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# Bibliometric Analysis on Artificial Intelligence Aided Architectural Design

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**Abstract:** Technological advancements have created new dimensions in various fields, including architecture. The widespread use of information technology has particularly transformed architectural designs. In architectural design processes, methods and tools have diversified beyond traditional approaches, incorporating computer-aided programs, computational functions with plugins, and even contemporary artificial intelligence (AI)-supported software and applications tailored to specific needs. It is inevitable that AI-supported designs will increasingly feature in the future of architecture. The purpose of this study is to determine the role of AI applications in architectural design. To this end, a bibliometric analysis was conducted on 137 articles related to artificial intelligence and architectural design from the period 1991-2024, sourced from the Web of Science (WoS) database. The analysis focused on main topics, keywords, authors, sources, highly cited articles, and countries. The selected articles were analyzed using VOSviewer to examine the use of AI applications in architectural design. Quantitative analyses providing an overview of the topic are presented in tables, graphs, and maps. It has been determined that at least 30% of the studies were conducted in the field of architecture. It was found that studies on the subject have rapidly increased since 2020. The continued growth of AI usage across all fields is expected to extend into architectural design as well. Therefore, it is deemed necessary to address AI in architectural design education to align with these advancements. Finally, the paper discusses forward-looking recommendations on how to incorporate AI into architectural design education.

**Keywords:** Architectural design, Architectural education, Artificial intelligence (AI), Bibliometric analysis.

## 1. Introduction

Technological advancements have, as in other fields, introduced various perspectives within architecture. Particularly with the increased use of information technologies, architectural design processes have undergone significant transformation. In architectural design processes, which can be summarized as problem-solving through the synthesis of theoretical knowledge, inquiry, research, development, and application, the methods and tools required are continuously evolving in line with contemporary advancements.

Today, the tools and approaches used by architects have become crucial elements affecting the design and process of buildings. Applications ranging from sketches and two-dimensional drawings to physical models, and even to the creation of specialized design tools for specific solutions, are now part of the process. The automation of architects' work began with computational functions added to traditional computer-aided design tools. With advancements in information technology, architects are increasingly inclined to use

specialized tools and even AI (Cudzik & Radziszewski, 2018). Recent technological developments are even enabling AI-supported unique designs. It is inevitable that AI-supported designs will become more widespread in the field of architecture in the future. Therefore, examining the relationship between artificial intelligence and architecture today and discussing advancements in this area are crucial for determining the place and potential of AI applications in the future of architecture. In this context, creating new perspectives on how architectural education should be updated is essential for staying current.

In recent years, artificial intelligence (AI) research has been gaining significant momentum. AI-based systems enable the development of design tools specifically tailored for architects to address particular problems. The integration of AI applications into architectural practice is also causing significant shifts in architectural education. Both students and educators may encounter challenges in adapting to these processes during learning and teaching phases. With the advent of digital transformation, the integration of AI applications into innovative educational approaches has become a point of critical discussion. Evaluating AI applications alongside digital learning approaches in architectural design education is crucial for understanding the current state of architectural education and ensuring smooth adaptation to new methodologies. This study aims to assess the place of AI developments in architectural design, providing significant contributions to the future of architectural education.

The aim of this study is to determine the place of AI applications in architectural design by measuring usage models through bibliometric analysis and to contribute to the inquiry of their role in future design education. The results provide an overview, structure, and key reference studies on AI in architecture. Additionally, the main objectives of the research include providing a foundation for researchers interested in the topic, serving as a reference point for future researchers, and offering a general perspective on the field. To achieve this, trends emerging from studies published between 1991 and 2024 in the Web of Science database are analyzed. The results are evaluated to create a discussion environment regarding the place of AI applications in architectural design education.

## 2. Background

Architectural design can be defined as a process of generating solutions either in response to clearly defined problems or, at times, identifying and addressing ill-defined or ambiguous problems. These solutions can be developed not only through traditional methods but also with the support of computerized digital technologies and AI applications. Today, a wide range of computer-aided design (CAD) software, visualization tools, post-production applications, graphic representation tools, and even AI applications specifically designed for these purposes are utilized by both designers and architecture students.

Architectural design education is a learning process characterized by the mutual interaction between the student and the instructor. One of the primary goals of design education is to uncover and cultivate the creative thinking that resides within students. With advancing technology, AI applications, which are increasingly employed in various fields, are now being used by students to generate visual design alternatives in a rapid and practical manner. This is achieved through the use of chatbots that provide written solutions. In this context, it is essential to consider how AI will be integrated into architectural design education.

In line with this, chapter 2.1 provides a brief background on architectural design and presents a literature review on the use of AI in architectural design. Following this, chapter 2.2 offers a brief background on architectural education and discusses the use of AI in architectural education through a literature review. Within the scope of this study, the design studio, which forms the foundation of architectural design education, is framed as a

learning environment where the design/learning process takes place.

**2.1. Use of AI in Architectural Design**

According to Simon (1996: 111), design can be defined as the process of transforming the current state into the desired state. He argues that anyone who is capable of planning this transformation can engage in design. Simon offers another definition of design as follows:

> "Design…means synthesis. It means conceiving of objects, of processes, of ideas for accomplishing goals, and showing how these objects, processes or ideas can be realized. Design is the complement of analysis for analysis means understanding the properties and implications of an object, process, or idea that has already been conceived."

Simon defines design as follows in his description, which can be considered a modeling approach within artificial intelligence (Visser, 2006: 50):

> "Design is inherently computational-a matter of computing the implications of initial assumptions and combinations of them. An omniscient God has no need to design: The outcome is known before the process starts. To design is to gather information about what follows from what one has proposed or assumed. It is of interest only to creatures of limited information and limited computing power-creatures of bounded rationality like ourselves."

According to him, the act of designing can be described as a synthesis activity and a phenomenon involving various combinations based on computation.

Lawson (2005: 3), summarizing architectural design as a process, emphasizes the necessity for a designer to be trained to understand problems that others might find difficult to define and to produce effective solutions. He highlights that such work requires more than just a 'feeling' for materials, forms, shapes, or colors; it necessitates a wide range of skills (Lawson, 2005: 5-6).

In the design process, which is a mental activity, graphical representation techniques are used to externalize the images created. These include traditional two- or three-dimensional drawings and models that evolve from abstract to concrete representations (Güç & Karadayı, 2007). With the integration of computers and communication technologies into the architectural design process, digital technologies have become valuable tools for visualizing the design process in addition to traditional forms of expression (Yıldırım, Özen Yavuz & İnan, 2010). Today, the increasing use of AI applications has undoubtedly introduced a new dimension to this field.

In architectural design, computing relies on calculation and automation. Design software provides various automatic tools that support the creative process. The most suitable for computer-automated design are those that use visual scripting, allowing users to create their own algorithms through a common programming language or visual scripting techniques. No other system offers designers such a high level of control and the ability to create custom design tools suited to their needs and habits. Automated design systems are widely used in contemporary architecture due to their potential to increase productivity and flexibility, even in complex environments, by developing specialized, topic-specific tools (Cudzik & Radziszewski, 2018).

Among many algorithmic design strategies, evolutionary algorithms, swarm intelligence, and neural networks are shifting the computational architectural toolkit towards AI approaches. The evolutionary algorithm computational model provides optimized configurations based on specified goals by adjusting input parameters. Swarm intelligence relies on the collective behavior of self-organizing systems. Neural networks, on the other hand, are machine learning programs based on training with examples of input parameters and corresponding output values, similar to human decision-making processes.

Various forms of AI approaches are used in architectural design processes, each offering new ways to create architectural forms that lead to different spatial effects. However, the role of the architect in the process remains indispensable, as it is the architect's responsibility to select the most suitable solution from the many design options offered by AI with a critical perspective (Cudzik & Radziszewski, 2018).

### 2.2. Use of AI in Architectural Education

Architectural design education shares several common fundamental characteristics. Design studios are the core component of this education. Conceptually, a studio is a hands-on learning process where answers are sought through a defined design problem (Lawson, 2005: 7). Globally, design education is largely studio-based, where students learn by engaging with problems rather than merely acquiring and applying theory. Architectural design education requires a delicate balance between guiding students to acquire knowledge and experience while not mechanizing their thought processes to the extent that it stifles the emergence of original ideas (Lawson, 2005: 156-157).

With the rapid development of technology today, architectural designs are increasingly supported by computer-aided applications, including drawings, 3D visualizations, and, more recently, the growing use of AI applications, in addition to traditional methods such as hand drawings, sketches, and models. This situation necessitates an architectural education that incorporates new applications alongside traditional academic-based design education.

The use of AI in education has become a significant research topic with the rapid advancement of computer technologies. Over the past two decades, there has been substantial growth in the application of AI in education, ranging from laboratory environments to various field applications. The use of AI in education has evolved into optional approaches for applications such as computer-aided educational design, speech recognition, language processing, and robot control (Jordan & Mitchell, 2015; Yo, 2020).

How design education should be conducted will likely remain as debatable as design itself (Lawson, 2005: 8). AI applications represent a broad field requiring specific goals, provided by a wide range of tools. Thus, determining which AI tools and applications are suitable for particular tasks and learning processes and selecting the scope of instructional content is challenging. Proposing appropriate strategies for AI education in architectural design is both complex and difficult. Identifying suitable AI applications requires substantial practical experience (Başarır, 2022).

The integration of AI into architectural design education equips students with a range of powerful tools to explore new design methods and optimize existing designs. However, to effectively incorporate AI into design education, appropriate educational models and strategies must be developed to adapt to rapid technological advancements (Zhang, Fort & Giménez Mateu, 2023).

## 3. Method

In this study, bibliometric analysis has been utilized to uncover distribution patterns and trends in the use of AI in architectural design research. The bibliometric analysis method is employed to reveal the current structure of research trends within a specific field and to identify gaps in the literature (Donthu et al., 2021; Tranfield, Denyer & Smart, 2003). This method involves analyzing the relevant literature through statistical and mathematical approaches (Zou, Yue & Le Vu, 2018). It also aids in obtaining an overview of the subject, identifying knowledge gaps, generating new research ideas, and providing intended contributions to the field (Donthu et al., 2021). Additionally, this method facilitates the identification of emerging research areas and promotes collaboration between institutions and researchers (Fahimnia, Sarkis & Davarzani, 2015).

The recent emergence of scientific databases such as Pubmed, Scopus, and Web of Science

has made it easier to obtain large volumes of bibliometric data. Bibliometric software such as Bibliometrix, Gephi, VOSviewer, and Leximancer enables the pragmatic analysis of such data (Donthu et al., 2021). For this study, the Web of Science (WoS) database was used for bibliometric analysis. A search conducted on March 3, 2024, using the keywords "artificial intelligence," "architectural design," and "architecture" resulted in a total of 260 studies. The analysis focused on articles published in scientific journals, which represent a sample of international scientific activity (Velasco et al., 2011; Durán-Sánchez et al., 2018), excluding editorials, news, meeting papers, conference proceedings, books, chapters in books, technical reports, and other types of documents. A total of 137 articles from various disciplines/fields, ranging from the earliest data in 1991 to the most recent in 2024, were analyzed using VOSviewer software. The obtained data was examined through year, co-authorship, country, keyword, and citation analyses (Figure 1).

## 4. Findings

In the study, a total of 137 articles related to architectural design and AI were identified through a search conducted on the Web of Science. The increase in the number of articles

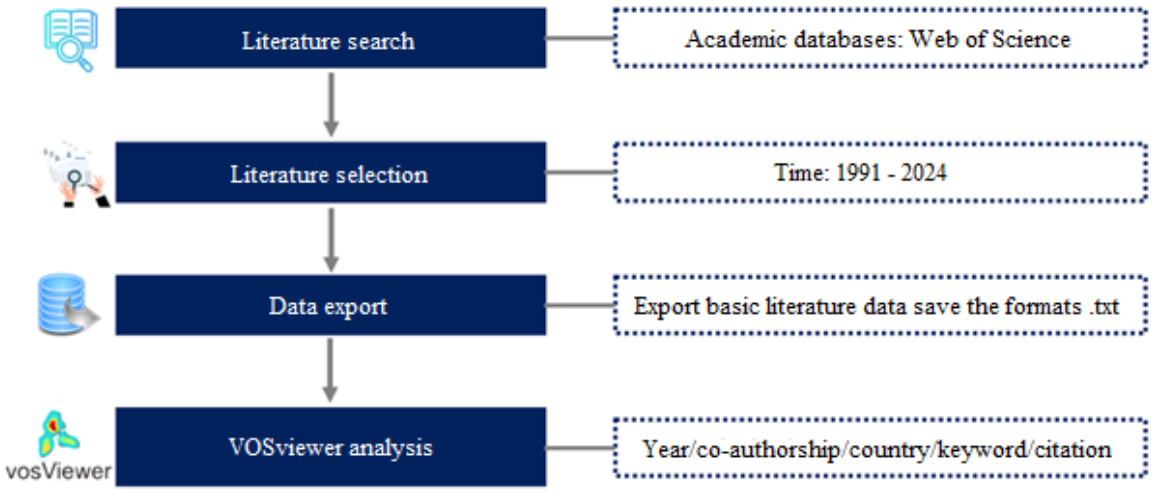


***Figure 1:*** *Methodology used in the research*

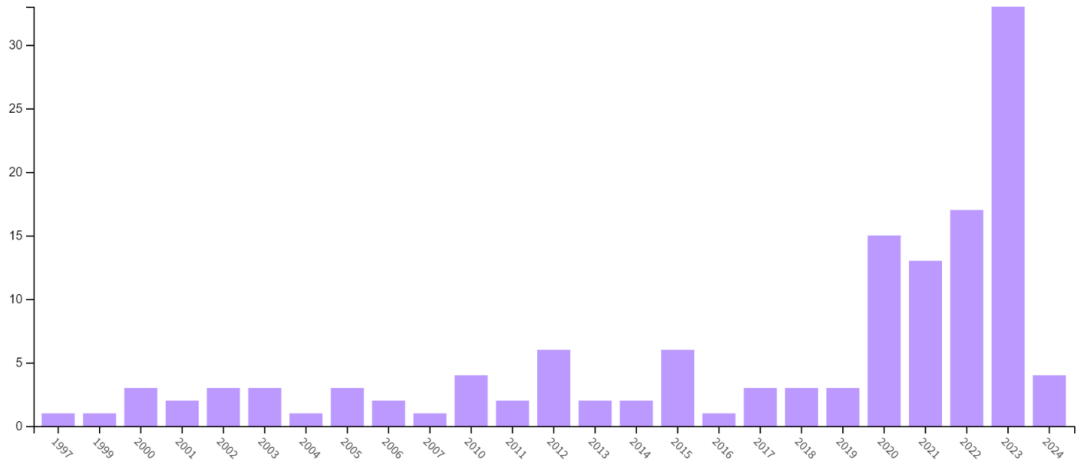


***Figure 2:*** *Yearly growth graph of studies conducted in the fields of AI and architectural design*

over the years is illustrated in Figure 2. In the WoS database, which includes keywords such as artificial intelligence, architectural design, and architecture, there were at most 6 articles per year from 1991 to 2019. However, in 2020, there were 15 articles; in 2021, 13 articles; in 2022, 17 articles; and in 2023, 33 articles. As depicted in the graph, a noticeable surge in the number of publications related to the topic is evident starting from 2020, with a significant spike observed particularly in 2023 (Figure 2). The number of articles published in 2023 constitutes 24% of the total number of publications on the subject.

As shown in Figure 3, in the analysis of co-authorship with the keywords "artificial intelligence," "architectural design," and "architecture," the most connected authors include Jonathan Byrne, Michael Fenton, Erik Hemberg, Martin Hemberg, James McDermott, Ciaran McNally, Michael O'Neill, Elizabeth Shotton, and John Mark Swafford.

The countries with the highest number of publications on the topic are as follows: the United States (31 articles), China (22 articles), the United Kingdom (11 articles), Türkiye (10 articles), Germany (10 articles), Spain (8 articles), Belgium (7 articles), and Italy (6 articles). In the co-authorship analysis with the keywords "artificial intelligence," "architectural design," and "architecture," Spain is identified as the country with the highest level of

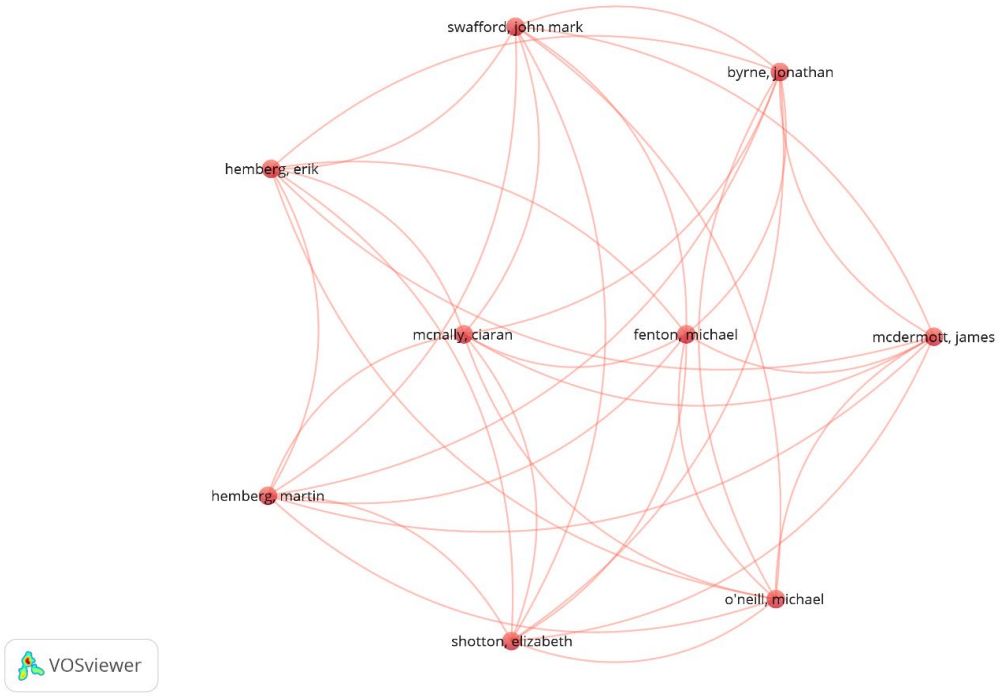


***Figure 3:*** *Co-authorship analysis*

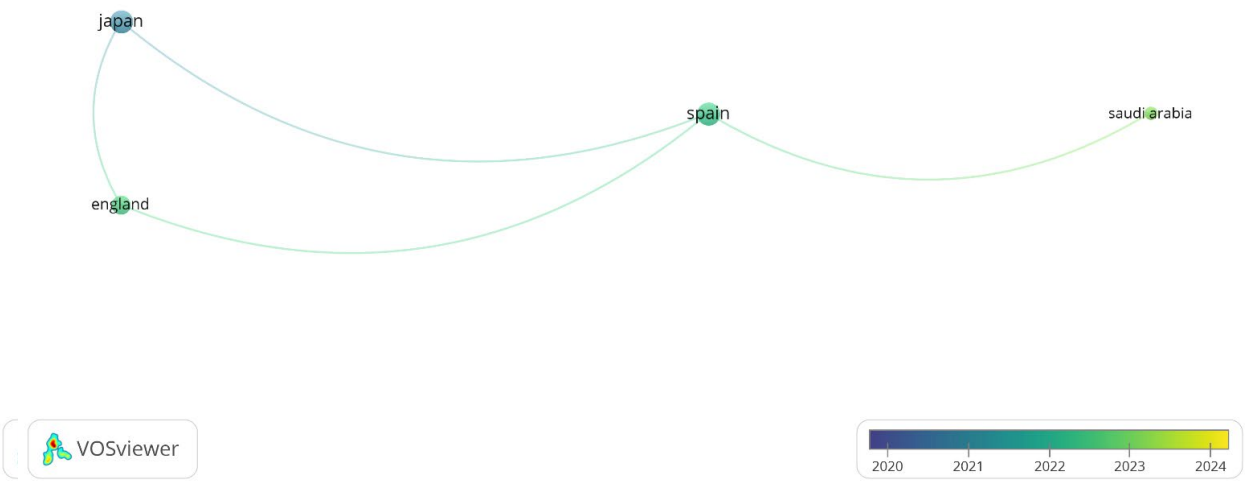


***Figure 4:*** *Country co-authorship analysis*

collaboration (3 articles), followed by the United Kingdom, Japan, China, and the United States (2 articles each) (Figure 4).

Figure 5 illustrates the connections among the total of 265 keywords that appear at least once in the Web of Science search for the keywords "artificial intelligence," "architectural design," and "architecture." The top 10 keywords based on their frequency of occurrence are: "artificial intelligence" appearing 25 times, "architectural design" 13 times, "architecture" 8 times, "generative design" 4 times, "deep learning" 4 times, and "design process," "machine

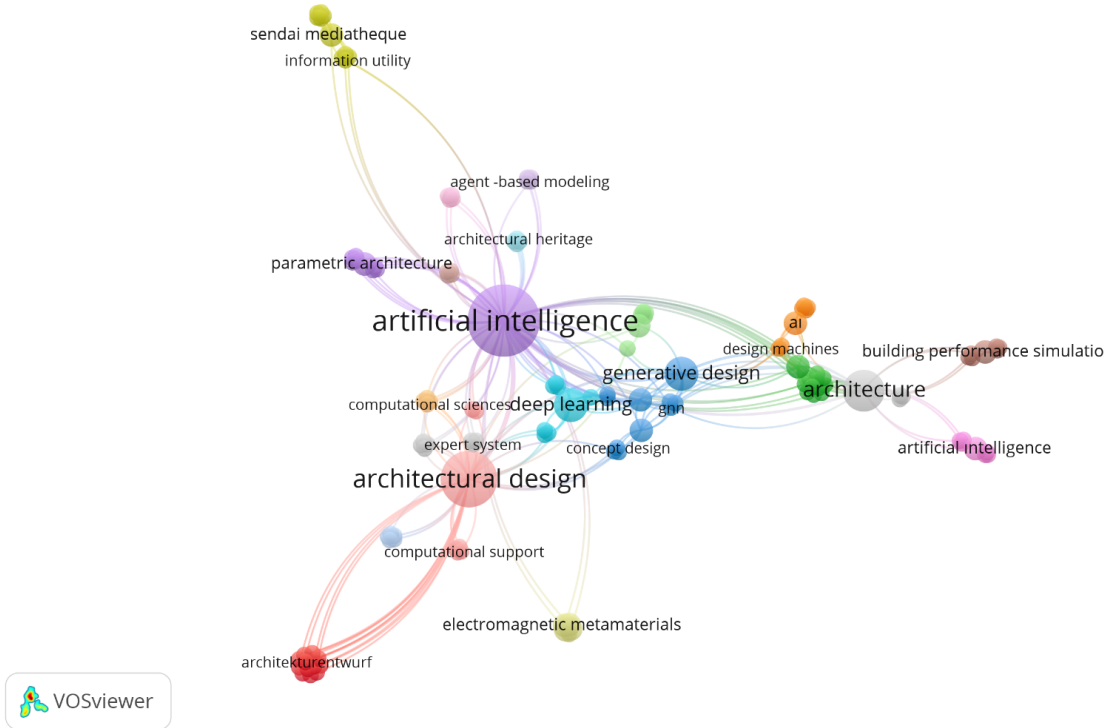


***Figure 5:*** *Keyword analysis*

learning," "parametric architecture," "shape grammar," and "information metamaterials" each appearing 2 times.

Figure 6 illustrates the connections among the total of 58 keywords that appear at least once in the Web of Science search for the keywords "artificial intelligence" and "architectural education". Some of the featured keywords are: “futurism”, “image generation”, “immersive design”, “room configuration”, “space syntax”, “student-centred learning”, “text/image-to-image”, “virtual reality”, “digital drawing”, “digital transformation”, “curriculum learning”, “architectural form generation”, “architectural programming”, “architectural cognition”, “architecture design workflow”.

Table 1 presents the analysis of citation sources from the Web of Science for the keywords "artificial intelligence", "architectural design" and "architecture". The table lists the author names, publication years, titles, citation counts, and Web of Science categories for the top 10 most cited publications. It is observed that the highly cited publications focus on architecture, computer science, artificial intelligence, building technology, and environmental studies.

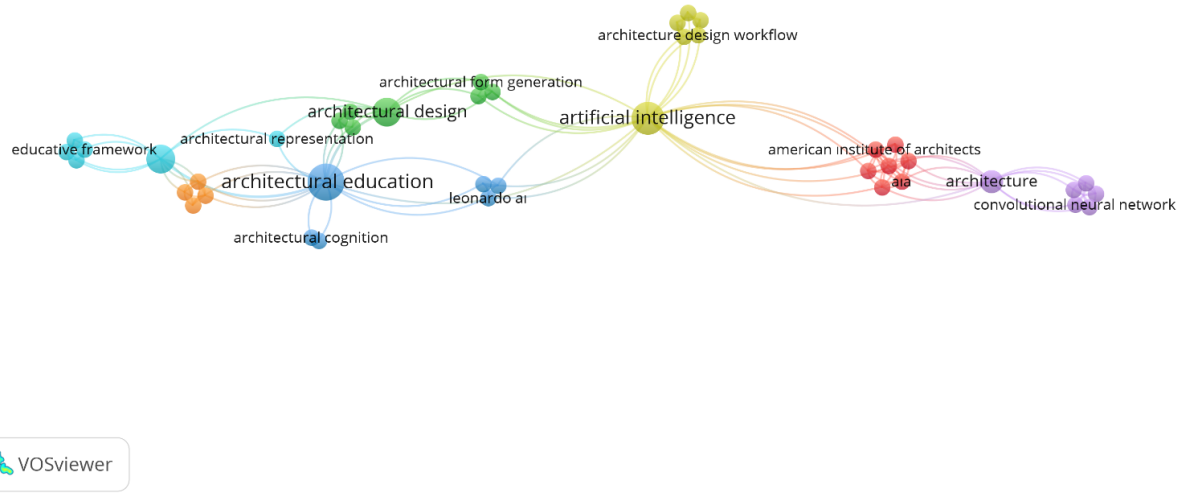


***Figure 6:*** *Keyword analysis*

***Table 1:*** *Information on the top 10 most cited publications*

| No | Author | Year | Publication Title | Citation Count | Web of Science Category |
|---|---|---|---|---|---|
| 1 | As, I., Pal, S. & Basu, P. | 2018 | Artificial intelligence in architecture: Generating conceptual design via deep learning | 60 | Architecture |
| 2 | Do, E.Y.L. & Gross, M.D. | 2001 | Thinking with diagrams in architectural design | 58 | Computer Science, Artificial Intelligence |

| | | | | | |
|---|---|---|---|---|---|
| 3 | Wortmann, T., Costa, A., Nannicini, G. & Schroepfer, T. | 2015 | Advantages of surrogate models for architectural design optimization | 52 | Computer Science, Artificial Intelligence, Engineering, Multidisciplinary |
| 4 | Escobar, R. & De la Rosa, A. | 2003 | Architectural design for the survival optimization of panicking fleeing victims | 41 | Computer Science, Artificial Intelligence, Cybernetics |
| 5 | Werner, S. & Long, P. | 2003 | Cognition meets Le Corbusier - Cognitive principles of architectural design | 30 | Computer Science, Artificial Intelligence, Psychology, Experimental |
| 6 | Su, Z.Z. & Yan, W. | 2015 | A fast genetic algorithm for solving architectural design optimization problems | 17 | Computer Science, Artificial Intelligence, Engineering, Multidisciplinary |
| 7 | Yi, H. & Kim, Y. | 2021 | Self-shaping building skin: Comparative environmental performance investigation of shape-memory-alloy (SMA) response and artificial-intelligence (AI) kinetic control | 13 | Construction & Building Technology, Engineering, Civil |
| 8 | Yi, H. | 2020 | Visualized Co-Simulation of Adaptive Human Behavior and Dynamic Building Performance: An Agent-Based Model (ABM) and Artificial Intelligence (AI) Approach for Smart Architectural Design | 12 | Green & Sustainable Science & Technology, Environmental Sciences, Environmental Studies |
| 9 | McDermott, J., Swafford, J.M., Hemberg, M., Byrne, J., Hemberg, E., Fenton, M., McNally, C., Shotton, E. & O'Neill, M. | 2012 | String-rewriting grammars for evolutionary architectural design | 12 | Environmental Studies |
| 10 | Wang, L.K., Janssen, P. & Ji, G.H. | 2020 | SSIEA: a hybrid evolutionary algorithm for supporting conceptual architectural design | 10 | Computer Science, Artificial Intelligence, Engineering, Multidisciplinary |

As illustrated in Figure 7 and Table 1, the most-cited publication is a 2018 study by As et al. on AI in the field of architecture. The key terms of the study include architectural design, conceptual design, deep learning, artificial intelligence, and generative design. The study presents a model that utilizes graphics to create conceptual designs through deep learning. The system developed by As et al. (2018) enables the evaluation and scoring of designs using a variety of deep learning tools, allows the decomposition of designs into fundamental building blocks, and facilitates the recombination of these blocks into new design variations.

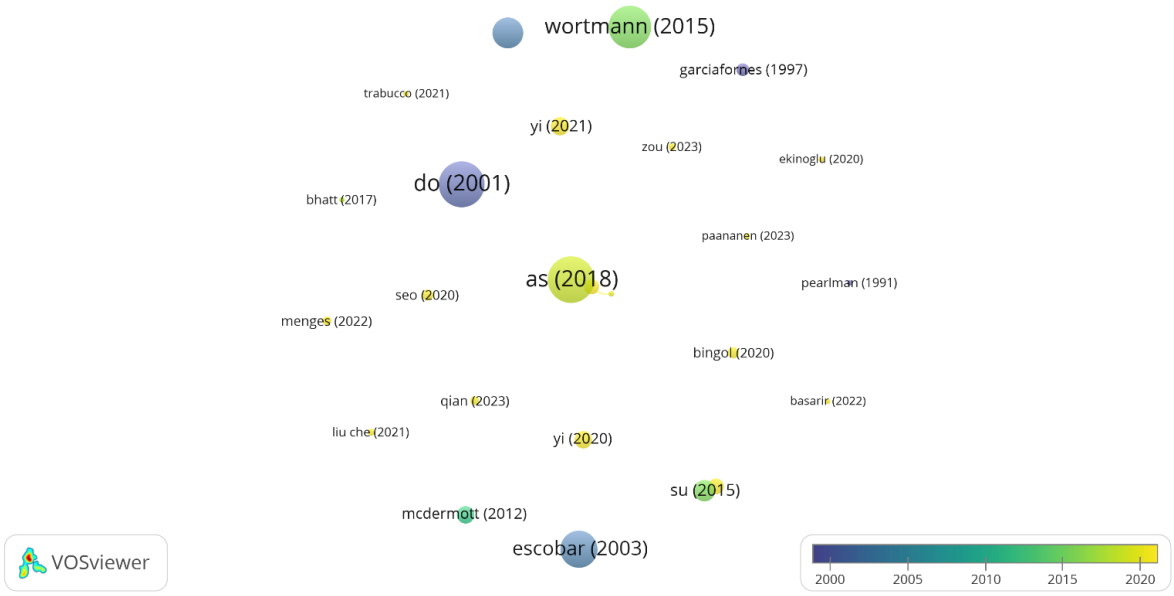


***Figure 7:*** *Source citation analysis*

## 5. Discussion and Conclusions

Recent years, particularly since 2020, have seen a significant increase in the number of studies related to AI, underscoring the growing importance of this topic within the field of architectural design (Figure 2). Currently, AI research has accelerated to facilitate the development of AI-based systems specifically designed for architects. The Web of Science (WoS) database lists 14 studies published in 2024 related to AI-supported architectural design. The content analysis of these studies is presented in Table 2.

***Table 2:*** *Content analysis of studies related to AI in the field of architecture conducted since the beginning of 2024*

| No | Author | Year | Publication Title | Content |
|---|---|---|---|---|
| 1 | González, A.F. & Garcia, M. | 2024 | A Posthuman Architectural Artificial Intelligence Speculum? Text and Images in Future Spaces | To what extent can AI assist in the development of superhuman architectures, and how can we explore the symbiotic relationship between language and artificial intelligence as a means of speculating about the future of space? |
| 2 | Bottazzi, R., Hosmer, T. & Claypool, M. | 2024 | Disruptive Ecologies: Design with Nonhuman Intelligences | Innovative research examining various aspects of design and digital technology (biotechnology, computation and artificial intelligence, digital fabrication, robotics) |
| 3 | Sukkar, A.W., Fareed, M.W., Yahia, M.W., Mushtaha, E. & De Giosa, S.L. | 2024 | Artificial Intelligence Islamic Architecture (AIIA): What Is Islamic Architecture in the Age of Artificial Intelligence? | Investigating the impact factors of AI technologies on the understanding and interpretation of traditional Islamic architectural design processes |

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|---|---|---|---|---|
| 4 | Ploszaj-Mazurek, M. & Rynska, E. | 2024 | Artificial Intelligence and Digital Tools for Assisting Low-Carbon Architectural Design: Merging the Use of Machine Learning, Large Language Models, and Building Information Modeling for Life Cycle Assessment Tool Development | A new AI-assisted approach to optimizing the environmental impact of architectural projects |
| 5 | Jo, H., Lee, J.K., Lee, Y.C. & Choo, S. | 2024 | Generative Artificial İntelligence and Building Design: Early Photorealistic Render Visualization of Facades Using Local İdentity-Trained Models | Developing an additional training model to generate alternative architectural design options based on local identity through the application of generative AI in building facade design |
| 6 | Tan, L.N. & Luhrs, M. | 2024 | Using Generative AI Midjourney to Enhance Divergent and Convergent Thinking in an Architect's Creative Design Process | An architectural design methodology utilizing Midjourney, a text-to-image generative AI software |
| 7 | Jin, S.T., Tu, H.J., Li, J.F., Fang, Y.W., Qu, Z., Xu, F., Liu, K. & Lin, Y.Q. | 2024 | Enhancing Architectural Education through Artificial Intelligence: A Case Study of an AI-Assisted Architectural Programming and Design Course | Evaluating the impact of AI technology-assisted instruction on student learning in architectural education |
| 8 | Karimi, H., Adibhesami, M.A., Hoseinzadeh, S., Salehi, A., Groppi, D. & Garcia, D.A. | 2024 | Harnessing Deep Learning and Reinforcement Learning Synergy as a Form of Strategic Energy Optimization in Architectural Design: A Case Study in Famagusta, North Cyprus | Presenting a new framework utilizing AI technologies to enhance energy efficiency in architectural design |
| 9 | Zhang, Z.H., Fort, J.M. & Mateu, L.G. | 2024 | Decoding Emotional Responses to AI-Generated Architectural İmagery | Examining the impact of architectural education on emotional perception and the ability of AI to evoke specific emotional responses through architectural imagery |
| 10 | Zhao, L., Song, D.X., Chen, W.Z. & Kang, Q. | 2024 | Coloring and Fusing Architectural Sketches by Combining a Y-shaped Generative Adversarial Network and a Denoising Diffusion Implicit Model | Developing an AI tool for coloring and integrating architectural sketches |
| 11 | Kakooee, R. & Dillenburger, B. | 2024 | Reimagining Space Layout Design Through Deep Reinforcement Learning | Presenting a new framework that leverages the potential of deep reinforcement learning algorithms to optimize spatial layouts |
| 12 | Jang, S., Lee, G., Oh, J., Lee, J. & Koo, B. | 2024 | Automated Detailing of Exterior Walls Using NADIA: Natural-Language-based Architectural | Performing architectural detailing through natural language-based AI applications |

| | | | | |
|---|---|---|---|---|
| | | | Detailing Through Interaction with AI | |
| 13 | Yan, L.A., Chen, Y.L., Zheng, L. & Zhang, Y. | 2024 | Application of Computer Vision Technology in Surface Damage Detection and Analysis of Shedthin Tiles in China: a Case Study of the Classical Gardens of Suzhou | Detection and analysis of surface damage on materials using AI tools |
| 14 | Jurshari, M.Z., Tazakor, M.Y. & Yeganeh, M. | 2024 | Optimizing the dimensional ratio and orientation of residential buildings in the humid temperate climate to reduce energy consumption (Case: Rasht Iran) | Calculating energy consumption through artificial intelligence software to optimize building aspect ratios and orientations while minimizing energy usage |

Table 2 illustrates that recent studies related to AI in architectural design encompass various methodologies, including: how AI-supported architectural design can be realized, the application of specific AI tools for various purposes, the integration of customized software tailored to design objectives, and the use of AI technologies to minimize environmental impacts and enhance energy efficiency. Additionally, these studies explore how these methodologies can be incorporated into architectural design education.

As evidenced by current research, designing and constructing buildings and cities through superhuman – non-human AI, robotic technology, and smart technologies, and adapting these advancements to design education are key areas of focus. The technological era necessitates the integration of AI applications into architectural design. While the ambiguous nature of design problems complicates the effective application of AI-based tools and services, the integration of AI into architectural design is transforming design education as well.

Teaching architecture in the digital age is a challenging task that requires constant adaptation. The rise of AI has sparked numerous discussions about its potential uses for architects. Due to this revolutionary advancement in technology, students are able to utilize intelligent design tools to generate and evaluate design solutions, analyze data, simulate building performance, and explore innovative ideas. This situation necessitates the continued examination of AI's role in architectural design and, by extension, its implications for architectural design education. While AI holds the potential to revolutionize the field of architecture, it also presents new challenges and considerations for architectural education. Thus, it is crucial to reflect on how AI tools and applications will be incorporated into design education to stay current with developments.

The results of this study provide a general overview and structure of the literature on AI-supported architectural design. Furthermore, examining how the topic is addressed within the field of architecture offers academic and research insights to scholars and researchers, providing a comprehensive perspective on the subject at its current and future state. Additionally, it serves as a foundational reference for future researchers interested in the topic.

To advance research in the field, models developed by researchers such as González, A.F. & Garcia, M. (2024), Bottazzi, R., Hosmer, T. & Claypool, M. (2024), Jin, S.T., Tu, H.J., Li, J.F., Fang, Y.W., Qu, Z., Xu, F., Liu, K. & Lin, Y.Q. (2024), Tan, L.N. & Luhrs, M. (2024), Başarır, L. (2022), and As, I., Pal, S. & Basu, P. (2018) could be applied to architectural education, providing a basis for evaluating challenges and opportunities.

The identification of the increasing use of AI applications in the field of architectural design underscores the significance of technology-based applications in architectural design education and the necessity for their permanent integration into the learning process. In this context, developing course alternatives that incorporate various AI applications into the curriculum is crucial for keeping pace with current advancements. Finally, updating the curriculum as needed is considered essential for adapting the process to architectural education.

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