printing technologies, as well as to identify areas with high potential for the implementation of various types of architectural objects created on the new generation of 3D printers.

Theoretical Framework or Literature Review

Competent visualization with a demonstration of the virtual model is the key to success in attracting investment in buildings under construction and in the sale of existing facilities, as the 3D model is a visualization.

Benefits of using 3D technology in architecture and design:

1. The speed in creating a layout-process of manual layout, depending on the complexity of the project can take up to several months, while 3D printing will allow you to get a functional and the most accurate visualization in a few hours;
2. Cost-saving - affordable consumables based on gypsum, inexpensive photopolymers, and ABS plastic (the cheapest consumable material in the segment) are used to create a model;
3. No need for post-processing and painting of the sample - modern 3D printers are capable of reproducing any color solution in the CMYK palette;
4. Excellent quality of detail - the majority of 3D devices intended for use in architecture have high indicators of building accuracy and resolution(Zhang et al., 2018);
5. Model reliability - the dense structure of the production material guarantees greater durability of the finished product as compared to analogs obtained by hand modeling, also the object can be subjected to some types of post-processing (Jiménezetal., 2019, p. 1–30).

Visibility is the golden rule of architectural engineering and design, and with the use of 3D technology, designers and architects have the opportunity to qualitatively improve, accelerate and simplify modeling processes due to the high productivity of 3D printers and low material waste rates.

We can no longer imagine today's world without three-dimensional technology. They are everywhere: in the film industry, entertainment, art, photography, and even printing. Over the past few years, mankind has been able to step far ahead. We are making great strides in innovative technology, creating more and more useful devices designed to make our lives easier. One of the most interesting inventions of recent years is the 3D printer. As the variety of technologies for making 3D printers has increased, so has their field of application. Whereas previously they were used exclusively in the research of the largest companies, now the possibilities of 3D printing are available to almost everyone. Such printers are used in areas such as science, medicine, design, jewelry, and even cooking. There are now many 3D printing schemes available on the Internet. All of this makes the future even more comprehensible to us (Heigel et al., 2015).

Architecture and design are fields in which 3D printers are very actively used. Characteristically, in recent years 3D printing has become an indispensable assistant not only to large companies but also to small architectural studios around the world. 3D printing has become a real revolution in the field of construction modeling, which is in demand in architecture, engineering, and design (Wagner & Prester, 2019).

Advantages of using 3D printing of architectural models:

– visibility. The physical model of the building is clearer and more understandable than a picture on the monitor. The 3D model allows the architect to effectively evaluate the details, and the customer to understand his idea and assess the scale.
– saving time. Making layouts by hand is a complicated, time-consuming and costly process. More often than not, it takes months to create an architectural model in the traditional way. With a 3D printer, the production time is reduced to a few hours.
– high level of detail. Modern 3D printers allow printing models of any shape, color and size. You can get a color model of a building, complex or the entire city with high detail and clarity.
– money saving. A 3D model will save time for the architect and money for the customer by promptly making changes to the existing design. 3D-printing can be done in different ways and using different materials, but any of them is based on the principle of layer-by-layer creation (growing) of a solid object (Ding et al., 2015).

At the moment there are two main technologies for growing layers - laser and inkjet. Laser 3D printing includes stereolithography (SLA), which allows you to create a three-dimensional model from computer CAD drawings. SLA printers can print parts up to 75 cm in height. However, the devices themselves are very expensive and large in size, they weigh about a ton and cost in the region of 150 thousand euros. They have a low reproduction speed of only a few millimeters per hour. What compensates for the slow speed and high price is the high quality of the final model, which also becomes very reliable and robust (Androshchuk & Androshchuk, 2017).

A faster and cheaper technique is laser sintering technology (SLS), where it is no longer a photopolymer but a powder of fusible plastic in the role of the blank material. Laser sintering makes it possible to obtain very high-quality and

durable models at a relatively high speed (about several centimeters per hour plus the time for heating and cooling). Of the major positives, it is possible to print metal parts. The result is a metal part made of a mixture of steel and bronze, ready for use. Ceramics or glass can be used as a base in such a powder, which makes it possible to create a heat-resistant or chemical-resistant model after the curing procedure (Androshchuk & Kopyl, 2016).

Streaming 3D printing is very similar to the work of a regular printer, only instead of paint, a nozzle squeezes out a certain amount of heated plastic on a cooled platform, this is the so-called Fused Deposition Modeling (FDM) technology. The droplets solidify very quickly and form one of the layers of the future three-dimensional model (as in laser printing, the model is created in layers). There is a development of 3D-jet printing and the introduction of polymer powder. A special head injects an adhesive base onto plaster or starch powder which forms one of the layers of the future model when it hardens. The peculiarity of this technology is that dyes can be added to the glue and make the model not only three-dimensional but also multi-colored. Printers working according to this principle cost relatively little - from 8 to 30 thousand dollars, which is tens of times less than the cost of laser counterparts (Androshchuk&Kopyl, 2016).
Methodology

The fruits of technical fantasy have always sought to pour onto paper, and then translate into life. If before, to imagine what would look like a house or the interior of a room we could only drawings or pictures, with the advent of the computer three-dimensional modeling has been possible to create a three-dimensional image of the designed structure. It is characterized by photographic accuracy and allows you to better imagine how the project will look, embodied in life, to make certain adjustments. Three-dimensional visualization usually makes a much bigger impression than all other ways of presenting a future project. Advanced technology allows for achieving stunning results.

Three-dimensional graphics (3D, 3 Dimensions) - a section of computer graphics, a set of techniques and tools (both software and hardware), designed to image three-dimensional objects. Most often used to create images on a plane screen or sheet of printed matter in architectural visualization, film, television, computer games, printed matter, as well as in science and industry (Heigel et al., 2015).

A three-dimensional image on the plane differs from the two-dimensional one in that it involves building a geometric projection of a three-dimensional model of the scene on the plane (for example, a computer screen) using specialized programs. In this case, the model may correspond both to objects from the real world (cars, buildings, hurricane, asteroid) and be completely abstract (projection of a four-dimensional fractal) (Androshchuk & Kopyl, 2016)].

Based on drawings, drawings, detailed descriptions, or any other graphic or textual information, the 3D-designer creates a three-dimensional image. In a special program, the model can be viewed from all sides (top, bottom, side), embedded on any plane, and in any environment (Zhang et al., 2018).

Three-dimensional graphics can be of any complexity. You can create a simple three-dimensional model with low detail and a simplified shape. Or it can be a more complex model, in which there is the elaboration of the smallest details, texture, and used professional techniques (shadows, reflections, refractions of light, etc.). Of course, this seriously affects the cost of the finished three-dimensional model but allows you to expand the use of the three-dimensional model (Lewandowski & Seifi, 2016).

Three-dimensional model visualization is used today in very many areas. Of course, first and foremost, it is construction. This may be a model of the future home, both private and apartment or office building, and in general any industrial facility. In addition, visualization is actively used in interior design projects (Maya, 2016; Cozens & Love, 2015).

Three-dimensional visualization becomes indispensable in cases where the project involves significant financial investments. For example, in the design of large shopping areas, entertainment and hotel complexes, large business centers, and just offices of large companies. 3b-projects allow doing without a pile of architectural plans and with the use of architectural animation gives an absolutely complete idea to the customer about the future organization of space, interior, and decor details (Meyers et al, 2018). Large customers and investors, being progressive and professional people themselves, value their time, do not want to waste it on studying a lot of obscure drawings, they want to see and evaluate what they have to finance clearly and distinctly. The realism of the three-dimensional computer

image allows us to do this easily, efficiently, and most fully (Androschuk, 2017).

Modern customers are well aware that by ordering a design project of an interior with three-dimensional visualization, they save time and get a clear result - save your money (Shalaginov et al., 2017; Oriozabala et al., 2016). 3D models are very popular in site-building. To create a special effect, some website creators add to the design, not just graphic elements, but three-dimensional models, sometimes even animated. Programs and technology of three-dimensional modeling are widely used in manufacturing, for example in the production of cabinet furniture, and in construction, for example, to create a photorealistic design project of future premises. Many designers have long since passed from using a ruler and pencil to modern three-dimensional computer programs. Gradually, other companies, primarily manufacturing and retail companies, are adopting new technologies as well. (Printed electronics now, 2019).

Of course, three-dimensional models are mostly used for demonstration purposes. They are indispensable for presentations, and exhibitions, and are also used in working with clients when it is necessary to clearly show what the final result will be (Noorani, 2017). In addition, three-dimensional modeling techniques are needed where it is necessary to show in volume already finished objects or objects that existed once upon a time. Three-dimensional modeling is not only about the future, but also about the past and the present (Zhang et al., 2018, p. 022081).

The advantages of three-dimensional modeling over other methods of visualization are quite numerous. Three-dimensional modeling gives a very accurate model, as close to reality as possible. Modern programs help to achieve high detail (3D Printer, 2017). At the same time, the visibility of the project is greatly increased. Expressing a three-dimensional object in the two-dimensional plane is not easy, while the reinforced concrete visualization gives an opportunity to work thoroughly and, most importantly, to view all the details. It is a more natural way to visualize (Ding, Pan, Cuiuri, & Li., 2015, 465-481).

It is very easy to make almost any changes to the three-dimensional model. You can change the design, remove details and add new ones. The imagination is almost unlimited, and one can quickly choose exactly what fits best (Wang &Tang, 2016; Sahoo &Chou, 2016).

However, three-dimensional modeling is not only convenient for the client. Professional programs offer many advantages to the manufacturer as well (De la Torreetal, 2016). Drawings of any components or the entire structure can easily be extracted from the three-dimensional model. Despite the fact that the creation of a three-dimensional model is quite a time-consuming process, it is much easier and more convenient to work with it later than with traditional drawings. As a result, design time is significantly reduced and costs are reduced (Maraketal., 2019, 87-103).

Dedicated programs enable integration with any other professional software, such as engineering applications, machine tool programs, or accounting programs. The implementation of such solutions in production gives significant savings of resources, significantly expands the capabilities of the enterprise, simplifies the work, and improves its quality.

Results

Generalization of practical examples of digital technology use in architecture and design allows us to assert that the typology of digital design genres and forms of its interaction with the architectural environment today is far from being exhausted and will be constantly replenished due to the growing technical capabilities of accessibility to an ever-wider range of people. At the same time, we can note that in the current practice digital technologies are used by architects and artists in the urban environment quite locally, without development in the nearby spaces, in fact, in the framework of individual private initiatives, which, on the one hand, creates a “flicker” of meanings, statements. but at the same time, it violates the integrity of the urban space (Lewandowski & Seifi, 2016, p. 151–186). The architectural language is saturated with spatio-temporal digital statements, which translate into the spatial environment of modern cities the idea of changeability and variability, the management of a constant flow of information, and the creation of new meanings. In this regard, the content, the content of created objects, the integrity of the architectural image of the city becomes especially important.

The need for a holistic approach in urban design, focused on the needs of an emerging creative economy, correlates with the emergence of state programs for the development of a comfortable urban environment. The formation of the urban environment is understood as a set of measures aimed at creating conditions for providing

comfortable, safe, and accessible living conditions for the population of the municipality. Roadmaps for the development of a comfortable urban environment have been developed for almost all constituent entities of the Ukraine, a methodology and actual verified indicators of urban environment quality assessment have been approved, based on a comprehensive analysis of which we can get an idea of its most significant components. Other indicators include the level of urban space exterior design, which has a great influence on the general perception of the environment, the proportion of objects equipped with architectural lighting, the diversity of cultural, leisure, and sports infrastructure.

Studying the quality indicators of the urban environment, we can conclude that their main part characterizes the functional and material-technical condition of the urban infrastructure. At the same time, a modern city is evaluated by professionals and residents not only in terms of physical properties of infrastructure facilities, their functionality, and convenience. The contradiction in the development of modern cities arises from the fact that the established schemes of layouts, organization of the city, its physical objects, and infrastructure naturally become obsolete, while the lifestyle of citizens, the perception of the surrounding reality, and the experience of its use by man are renewed. Along with the physical environment, citizens are continuously included in the interaction with the virtual, technological environment. Specialists fix the need to adapt urban metabolic processes, as well as external manifestations (forms, images, spatial formations, visual grammar) to the development of information and technological system as one of the manifestations of digital technology and initiate the development of instrumental functions of digital design in the context of urban environment formation.

The use of digital design as a tool shows its multidimensionality and the possibility not only to shape the urban environment but also to involve in the digital space citizens, guests of the city, create “places of gravity” in degraded areas and a special digital visual language. Psychological comfort, mental state of residents, “living in the environment” - including physical, cultural, emotional activity, and mastering activities peculiar to the person living in the city - are important.

At the same time, modern digital technologies, which have firmly entered the city environment, cannot be regarded as neutral and even more so as exclusively beneficial in terms of their impact on society. Despite the widespread use of digital design as a tool for the formation and transformation of urban spaces, we should remember that their irresponsible introduction can provoke crises in the emotional, value aspect of environmental perception.

A number of new problems are currently being recorded:

– the problem of visual perception by young people accustomed to screen information, large architectural volumes and spaces, and the need to specifically teach them the perception of classical architecture;
– the problems of determining the moral limits of the atricalization and the optimal duration of the existence of objects of digital design in the urban environment, the problem of inevitable emotional exhaustion and discomfort from the bright and constantly flickering images of permanent residents;
– the problems related to the moral aspects, actualizing the issues of admissibility of large-scale application of computer technologies in terms of their impact on the environmental properties of urban spaces,(ultimately, the use of digital technologies to create projections and other effects distorts the real environment of the situation (Meyers et al., 2018, p.3709–3717);
– problems of perception of three-dimensional objects in the urban environment The creation of a virtual flat or 3D illusion leads to a change in the traditional status of the enclosing structure of the facade plane as the archetypal material limit of the architectural object (Noorani, 2017).

Architecture is transformed into a screen. Under the influence of projected images, the choice of which is largely determined by the computer technology used, it loses its own artistic expressiveness.

All these problems require professional study and evaluation. But it can be predicted that it is a digital design, considered as an innovative tool for shaping the urban environment, concludes the possibility of resolving existing contradictions through interdisciplinary interaction, comprehensive study, and analysis of various groups of data, implementation of wide access to them by interested professionals, an integrated approach to the project. Digital design as the heir to all design methods and technologies currently opens up opportunities to harmonize various

technological aspects of digitalization and spiritual, humanistic aspects of human existence in urban space.

In the contradictory situation of the aging of urban spaces and the renewal of the ways people perceive and use these spaces, the possibility of synthesizing information contained in digital design allows us to find a compromise between the need to preserve the historical architectural environment and its simultaneous renewal and actualization of spaces. This possibility lies in: the variability of digital objects; in the relative simplicity of technologies for creating virtual environments; in the ability to adapt to short-term tasks, without making global changes to the physical basis of cities; in the ability to create local points of attraction without violating the historic environment and the integrity of monuments, which is especially relevant for ancient cities (Heigel et al., 2015, p. 1295–1308); in the ability to draw attention to the features of architecture and level out its shortcomings, as well as to form scenarios of its perception with the help of color and light; in blurring the boundaries of the exterior and interior of buildings; in expanding the functionality of buildings by introducing interactive technologies, and much more.

Digital design is simultaneously a way of being in the modern urban environment, and aesthetic value of society, and artwork that exists in a single space. In this case, the study of all facets of the issue allows us to formulate an understanding of digital design as a universal and multifunctional tool that can not only influence the existing urban environment but also comprehensively form a new reality of urban spaces through the prism of the relationship with man, taking into account innovative technologies.

There is no doubt that even in the conditions of digitalization architecture continues to fulfill its fundamental role - the creation of space to meet human social needs, and the architect's professional perspective determines the imagery, artistic value of the created object, its socially significant qualities and those principles that will determine the approaches to the use of digital tools in the design of the urban environment. Digital tools, in the experienced hands of the artist, designer, and architect, help to create beauty, but the value component of digital design, first of all, lies not in the power of technology and the breadth of its application as such, but in the limitlessness of the human mind, capable of creating and using modern tools for the benefit of society.

Discussions

Additive technologies, widely used in various fields of human activity, such as medicine, construction, design, have also found application in architecture. By creating unusual futuristic forms, the architect designs a model, which in the future can be built or molded by a robot - a 3D printer from different materials when calculating the load(Ruggieri et al, 2018; Wang et al., 2018). Jobs can be programmed, to repeat the movements of insects, to act at a distance from the digital source, or to repeat the same manipulation at different frequencies, thus forming a volume similar to cellular or fractal; synthetic materials, their internal structure, and cellular structure can be programmed in the way that the load calculation requires. Such materials, created from mixtures of polymers, organic substances, and even living bacteria, are called synthetic materials and are used in additive technologies. These technologies are used to improve the strength characteristics of structures, to build in space, and to make unusual architectural solutions a reality (Wohlers, 2012). The theoretical and methodological analysis of 3D technology in architecture and design shows that:

- to date, sufficient empirical material has been accumulated on the development of architectural projects using additive technology, with a set of features that allow us to separate them into one group, a detailed study of which will form the theoretical basis for the establishment of design methodology using additive technology (Xia et al., 2016);
- in modern architecture and design, the influence of experimental technology on construction and design is clearly visible (including under the influence of scientific and technological progress);
- there are many works devoted to additive technology in various applications, but its impact on the development of new styles and trends in architecture and design has not been sufficiently studied (Chauhan & Aluvalu, 2016; Zhang et al., 2018, p. 022081)
- there is no evaluation scale (criteria, evaluation system) that allows classifying buildings and structures made with the use of additive technologies when there is a significant number of realizable objects (Wohlers, 2012);
- there is a contradiction in assessing the

effectiveness of architectural objects made with the use of additive technology, from an economic point of view; this aspect requires careful study;
– additive technology is considered a promising direction in construction and architecture.

Conclusions

Analysis of the international practice of creating architectural objects using 3D printers leads to the following conclusions: the technology of manufacturing buildings and structures has critical advantages, but also certain disadvantages.

Advantages of using 3D printers in architecture and design:

1. No restrictions on the complexity of the designs created;
2. Fast start of production;
3. Wide potential of application in almost any field of activity;
4. Availability to a wide range of businesses and population;
5. Possibility of application of various materials which list constantly extends;
6. Possibility of alternate manufacture of fundamentally different models with minimal change of settings, no need in reprofiling of production for the release of new products;
7. Economy of any used raw materials, almost no waste.

Despite the above-mentioned negative aspects of the introduction of 3D printers in the creation of architectural objects, we must state that 3D-printing in world architectural practice contains a number of significant advantages. They are as follows:

Despite the positive aspects of the introduction of 3D-printers in architecture and design, there are a number of disadvantages of their use in practice:

1. Less accuracy in compliance with given dimensions, compared to stamping and CNC milling (time complexity, more and more accurate new models are being developed);
2. Limited size indicators of printed products for most models of printers (already there are 3d-printers with a printing chamber the size of a cube with an edge of 1 m or more, the cost of their true much higher than usual);
3. Limited use of materials, even with the constant introduction of new materials, some natural materials cannot be used in 3D-printing while retaining all their useful properties;
4. Poor developed labor market for specialists in this field, provided that industrial 3D-printing requires high qualifications (the issue is gradually being solved - more and more educational institutions are training the relevant specialists.

Digital design and architecture are at the same time a way of being in the modern urban environment, the aesthetic value of society, and artistic creation, which exists in a single time-space. In this case, the study of all facets of the matter allows us to form an understanding of digital design as a universal and many functional tools, capable not only of influencing the existing urban environment but also of comprehensively shaping a new reality of urban spaces through the prism of interconnections between people, taking into account innovative technologies.

It is not incontestable that even in the conditions of digitalization architecture and design continue to fulfill their fundamental role - creating a space for satisfying people's social needs, and the professional view of the architect encourages imaginativeness, the artistic value of the created object, its socially meaningful qualities, and the principles that will define the approaches to the use of digital tools in the design of urban environments. Digital tools, staying in the skilled hands of the artist, designer, and architect, help to create beauty, but the value of digital design, above all, is not in the power of technology and the breadth of its use as such, but in the limitlessness of the human mind, capable of creating and using modern tools for the benefit of society.

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