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FEATURES OF THE USE AI IN GENERATIVE DESIGN OF BUILDING AND STRUCTURES

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Abstract

The authors of the article consider what features appear when using artificial intelligence (AI) in the generative design of construction facilities. Every day artificial intelligence becomes more and more important in various fields of human activity. One of the areas of activity in which AI is actively being implemented is construction, namely digital (BIM) and generative (GD) building design. These areas of design include the development of design solutions for an object using computer algorithms and mathematical models. The article examines the positive aspects of implementing AI in generative design, compared to traditional design methods. The use of AI in generative design can improve the quality of produced design documentation by reducing the number of unintentional mechanical and technical errors, providing designers with a more extensive amount of analytical data. The authors focus on the main AI methods that are involved in GD, as well as the problems and limitations that arise when using AI in design.

Keywords: Artificial Intelligence (AI), generative model (GD), Information Model (BIM), Information Modelling Technologies (TIM), Generative design.

I. Introduction

Generative design is an iterative process of creating and optimizing projects using computer algorithms based on mathematical models and rules. The main difference from traditional design methods: the customer, designer, or engineer is not looking for a solution to the task, but describes its parameters and limitations in the program, after which the program creates solution options that form the vision of the product» [XII, XXIII].

A study conducted by PlanRadar made it possible to compare the level of implementation and effectiveness of BIM technologies in 7 leading European countries. It turned out that the use of BIM in construction and design practice differs significantly from country to country. Some countries such as Germany, Great Britain, and France have shown a high degree of implementation and application of BIM. Countries lagging behind in the implementation and use of BIM may hinder their development and competitiveness [XIII].

In Russia, less than 10% of design organizations have full-fledged experience in using BIM. At the same time, Russian companies realize that using the maximum capabilities of BIM will allow them to fully and effectively manage the entire project lifecycle. At this level, it is possible to integrate data and information as much as possible, ensuring better coordination, cooperation, and decision-making among all project participants [II, XVI, XIV]. An increase in the Net Present Value (NPV) of organizations as a result of the introduction of information modelling can reach 30%/ At the same time, NPV may not change for design and construction organizations. The use of information modelling in such organizations helps to reduce the labour intensity of design and construction, which is especially important when reusing projects. A construction company whose fixed assets need modernization has to update and replenish non-current assets in order to remain competitive in the market, this also applies to digital technologies. Further progress in the digitalization of the design industry will be inextricably linked with the use of AI, including in generative design [IXX, XX, XXI, XXIV]. The use of AI in generative design makes it possible to automate the process of creating design solutions and improve the quality of the final product. Based on the results of the analysis of the data obtained, customers or designers can make changes to the input parameters of the model or select the necessary output parameters manually or using AI [IX, XVII].

The scheme of generative design as an iterative process, indicating the role of the designer in this process, was developed by the disciplinary team for the book "Generative Gestaltung". Image by Hartmut Bohnacker, licensed by CC BY 3.0, via Wikimedia Commons [IV].

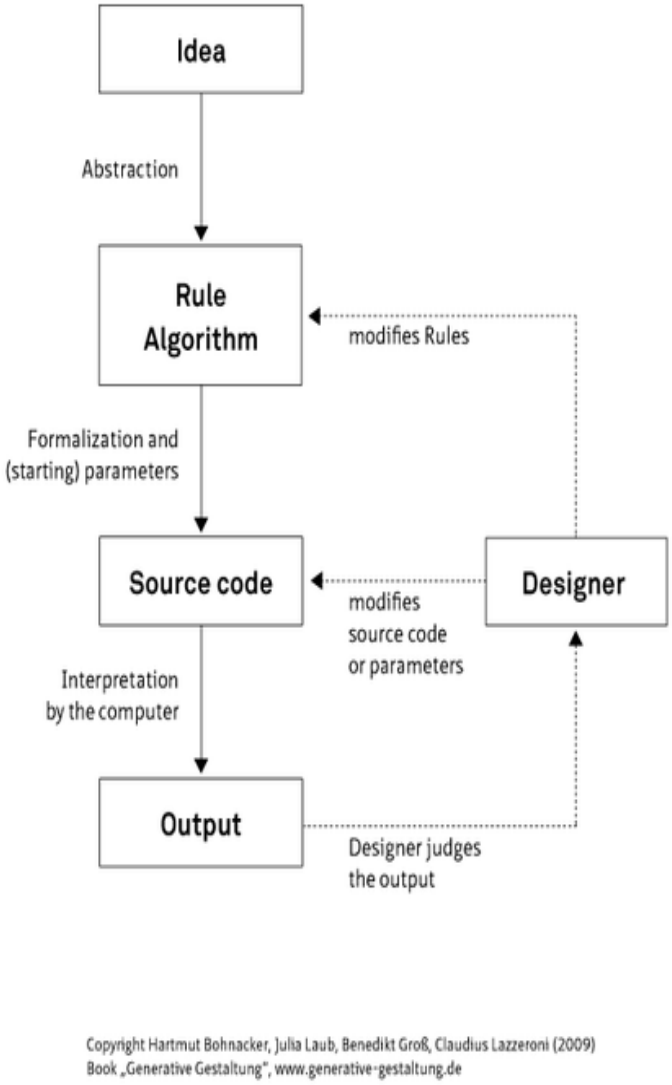

Fig.1. Schema of generative design as an iterative process

The authors of the article replace the role of the designer with AI.

II. Methodology

The authors of the article consider the most popular AI methods that can be used in GD and conduct a comparative analysis between generative design and BIM design. AI methods in generative design include neural networks, fuzzy systems, evolutionary computing, deep learning, expert systems, machine learning, etc. Each of the methods has its own characteristics and can be applied depending on the requirements of the project and the tasks being solved [III].

Neural networks create models based on a large amount of information, while they are constantly learning, which allows them to create better design solutions and improve them. The main task when working with neural networks is the correct training of the network, which allows you to get the desired result. With proper configuration, neural networks will be able to predict important project characteristics such as safety, energy efficiency, and many others. From the huge variety of neural networks, 2 types of neural networks can be distinguished for GD. These are recurrent neural networks (RNN), which are used to create sequences, and generative-adversarial networks (GAN), with which new and diverse project variants are created. For the same tasks, deep learning can be used, which uses multi-level neural networks and generates design solutions taking into account the limitations and requirements of the project. But you need to understand that a neural network cannot think like a human, it works according to specified algorithms, but fuzzy systems are based on fuzzy logic and fuzzy sets while generalizing both of these directions. Evolutionary calculations differ from other methods in that they are based on the principles of evolution and use selection, crossing, and refinement of design solutions in their work to optimize them. As an example, evolutionary calculations are used to consider all possible options for the arrangement of structures and to find the optimal design scheme. The variety of machine learning methods can be reduced to the main tasks that need to be solved. This directly affects the type of training. To classify some data, the project uses teacher training, for regression, teacher-based testing is used, and clustering is performed without teacher training. Given the variety of AI methods that can be used in generative design, the optimal solution for GD would be to use several AI tuning methods simultaneously, which would contribute to obtaining a better design result [II, V, VI, X, XI, XV].

III. Results

To determine the features of using AI in generative design, the authors first of all figured out how generative design differs from the currently more developed BIM design. For this purpose, a comparative analysis of BIM modelling and generative design was performed.

Here is a comparison between them:

Table 1. Comparative analysis of the information model (BIM) and the generative model of building and structure design

Indicators	BIM	GD
Description	Preparation of a digital model of a building that contains all parameters and information about structures and elements of the future building, materials, and equipment necessary for construction. Working in a BIM model, architects, designers, and engineers can create, analyze, and change the parameters of a building's construction in real time.	GD is an iterative process where the user sets the initial parameters for a building, and AI analyzes them and provides a variety of design solutions, observing the specified rules and parameters.
Tasks to be solved	First of all, the task of BIM modeling is to create a building information model. The model contains complete information about the object	GD offers design solutions for subsequent use and also contains all information about the project in the model.
Algorithms of operation	With the help of BIM, a digital model of the future object is created, to which all information is added throughout the entire life cycle of the project. The digital model is used by all project participants, starting from the designer and ending with the maintenance service.	Generative design consists in the fact that, based on the input parameters, AI creates a large number of design options, from which the Customer chooses the most appropriate option.

Work processes	With the help of BIM tools, designers model and visualize future buildings in 3D, while BIM technologies allow integrating solutions for architecture, engineering systems, structural schemes, etc. into the model, taking into account properties and characteristics of materials and energy efficiency when creating model, managing data, creating final design documentation and specifications.	Generative design automatically generates a variety of solutions in terms of architecture, engineering, design, etc., which allows you to obtain effective and already interconnected design solutions.
Basic properties	BIM technologies allow you to create a model of a real building and, if necessary, make changes to it, this adds efficiency and flexibility in design.	The generative approach also provides flexibility in design, but at the same time reduces the cost of variant elaboration of solutions and finalizing the final options, since AI is included in this procedure.
Automation	BIM automates part of the operational activities with the project, simplifying the work of the designer, for example, the exchange of information between related specialists, architects, and engineers, signals to the designer that errors (collisions) were made when assembling the model, but at the same time, eliminating these collisions is done manually.	Generative design is certainly a more automated process involving algorithms, mathematical models, and AI. This allows you not only to consider options for solutions but also to bring the project to the final result required by the Customer.

As you can see, according to the data presented in Table 1, it may seem that all characteristics of generative design using AI come down to automating the production

of design solutions and the use of algorithms instead of designers, but this is not entirely true. When using generative design, there will be limitations that are described later in the article. Today, generative design with AI is widely used in the creation of architectural solutions, visualization of buildings, and interior design of premises, but it is clear that with further development, this design method will cover the entire design process of objects. The main task for this remains preparation and correct configuration of incoming data for the correct operation of AI, as well as verification of the results obtained, in this case, it will be achieved a higher level of quality of produced documentation will be achieved, even compared to the BIM level 3 model, in which the entire project team participates in the creation of the building model. The dependence of the project quality level on the technologies used is shown in Fig. 2.

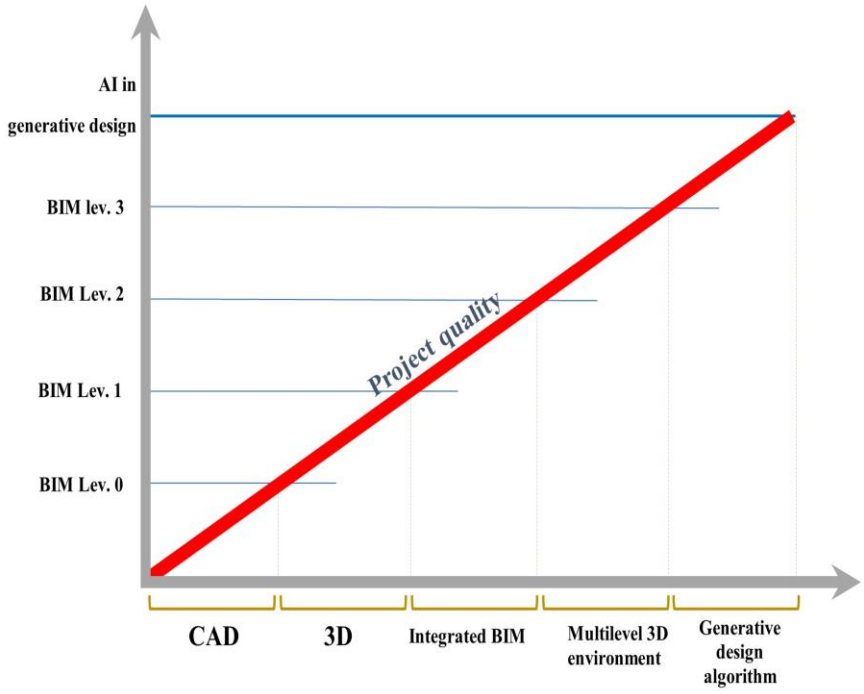

Fig.2. Quality level of the project

The main properties that the authors identify in generative design are summarized in Table No. 2.

Table 2: Properties of GD

Properties of GD	
Iterative design	As a result of GD work, designers receive the maximum number of design solutions based on the initial data of the model. This allows them to choose the most correct design solution without violating the requirements of the customer's technical specifications. based on input data loaded into the model. This allows them to choose the most correct design solution, without violating the requirements of the customer's technical specifications.
Design automation	Neural networks used in generative design make it possible to fully automate the process of developing design documentation, and the results obtained will be as accurate as the initial data for training the neural network were prepared in detail.
Consideration of regional requirements and regulations	If we correctly transmit information to the neural network about the requirements of regional norms and standards, we will receive design solutions that will take into account the requirements applicable to construction in a particular region. Such requirements may include environmental and social restrictions, structural loads, soil behavior, etc.
The procedure for the development and analysis of design solutions	A feature of GD is an iterative approach to design. The result allows you to refine and optimize design solutions. This leads to an improvement in the quality of the project by analyzing the proposed solutions at each stage of the iteration.
Individual approach	In addition to regulatory requirements, AI in GD takes into account the individual preferences and requirements of all project participants and personalizes the requirements of the main customer, which shortens the procedure for approving solutions and improves communications between project participants. At the same time, all requests submitted to the project from the Customer, without loss of any data, can be used on a repeat project from this Customer.

The undoubted advantage of GD using AI over traditional design methods is that when creating design documentation, more iterations of design solutions are carried out, and the use of manual work is reduced, which directly affects the reduction of design time, the number of reworks and reduces the cost of the project budget.

The formula for the proportional increase in the number of iterations can be represented as:

$$M=k*N \tag{1}$$

Where,

k- coefficient of difference in the number of iterations with and without an AI project;

N- number of design iterations without AI;

M- the number of iterations using AI

At the same time, it is necessary to clearly understand that while obtaining certain benefits from the use of AI in generative design, limitations arise, primarily related to the validation and verification of the results obtained with the help of AI and the increase in the cost of the project in terms of verifying these results. Figure 2 shows the redistribution of basic resources (time and cost) by design stages using AI and without AI.

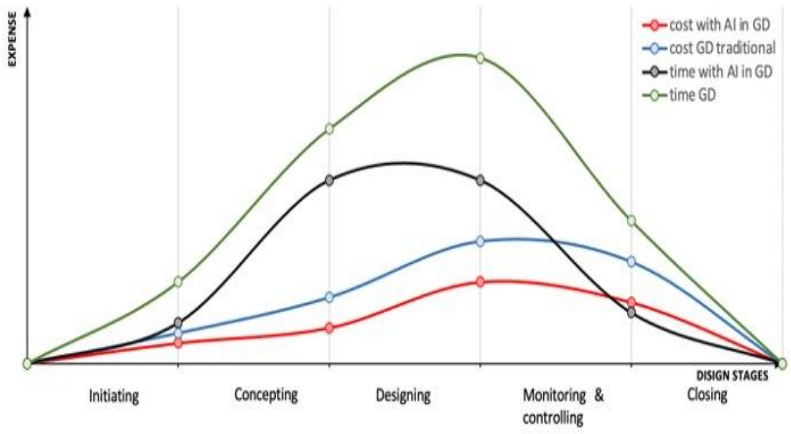

Fig. 3. Reallocation of resource

As a result of the conducted research and scientometric analysis, the authors highlight the features of using AI in generative design:

Table 3: Features of the use of AI in generative design

Development of design solutions	Based on the initial project data, AI creates several design solutions. The resulting options are analyzed by designers who choose suitable design solutions for the next stage of design. This iterative process continues until the project is approved by the Customer.
Scope of application	The generative design methodology using AI can be used to produce design documentation for various purposes. It is used to produce individual drawings, such as interior design, structural diagrams of engineering systems, and landscaping plans, and to prepare a complete set of working drawings throughout the building. This technique is applicable to buildings and structures of any functional purpose and building dimensions, and can be used for a complex of objects with interconnection of all design solutions.
Optimization of the characteristics and parameters of the design object	It helps designers optimize design solutions based on customer requirements, which often arise during the design process and require a lot of time. For example, a change in the number of floors of a building an increase in area, a change in technology or explication of premises. AI significantly reduces the processing time for new requirements from the customer.
Performing everyday tasks	Helps the designer in performing day-to-day and routine design tasks, such as creating initial drawings, preparing documentation for the release of work, sending design solutions for review and approval to project participants, etc.
Forecasting the application of design solutions	Designers often need to make design decisions without having a definitive vision of whether this decision is appropriate or not. So, the decision made to change any design or equipment at the initial stage seems correct, but with subsequent elaboration or linking of design solutions with each other, it turns out that the initial decision is erroneous. This throws the designer back a few steps, and in terms of saving time, it forces him to make rash decisions. AI completely eliminates such a problem in the design.

Feedback	Simulates the actual operating conditions of the building, for example, the operation of engineering systems or the impact of external loads on the facade and roof of the building. Informs developers about the need to change design solutions, if required.
Analyzing large amounts of data	GD requires constant analysis of a huge amount of information and data on the project. This increases the time frame if you do not use modern technologies and software created on the basis of AI.
Improving communication within the project	Interaction between project participants can be difficult, especially if designers and customers are located in different countries, in this case, the ability of AI to systematize ideas proposed by related specialists and coordinate interaction between designers will be very useful.
Forecasting and risk analysis	Analyzes and systematizes risks, and predicts possible problems and emergencies that may arise if solutions are chosen incorrectly, which allows specialists to take measures to eliminate risks or develop compensating measures.
Application of materials and equipment in the project	The selection of equipment and materials used in the project is always a painstaking and energy-consuming task for design organizations. AI simplifies this work, while taking into account the nomenclature of materials and equipment produced at the moment and excludes items that have ceased to be produced by manufacturers of materials.
Interaction with external factors and technologies	The combined use of AI with modern technologies such as augmented and virtual reality allows designers and customers to obtain a visualized model of the building, which can be studied at the design stage of the facility.

The features of using AI in generative design allow designers to create interesting and unique projects, while complying with the regulatory requirements for documentation in construction and design, as well as project indicators such as the facility budget, design and construction deadlines, and more accurately determine the resources needed for construction, materials and equipment [V, VI, X, XI].

IV. Conclusion

Every day artificial intelligence plays an increasingly important role in various spheres of human activity. Naturally, in such an important industry as construction and, in particular, in design, AI-based technologies are being introduced everywhere, with the help of which new design tools are being developed. In generative design, which is one of the methods of developing project documentation, in the near future it is possible to fully unlock the capabilities of AI, which is able to process huge layers of information, constantly analyze changing project requirements, and create various design solutions. AI in design enables designers to create unique and innovative solutions in all areas of design, such as architecture, structural solutions, engineering systems, and landscaping. This allows designers to save time and resources on the design process itself, optimize the parameters of the object, as well as quickly respond to changes to the project, not waste time on everyday tasks and pay more attention and time to analyze the proposed design solutions. However, along with the huge advantages of using AI in design, the authors in the course of the study identified the limitations that arise with such cooperation:

- It is necessary to work out in great detail and prepare the terms of reference for the design, indicating all the requirements for the project. At the time of design, this data may be incomplete or completely absent;
- Neural networks are capable of self-learning, and it is not always possible to track what the AI is learning and where it gets the data for training. This can lead to incorrect design solutions being used in the design;
- The issue of approving design solutions for the execution of work is very important. The issued documentation must be approved and signed by the designer who prepared it. The use of AI, have are gaps in the laws. The designer may not be satisfied with the options that AI offers;
- Neural networks follow clear rules and specified algorithms, which, unfortunately, cannot always be applied by designers, especially if we are talking about architectural techniques or design solutions;
- There is always a challenge in interpreting and verifying the results of AI activities. Some decisions made are difficult to understand and explain and they may not be typical for the project; this again leads to the fact that the project is difficult to justify and defend to the Customer.

The authors of the article concluded that the use of AI in GD is promising in design and is developing at a tremendous pace The authors of the article concluded that the use of AI in GD is promising in design and is developing at a tremendous pace. Designers are beginning to use this technique more often and switch to designing using AI. At the same time, I would like to note that the process of implementing AI in design should be controlled and careful, and take into account the limitations on the use of AI described in the article [XVIII, I, XX, VII, VIII].

Conflict of Interest:

The author declares that there was no conflict of interest regarding this paper.

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