EVOLUTION OF ARTIFICIAL INTELLIGENCE AND ITS INTEGRATION IN ARCHITECTURAL DESIGN

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Abstract: This article analyzes the conceptual formation and historical development stages of artificial intelligence (AI) within the context of architectural design. The study examines the evolution of AI technologies, from early rule-based systems to advanced approaches such as deep learning and generative models. The paper evaluates the emergence of AI tools in architectural design, their functional capabilities, and their role in optimizing design decisions. It highlights how AI is being integrated into contemporary architectural practice through approaches such as shape grammar, parametric design, generative adversarial networks (GANs), and large language models (LLMs). The article aims to provide a systematic analysis of the interrelation between AI and architecture.

Keywords: artificial intelligence, architectural design, historical development, generative design, parametric design, deep learning, large language models, evolutionary algorithms.

Аннотация: В данной статье рассматриваются становление и исторические этапы развития понятия искусственного интеллекта в контексте архитектурного проектирования. Проанализирована эволюция искусственного интеллекта — от первых экспертных систем, основанных на правилах, до современных подходов, таких как глубокое обучение и генеративные модели. Особое внимание уделяется интеграции искусственного интеллекта в архитектурную практику, включая его применение в параметрическом проектировании, генеративном дизайне, работе с большими языковыми моделями (LLM). Работа направлена на системный анализ взаимосвязи между искусственного интеллекта и архитектурной средой, а также на оценку влияния искусственного интеллекта на процесс принятия проектных решений.

Ключевые слова: искусственный интеллект, архитектурное проектирование, историческое развитие, генеративный дизайн, параметрический дизайн, глубокое обучение, большие языковые модели, эволюционные алгоритмы

Annotatsiya: Ushbu maqolada sun’iy intellekt tushunchasining shakllanishi va tarixiy rivojlanish bosqichlari arxitektura dizayni kontekstida tahlil qilinadi. Sun’iy intellekt texnologiyalarining dastlabki qoidalarga asoslangan tizimlardan boshlab, chuqur o‘rganish va generativ modellar kabi ilg‘or yondashuvlargacha bo‘lgan evolyutsiyasi ko‘rib chiqiladi. Tadqiqotda me’moriy loyihalashda sun’iy intellekt vositalarining paydo bo‘lishi, ularning funksional imkoniyatlari hamda loyihaviy qarorlarni optimallashtirishdagi o‘rni baholanadi. Shape grammar, parametrik dizayn, GAN va LLM kabi yondashuvlar asosida zamonaviy arxitektura amaliyotiga sun’iy intellektning qanday integratsiyalashayotganligi ochib beriladi. Maqola sun’iy intellekt va arxitektura o‘rtasidagi uzviy bog‘liqlikni tizimli tahlil qilishga qaratilgan.

Kalit so‘zlar: sun’iy intellekt, arxitektura dizayni, tarixiy rivojlanish, generativ dizayn, parametrik dizayn, chuqur o‘rganish, katta til modellari, evolyutsion algoritmlar

Introduction. In recent decades, the rapid development of artificial intelligence (AI) technologies has led to significant changes in various areas of society, including architecture and design. The term AI is a product of the development of modern information technologies and science, which refers to the ability of computers and programs to perform tasks inherent in human intelligence. In scientific sources, AI is defined as "the ability of a digital computer or computer-controlled robot to perform tasks inherent in intelligent beings" [1].

The concept of AI was initially formed at the intersection of disciplines such as mathematical logic, neurophysiology, and cybernetics. In particular, the "Turing test" proposed by Alan Turing in the 1950s laid the foundation for AI theory [2]. In 1956, during a scientific seminar at Dartmouth College in the United States under the leadership of John McCarthy, the term "AI" was first officially introduced into circulation, and AI began to take shape as an independent scientific direction [3].

Architectural aspects of AI emerged as early as the 1960s and 1970s. For example, in The Architecture Machine, published in 1970 by MIT scientist Nicholas Negroponte, computers were interpreted as "intelligent design assistants," and he noted that in the future every citizen would be able to independently design a house using AI [4]. Today, advanced AI technologies such as generative design, parametric modeling, deep learning, and large language models (LLM) are increasingly used in modern architectural practice [5].

The main goal of this study is to study the historical development stages of the AI concept and analyze its impact on architectural design processes.

The study aims to:

Identify the main stages of the historical development of AI;

Analyze the approaches directly related to the field of architecture at each stage;

Evaluate the formation of AI-based methods and tools in architectural design;

Determining the role and prospects of SI in the modern architectural environment.

This study serves to provide a deeper understanding of the digital transformation of design processes by analyzing the evolution of SI in the context of architectural design.

Materials and methods used. In this study, a scientific-analytical method was used to analyze the development of SI in the field of architecture and design on a historical and conceptual basis. An evolutionary stage analysis was chosen as the main methodological approach. Through this, the development process of SI was studied step by step based on a historical sequence and the impact of each stage on architecture was systematically highlighted.

The study was based on the following main theoretical sources and concepts of the authors:

The concept of The Architecture Machine, put forward by Nicholas Negroponte in 1970, described the computer as an interactive intellectual assistant in design and defined the first theoretical connections between architecture and SI [4].

The theory of parametricism developed by Patrick Schumacher has become the basis for analyzing the algorithmic approach and the application of SI technologies to design in modern architecture [5].

The work of researchers such as John Frazer, Stanislas Chaillou, Kumaran Ramesh, Christopher Alexander, Omer Akin, and William Mitchell has served as the basis for analyzing approaches within the framework of SI, generative design, and evolutionary architecture [6], [7], [8], [9].

The main sources used in the study are scientific articles, dissertations, monographs, and practical project experiences, which were selected from databases such as Scopus, Google Scholar, Springer, MIT Press, and Architectural Design. Real project examples related to the use of SI technologies in architectural practice were also involved in the analysis (for example, ArchiGAN, Dreamcatcher, FloorPlanGAN, etc.) [8].

In general, the study is based on the following methodological approaches:

Historical-evolutionary analysis - separation of the development of SI by periods (1950–2020)

Theoretical conceptual analysis - revealing the logical consistency of the main ideas and methods

Scientific source analysis - linking advanced SI approaches with practical architecture

Results The integration of SI into the field of architecture and design took place gradually, based on historical development, and in each period its own technological approaches were formed. (Figure 1).

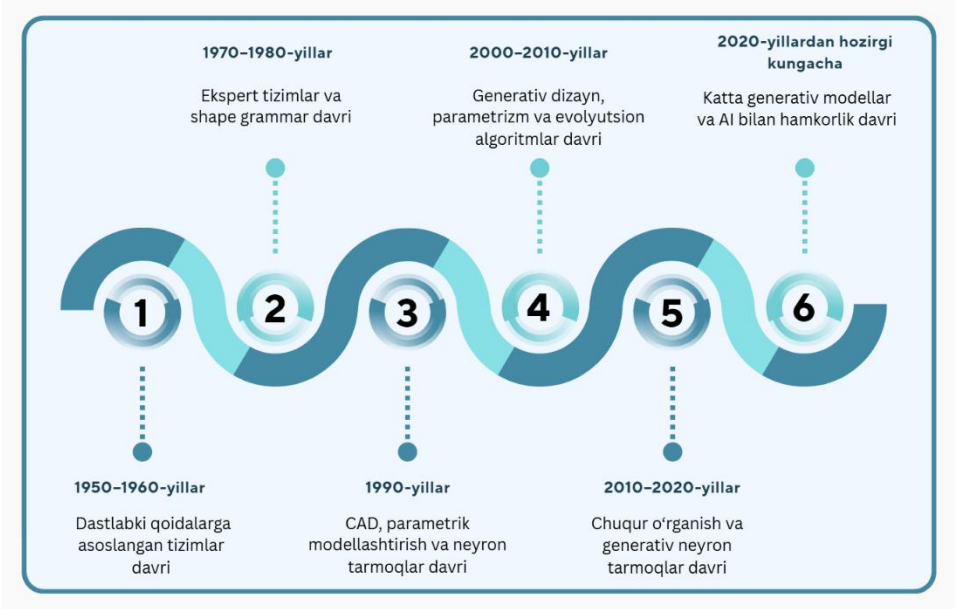


Figure 1. Stages of integration of AI into architecture and design, historical development stages

During the study, the following main stages were identified, each of which had a significant impact on architectural design:

1950–1960s — Early rule-based systems. This period is the stage of formation of the concept of AI and is characterized by the creation of early models based on logical rules. The "Turing test" proposed by Alan Turing and the "General Problem Solver" (GPS) program by Newell and Simon are considered the first fundamental studies of artificial intelligence [2]. These systems operated on the basis of strict logical rules, but their direct impact on the field of architecture was still limited.

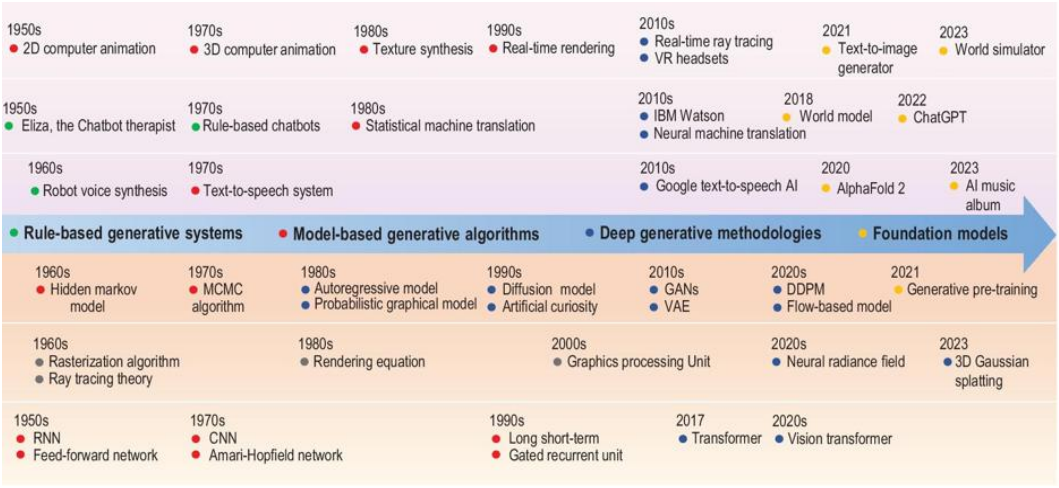


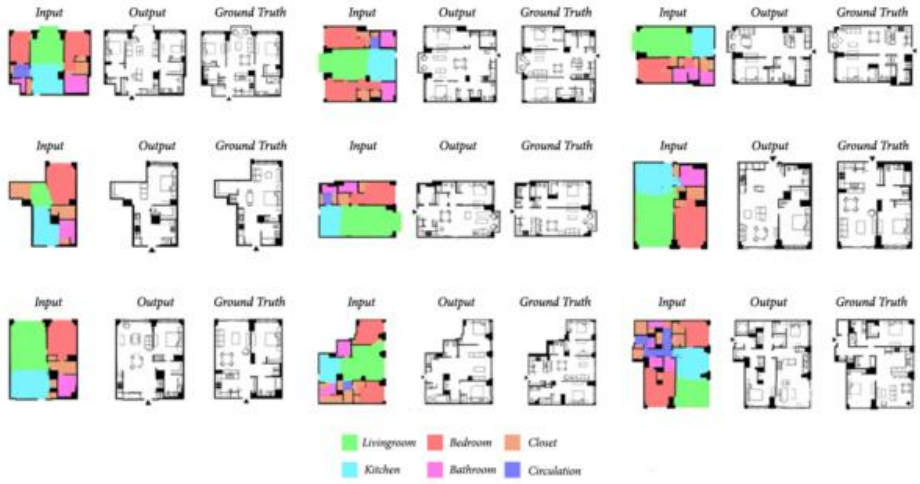
Figure 2. Timeline of the development of GAI methods and applications [10].

1970–1980s — Expert systems and shape grammar. At this stage, practical manifestations of SI in architectural design began to appear. Expert systems — that is, logical output systems based on expert knowledge — entered architecture as well as medicine and engineering. Researchers such as Omer Akin and Ulrich Flemming attempted to automate the architectural planning process [9]. At the same time, the shape grammar approach developed by George Stiny and James Gips allowed the creation of geometric shapes based on generative rules [11].

1990s — CAD, parametric modeling and neural networks. During this period, the widespread use of CAD (Computer-Aided Design) programs led to the digitalization of design. At the same time, the revival of artificial neural networks (in particular, the introduction of the backpropagation algorithm) paved the way for the growth of machine learning [12]. Concepts put forward by Christopher Alexander, William Mitchell, and others led to the algorithmic modeling of architectural design [8].

2000–2010s — Generative design, parametricism, and evolutionary algorithms. This phase saw the emergence of parametric design and generative methods that allowed architects to design complex shapes. Tools such as Rhino/Grasshopper allowed architects to control geometry through parameters. Patrick Schumacher called this approach "parametricism" and justified it as a modern architectural style [5]. At the same time, evolutionary algorithms — in particular, genetic algorithms (GA), particle swarm optimization (PSO) — began to be used to find optimal solutions to design problems [6].

2010–2020s — Deep learning and generative neural networks. During this period, deep learning methods, especially convolutional neural networks (CNN), made great strides in image processing. In the field of architecture, GAN (Generative Adversarial Networks) models — for example, ArchiGAN [20], FloorPlanGAN [9] — have been used to perform tasks such as building plan generation, semantic segmentation, and functional zoning. These technologies have opened up the possibility of creating designs through SI. (Figure 3-4).



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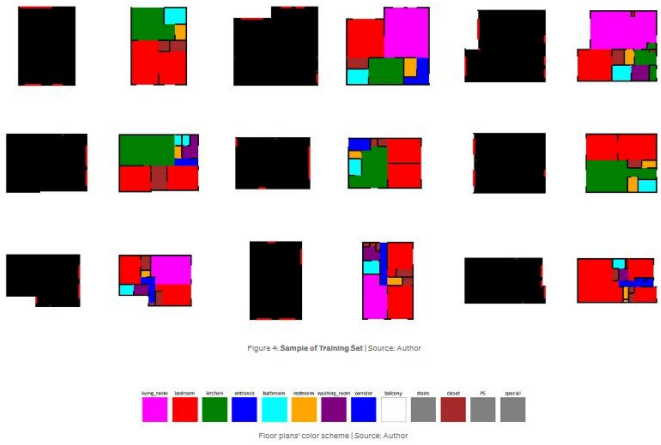

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2020s to Present — Large Generative Models and Collaboration with AI. At the latest stage, large language models (LLM) and multimodal generative systems (DALL-E 2, Midjourney, ChatGPT, Stable Diffusion) have begun to be used in the development of conceptual solutions in architectural design. For example, Sidewalk Labs' Delve platform and Spacemaker applications are developing optimal solutions for analyzing and placing urban environments using SI. In addition, useful experiences are being gained in areas such as AI-based automatic code generation (for example, scripts for Grasshopper), project analysis, and document creation.

Analysis and discussion. The studied historical stages and modern practical experiences show that SI technologies have not only created technical conveniences in the field of architecture and design, but also had a conceptual impact on the entire design process. SI-based approaches have made it possible to quickly develop architectural solutions, optimize them, and expand the range of options.

First, SI tools have enabled creative thinking and automated idea generation. In particular, architectural forms, interior plans, and spatial configurations are being automatically generated using GAN, VAE, and transformer-based models. (Figure 5). For example, the ArchiGAN model is able to create new combinations based on different apartment plans, while the FloorPlanGAN model suggests new living space plans based on parameters [8]. These technologies have made it possible to explore new options and test previously unavailable shapes and forms at the design stage. (Figure 5.)

Secondly, SI has made it possible to formalize architectural solutions and algorithmize work with them. In particular, in the framework of parametric design (e.g., Grasshopper, Dynamo), shape and geometry are controlled by mathematical expressions, which allows the designer to optimize, analyze, and automatically redesign complex forms based on various constraints [5]. Evolutionary algorithms — in particular, genetic algorithms (GA), particle swarm optimization (PSO) — are successfully used to find optimal solutions to architectural problems (for example, the degree of shading of facade panels, the location of rooms inside a building).

Third, the introduction of AI tools has created a new design paradigm in architectural practice, which is taking shape based on human-machine cooperation. The architect gives commands to the AI model in the form of prompts (requests) or parameters, and the AI generates, analyzes or recommends hundreds or thousands of options. In this process, human creativity and machine computing capabilities complement each other. In this regard, modern design is based on the "human-in-the-loop AI" model, where the architect retains creative control, but the computational and analytical part is assigned to the AI [4].

Fourth, the rapid development of AI also raises urgent issues related to ethics, law and copyright. Who owns the intellectual property rights of design products created using generative models? Who is responsible for technical errors or functional deficiencies resulting from the project? These questions have not yet been resolved on a global scale, but are widely discussed in scientific circles. In particular, in cases where large language models such as ChatGPT are used to create project documentation or automate communication with the client, there is a risk that SI tools will make incorrect or insufficiently substantiated decisions. Fifth, modern SI approaches are widely used at various stages of design: concept development (prompt-based generation), analysis of project options (testing options in a parametric model), preparation of final documents (writing automatic descriptions using LLM), and even studying the energy efficiency or structural calculations of the project (BIM+AI integration). For example, Delve and Spacemaker programs automatically recommend optimal locations based on urban location, building spacing, ventilation, and sunlight.

has reached. Now design is based not only on human experience and taste, but also on options analyzed, optimized and proposed by artificial models. This is taking the principles of efficiency, functionality and multivariate design to a new level in architecture. At the same time, new problems - for example, reducing the role of the human being, the risk of wrong decisions, and ethical issues - are also emerging as areas requiring scientific discussion and solution.

Conclusions and recommendations.

This study sheds light on the historical development of the concept of SI step by step, and its role and possibilities in architectural design are analyzed in depth. The results of the study show that SI technologies are integrated into the architectural environment not only technically, but also conceptually and creatively. The evolutionary path from traditional rule-based systems to deep learning, generative models (GAN, LLM) and parametric design has taken architecture to a new methodological level.

In the study, the evolution of SI was systematically analyzed for the first time in the context of

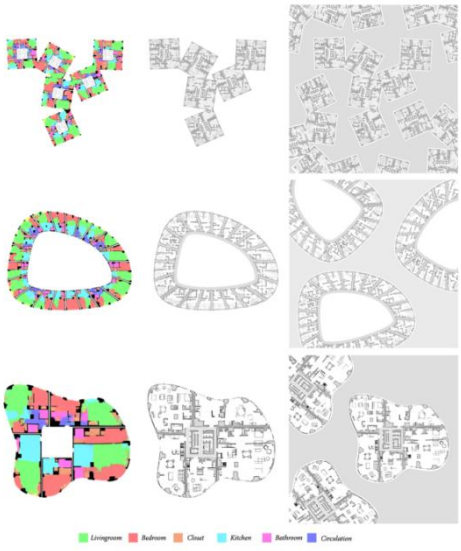

Figure 12. GAN-enabled building layouts

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architecture. It explains with well-founded examples and conceptual models how AI approaches emerged at each historical stage and how they influenced the design process. In particular, for the first time, how AI technologies motivated the development of shape grammar, parametricism, generative design, and LLM approaches in architecture has been systematized so clearly.

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