REVIEW ARTICLE

Artificial Intelligence (AI) and its Application in Architecture Design: A Thematic Review

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Abstract

The rapid advancement of AI technology has heightened interest in this field. It has broad implications across various industries, sparking extensive debates on AI's potential, a concern particularly resonant within the architectural design industry. Despite the growing number of publications on AI and architectural design, comprehensive reviews are lacking in exploring its evolution, strategies, and future directions. Few researchers have conducted a thorough inventory of AI's impact on architectural design or mapped current trends. Hence, this study specifically aimed to retrospectively analyze AI's impact on architectural design and explore the evolving trends within AI-based architectural design using thematic review (TreZ) method. Data for this research encompassed a thematic review of 54 publications spanning from 2019 to 2023. The use of ATLAS. ti 23 aided in documenting and indicating the research directions pursued by scholars. The analysis identified six primary themes: 1) Architecture and Science, which includes research on complex systems, genetic algorithms, and machine learning;2) Architecture and Construction Management, including the development of frameworks that support decision making; architecture and interior design, which includes work on space-planning optimization and furniture and occupant arrangement;3) Architecture Interior Design; 4) Architecture and Urban; which encompasses attempts to develop tools to help design new cities; architectural engineering, where building performance analysis was the most-common AI application; 5) Architectural Engineering; and 6) Design Education and Training, in which AI appears most promising for advancing problem-based learning. The research indicates a growing emphasis on AI in architecture, aiming to improve algorithms, integrate with diverse tools like BIM, and enhance efficiency in design and engineering management to promote building sustainability. Future studies are expected to focus on refining algorithms and integrating AI more closely with architectural tools to boost efficiency and sustainability in building design and project management, in addition to organizational influences aimed at advancing building sustainability.

Keywords: *Artificial Intelligence, Building, Architecture design, thematic review (TreZ), pattern and trends*

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Introduction

AI technology development has ignited discussions across multiple sectors regarding the potential replacement of numerous existing occupations by AI. Recent data from The Future of Jobs Report 2023 suggests that by 2025, 85 million jobs could be displaced due to changes in the human-machine division of labor, while 97 million new roles aligned with this new division could emerge, involving collaboration between humans, machines, and algorithms. This analysis became prominent during the COVID-19 pandemic. The combination of automation and the

COVID-19 economic downturn is creating ‘double-disruption’ scenarios for workers, as outlined in The Future of Jobs Report 2023. There is widespread recognition that automation, driven by artificial intelligence and machine learning, can perform precise and rapid calculations, predictions, designs, and project executions beyond human capabilities (Matthews et al., 2023)

However, according to Altavilla and Blanco (2020), the use of AI indicates a transformation in job roles rather than a total replacement. Furthermore, the research suggests that AI advancements have led to the consideration of new designer roles in the design process, highlighting the interaction between humans and AI (Altavilla & Blanco, 2020). The incorporation of artificial intelligence into architectural design is not a recent development (Trabucco, 2021). Architectural scholars have presented numerous similar elements in defining AI (Igwe et al., 2022). The proposal suggests that machines capable of mimicking human cognitive functions, such as problem-solving, style recognition, and learning, are classified as AI. Computer systems that perform tasks traditionally carried out by humans and exceed human intelligence through abilities like observation, reasoning, interaction, and learning are classified as artificial intelligence (AI) (Almusaed & Yitmen, 2023). Historically, architectural design has merged art and science, requiring designers to be well-versed in space, volume, materials, light, shadow, and natural elements to optimize functionality, aesthetics, and sustainability (Demery, 2010).

Designers are becoming more accustomed to utilizing artificial intelligence (AI) technology. Recent years have seen a rise in efforts to apply AI technology in urban and architectural design, driven by rapid advancements in AI technology (Rhee & Chung, 2019; Trabucco, 2021). Similar perspectives have been observed in studies on the integration of AI into architectural design. A significant portion of the extensive research on architectural design and AI has focused on evolutionary computational methods for design tasks. However, other research investigates the building design process directly. For example, Yi & Kim (2022) investigated the visual co-simulation of adaptive human behavior and dynamic building performance, employing Agent-Based Modeling (ABM) and Artificial Intelligence (AI) techniques for intelligent building design (Seo et al., 2020).

The advancement of building design automation technology employs AI through deep learning to comprehend, identify, and deduce architectural drawing features, including architectural elements and spatial compositions depicted in the drawings. Ahmed & Higaya (2022) Center Pompidou and Sendai Mediatheque and studies the handling of information, communication and feedback processes in these suggestive cybernetic environments. The first section of this paper analyzes Center Pompidou by researching the competition brief and the initial states of the winning entries presenting their preserved notions against the bureaucratic, political and budgetary constraints. The second section surveys the contemporary history behind the projection of a cultural center as a cybernetic or more precisely as information broadcasting entity by reviewing Geddes’s Index Museum, Malraux’s Le Musée Imaginaire (Museum Without Walls outlined the characteristics of AI architectural design, proposing that AI technologies operate imperceptibly within these cybernetic environments, autonomously handling information through collection, analysis, interpretation, dissemination, reception, and feedback provision. In addition to architectural design, scholars have expanded AI applications to related architectural domains. Zou et al. (2023) employed AI in the preservation of architectural heritage. This paper aims to conduct a systematic literature review on the implementation of AI approaches in architectural design between 2019 and 2023. Additionally, it seeks to investigate current global trends in AI application within architectural design, focusing on specific issues.

Additionally, significant interest exists in the impact of artificial intelligence (AI) on building technology, covering aspects from design to construction. Researchers highlight AI's potential to automate building design, enhance energy efficiency, and optimize construction processes (Abioye et al., 2021; Y. Pan & Zhang, 2021). Furthermore, scholars emphasize AI's crucial role in addressing complexity and sustainability challenges in traditional building design (Mehmood et al., 2019; Nishant et al., 2020). Some scholars focus on AI's advantages in building construction, especially in project management and resource allocation. Their review indicates that AI implementation can improve construction project efficiency and precision, leading to cost reduction and shorter durations (Bento et al., 2022; Gil et al., 2021). These reviews collectively illustrate AI's potential for various building technology applications, highlighting its ability to enhance design quality, streamline construction processes, and improve building performance. However, despite the opportunities presented by AI technologies, challenges such as data privacy and security issues require effective integration of AI with building technologies. This paper posits the following research question:

(RQ) What are the Contemporary Trends in AI Within Architectural Design as Discussed in Publications Between 2019 and 2023?

The aim is to systematically review publications from this period to explore AI methods' application in architectural design and identify future research directions and trends.

Research Method

This paper utilized articles and data sources obtained from SCOPUS, Web of Science, and Mendeley. Several journals collaborated with Mendeley to provide primary research data, which were then correlated with the articles to facilitate data acquisition for literature analysis. An essential aspect involved pattern identification and categorization, aiding in understanding global trends in applying AI in architectural design. Zairul (2020, 2021b, 2021a) outlined the thematic analysis procedure using ATLAS. ti 23 tools in the literature review (figure 1). Thematic analysis, as described by Clarke and Braun (2013), involves exploring patterns and theme development through extensive reading. Scrutinizing the trends of AI in architectural design publications included evaluating practices and formulating categories. The comprehensive project aimed to assess findings and propose future research avenues within AI and architectural design.

The study was conducted in five phases: formulating the research question, articles screening, articles filtering, the cleaning process, and synthesis & reporting. During the document screening phase, we initially formulated a research question that was neither overly broad nor excessively narrow. Subsequently, we employed a minimum of two databases, applied Boolean operators, and selected appropriate keywords for the search. The next step involved applying inclusion and exclusion criteria that aligned with the research question and the objectives of the study. We then verified the accuracy of metadata and organized the data correctly using Mendeley or a similar reference management tool. Finally, we presented both quantitative and qualitative findings to address the research question, utilizing ATLAS.ti for data analysis.

In the document screening phase, two main steps were involved: initially filtering the documents based on the research topic terms from the three selected databases, followed by downloading and importing them into the document management software. Subsequently, duplicates were identified and removed from the databases, and the content was reviewed to ensure alignment with the research themes of "Artificial Intelligence" and "Architectural Design." In the thematic analysis phase, 54 articles were imported into ATLAS.ti for further analysis. These articles underwent thematic coding using ATLAS.ti, where the main contents and gaps of the study were extracted through detailed article reading. Our study adopts an integrative approach, combining scientometric and bibliometric analyses to identify emerging patterns and suggest future research directions in AI-driven architectural design.

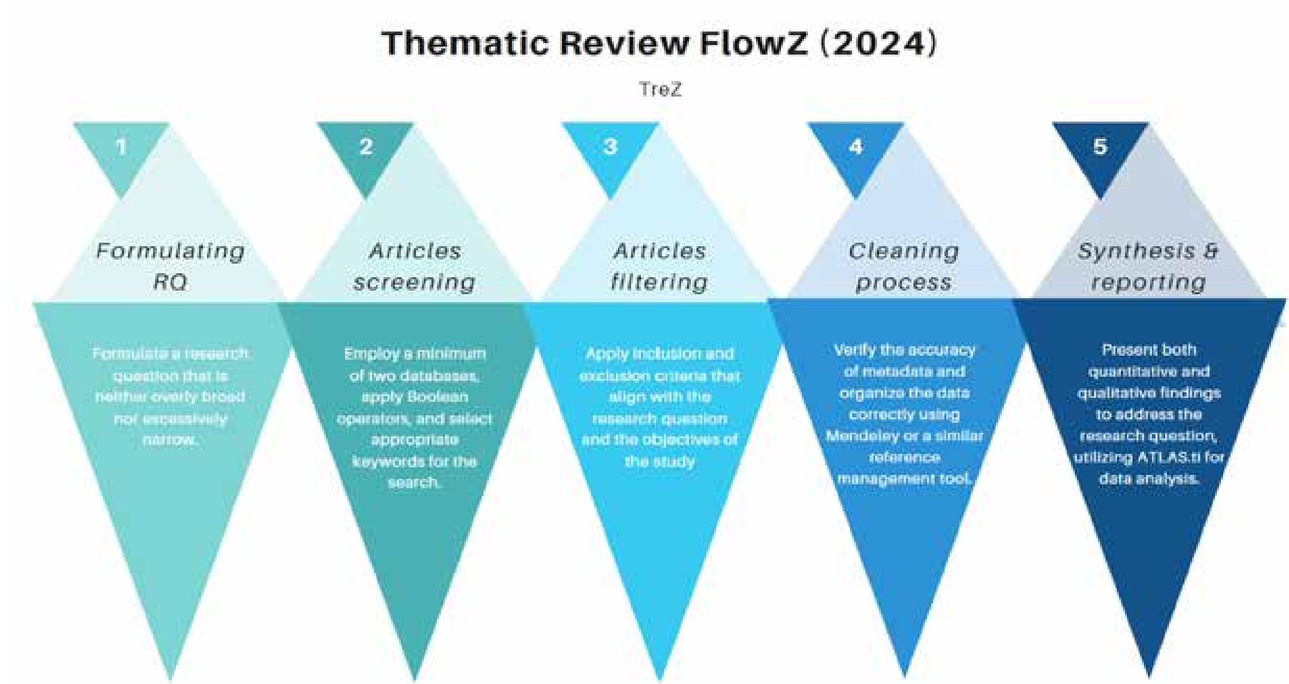

Figure 1: TreZ methodology developed by Zairul

Research articles were selected based on specific criteria: 1) publication between 2019 and 2023; 2) inclusion of the keywords ‘artificial intelligence’ and ‘architectural design’; 3) emphasis on architectural design issues; 4) English language; and 5) publication in journals indexed in Web of Science or listed as SCOPUS journals. The literature search employed search strings detailed in Table 1 across Mendeley, Web of Science, and SCOPUS. A search using “architectural design” and “artificial intelligence” keywords identified 330 articles across three databases. Between 2019 and 2023, Mendeley identified 94 journal articles on these topics. Web of Science yielded 93 similar articles. Moreover, the SCOPUS search with specified limitations produced 143 articles, with 94 articles retrieved concurrently.

Table 1: Search strings from Scopus, Mendeley, and WOS

Mendeley	“artificial intelligence” “architectural design” AND DOCUMENT TYPE: Journal (94) Year: [2019 TO 2023]	94 results
SCOPUS	(TITLE-ABS-KEY (“artificial intelligence”) AND TITLE-ABS-KEY (“architectural design”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (OA, “all”)) AND PUBYEAR > 2019	143 results
WoS	“artificial intelligence” (All Fields) and “architectural design” (All Fields) and 2019 or 2020 or 2021 or 2022 or 2023 (Publication Years) and Article (Document Types) and English (Languages)	93 results

274 documents were excluded from the articles due to premature or anecdotal results, or because they did not discuss “AI” and “architectural design”. Additionally, 39 duplicate articles across three databases, including two retracted ones, were removed. Furthermore, 227 articles were excluded because they discussed architecture design in computing, which although sharing the same term, has a distinct meaning. Lastly, 10 articles from the Mendeley database were inaccessible for download, resulting in their exclusion. Additionally, inaccessible or incomplete research articles, fragmented links, duplicates, and inadequate metadata were

removed. Consequently, the number of articles for assessment was reduced to 54 (refer to Figure 1). These articles were imported into ATLAS.ti 23 as master files, categorized by author, journal, publisher, issue and volume numbers, and publication year. Only English papers were included for analysis. Subsequently, the 54 articles underwent further analysis in ATLAS.ti 23 (see Figure 2).

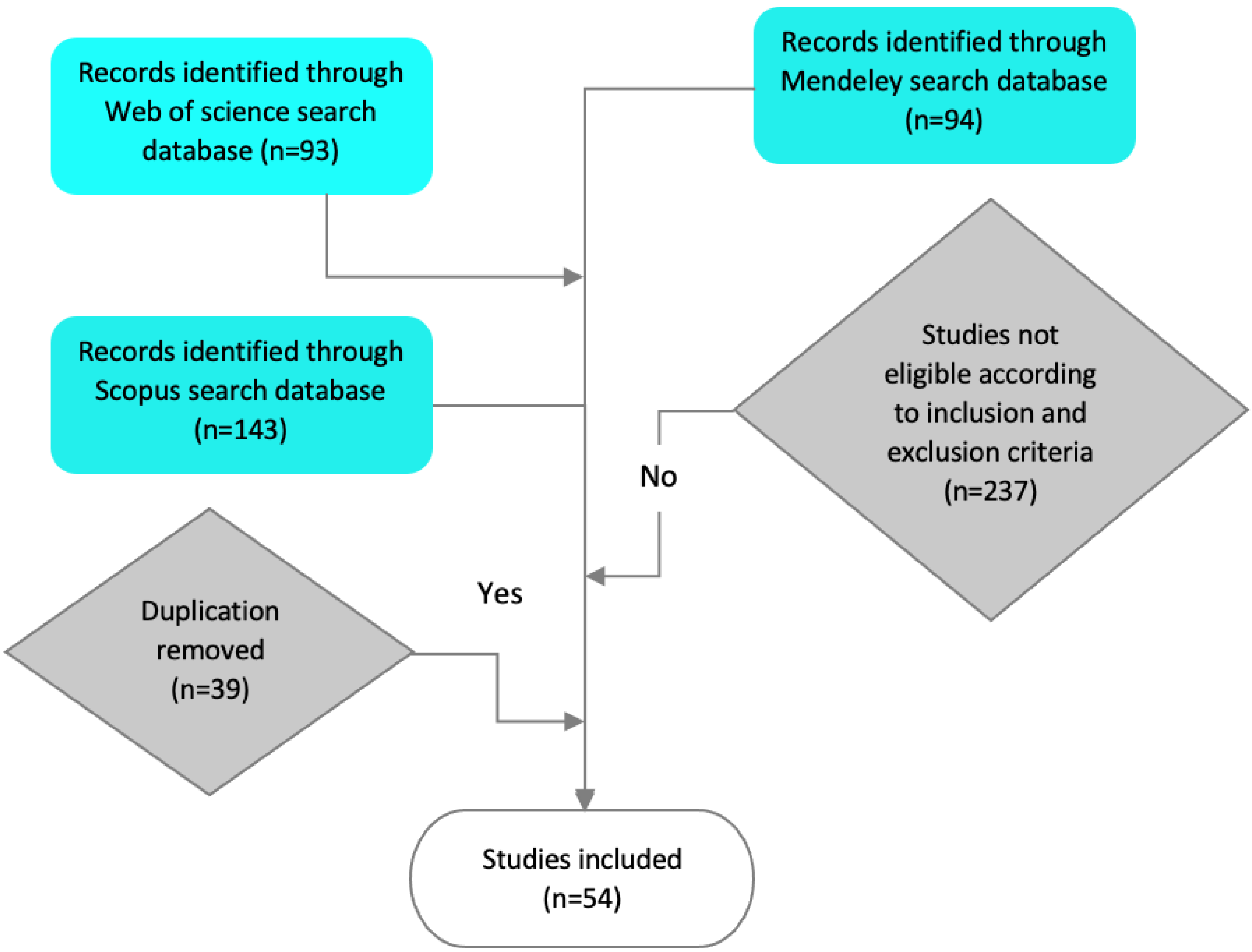

Figure 2: Inclusion and exclusion criteria for identifying articles for thematic review

The 54 final articles selected for examination were exported from three databases (WOS, Scopus, and Mendeley) and imported into literature management software. Duplicate articles were then removed, and each article was individually reviewed to ensure relevance to the research question. All selected articles were exclusively from scholarly journals. Thematic analysis was employed to analyze the articles within the scope of the investigation.

Results and Discussion

This section aims to elaborate on the primary outcomes of the thematic review, analyzing patterns and trends in “AI” and “Architecture Design” publications. Findings are categorized into quantitative and qualitative sections. The quantitative analysis begins with a word cloud derived from the primary analysis of 54 documents, followed by assessments of publication frequency over years, articles per journal issue, and the geographic distribution of publications. In subsequent qualitative analyses, the examination of 54 articles resulted in the creation of 12

Level 1 codes based on emerging trends and patterns. After iterative recoding and code integration in ATLAS.ti 23, six pivotal themes were extracted from the identified trends and patterns (Refer to Figure 5).

This paper aims to understand the trends in AI research within architectural design, consistent with the introduction. The research methodology, covering data collection, preparation, and result interpretation, is in line with recent findings and is presented sequentially. In the preliminary analysis, the word cloud reveals the most frequent words, specifically "design" and "building." Figure 2 displays high-frequency terms from 54 papers in the word cloud. "Design" is used 3739 times, "building" is mentioned 2085 times, "model building" appears 2,085 times, "model" occurs 1,661 times, and "architectural" and "information" appears 1,487 and 1,262 times, respectively. Additionally, "construction" is referred to 1,211 times.

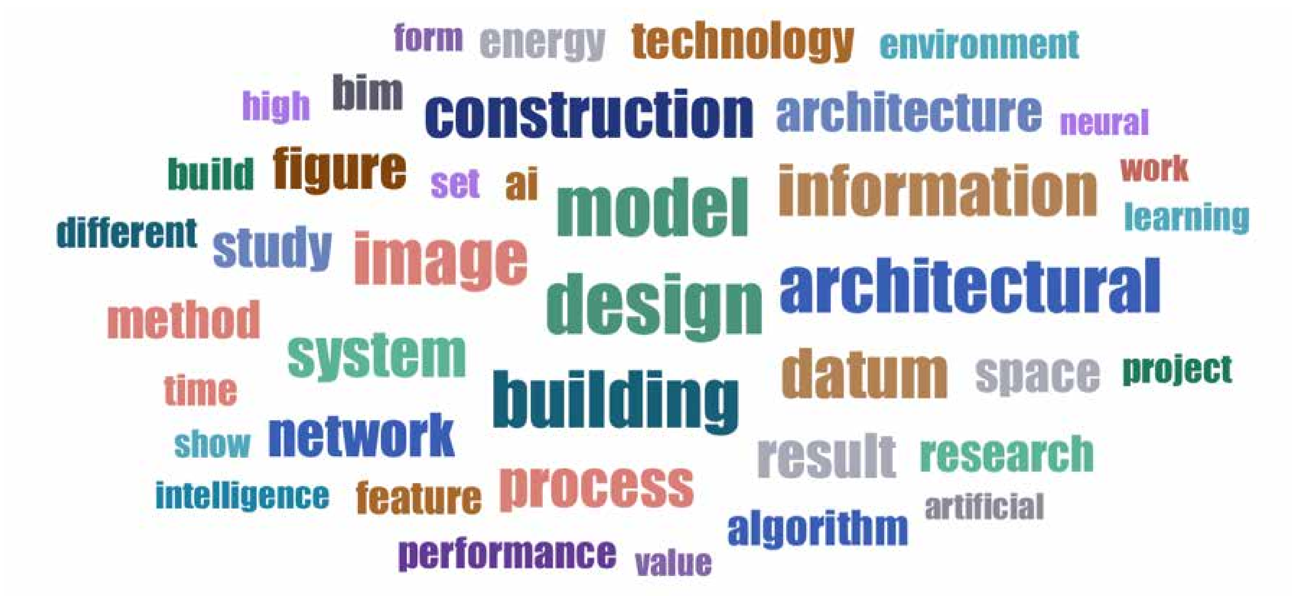

Figure 3: Word cloud generated from 54 articles.

Another analysis, presented in Table 2, outlines the journal selection process among researchers in Artificial Intelligence and Architectural Design. The report identifies "Sustainability" (Switzerland) as the most favored journal, followed by "Advances in Multimedia," "Computational Intelligence and Neuroscience," "Journal of Asian Architecture and Building Engineering," and "Techne." As previously mentioned, using "AI," "architecture," and "design" as search keywords retrieves tens of thousands of articles. However, narrowing the search to "AI" and "architecture design" significantly reduces and refines the results, highlighting the early stage of this field with substantial unexplored areas. Furthermore, the growing trend of "AI" and "architectural design" in recent years is apparent in the analysis, as illustrated by the evolutionary trajectory of articles in Figure 3.

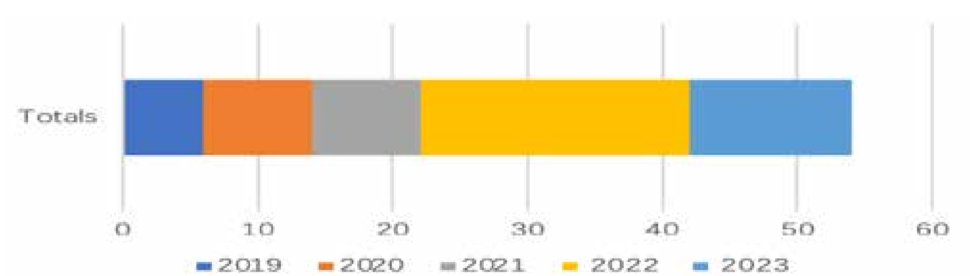

Figure 5 Articles per year of publication

Table 2: Number of articles per periodical

Periodical	2019	2020	2021	2022	2023
Academy of Management		1			
ACM Transactions on Computer-Human Interaction	1				
ACM Transactions on Graphics					
ACM Transactions on the Web					
Advances in Multimedia				2	1
Applied Mathematics and Nonlinear Sciences				1	
Applied Sciences (Switzerland)		1			
Architectural Design					
Architecture and Urban Planning				1	
Automation in Construction			1	1	
Building and Environment			1		1
Buildings					1
Case Studies in Thermal Engineering				1	
Complexity			1		
Computational Intelligence and Neuroscience		1		2	
Computer-Aided Design and Applications					
Construction Innovation				1	
Design Science		1			
Developments in the Built Environment		1			
Energies		1			
Energy and Built Environment					1
Gazi University Journal of Science				1	
In_Bo		1			
International Journal of Architectural Computing			1		
International Journal of Mobile Computing and Multimedia Communications				1	
International Journal of Parallel, Emergent and Distributed Systems					
Journal of Asian Architecture and Building Engineering			1	1	1
Journal of Civil Engineering and Management	1				
Journal of Computational Design and Engineering				2	
Journal of Information Technology in Construction	1			1	
Knowledge-Based Systems					
Mathematical Problems in Engineering				1	
Mobile Information Systems				1	
Periodica Polytechnica Civil Engineering	1				
PLoS ONE					1
Scientific Programming				1	
Security and Communication Networks				1	
Sensors					1
Soft Computing					1
Solar Energy			1		
Structures	1				
Sustainability (Switzerland)	1	1			2
Techne			1		2
Technology Architecture and Design			1		
Wireless Communications and Mobile Computing				1	

Geographical analysis reveals a notable increase in research on “AI” and “architectural design” in China, evidenced by 20 publications over the last five years, indicating substantial academic interest. Scholars have explored the influence of AI on architecture from diverse perspectives. Research in China on the utilization of AI technology in the construction sector covers a wide range of areas, including construction management (H. Wang & Hu, 2022) the author proposed the application of a deep learning-based AI technology in construction management system modeling. The 3 D reconstruction deep learning model is first introduced, and then the model idea of the construction progress reliability control system is designed based on BIM (building information model, Energy and Environmental Design (Li et al., 2022), Interior Design (Gong, 2023), landscape design (Y. Wang & Chen, 2022), and other related fields. AI technology in construction management facilitates progress monitoring, reliability warnings, and predictive capabilities (H. Wang & Hu, 2022) the author proposed the application of a deep learning-based AI technology in construction management system modeling. The 3 D reconstruction deep learning model is first introduced, and then the model idea of the construction progress reliability control system is designed based on BIM (building information model. AI technology enhances interior design by optimizing design solutions and improving overall outcomes (Gong, 2023). In landscape design, AI’s parametric analysis assists in architectural landscape planning, while enhanced algorithms optimize both urban architectural planning and landscape design (Shao, 2022).

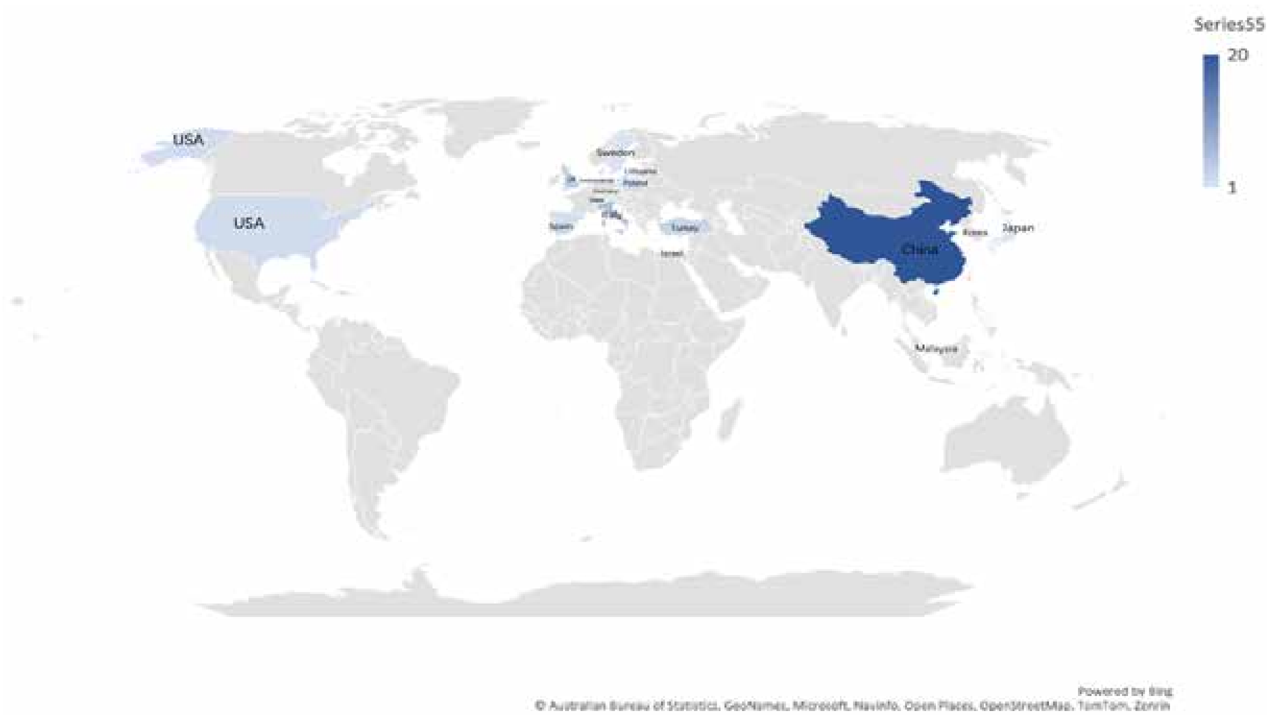

Figure 6 articles based on country publication

Italy followed with the second-highest number of studies, totaling six publications. The Italian architectural design sector is actively integrating AI technology. Research in Italy covers the evolution of architectural design in the AI era (Brunetti, 2023), future trends in AI-enabled architectural design (Brunetti, 2023), the application of AI in classifying architectural heritage, and other areas of focus (Croce et al., 2023). Studies also explore the realm of construction project management (Bongiorno et al., 2019; Ferrante & Romagnoli, 2023). South Korea closely follows with a contribution of five research papers. Research in South Korea focuses on developing datasets related to architectural design for future studies (Yu et al.,

2022) collection is difficult as sources are limited to existing models and sample libraries. This study developed a parametric augmentation approach to create synthetic copies of BIM elements, and thus rapidly supplement manually collected samples. The approach was used to create ArchShapesNet, a dataset consisting of 11 common architectural elements with an equal size of 4,000 samples per class. Two multi-view convolutional neural networks (CNN and exploring human-architectural interactions (Kim et al, 2021; Yi & Kim, 2022). Additionally, research has focused on the evolution of algorithms to optimize and automate building design (Yi & Kim, 2022). Academic literature on AI and architectural design has identified several key themes. Initially, 12 features were identified; however, through merging and reevaluation, these were consolidated into six main themes. The subsequent qualitative section elaborates on these themes in detail (Refer to Figure 4).

Qualitative results

This section explores the six primary themes derived from qualitative analyses to address the research questions. These themes, identified through thematic analyses of numerous papers and their frequency distributions, frequently overlap in the reviewed articles rather than existing independently. Many studies encompass multiple themes, and conversely. This section provides individual descriptions of these themes to offer a comprehensive response to the research queries. Additionally, Figure 5 offers an overview of the trends in AI research related to building design.

What are the Existing Research Directions and Trends in AI and Architectural Design Publications Discussed in the Literature Spanning from 2019 to 2023?

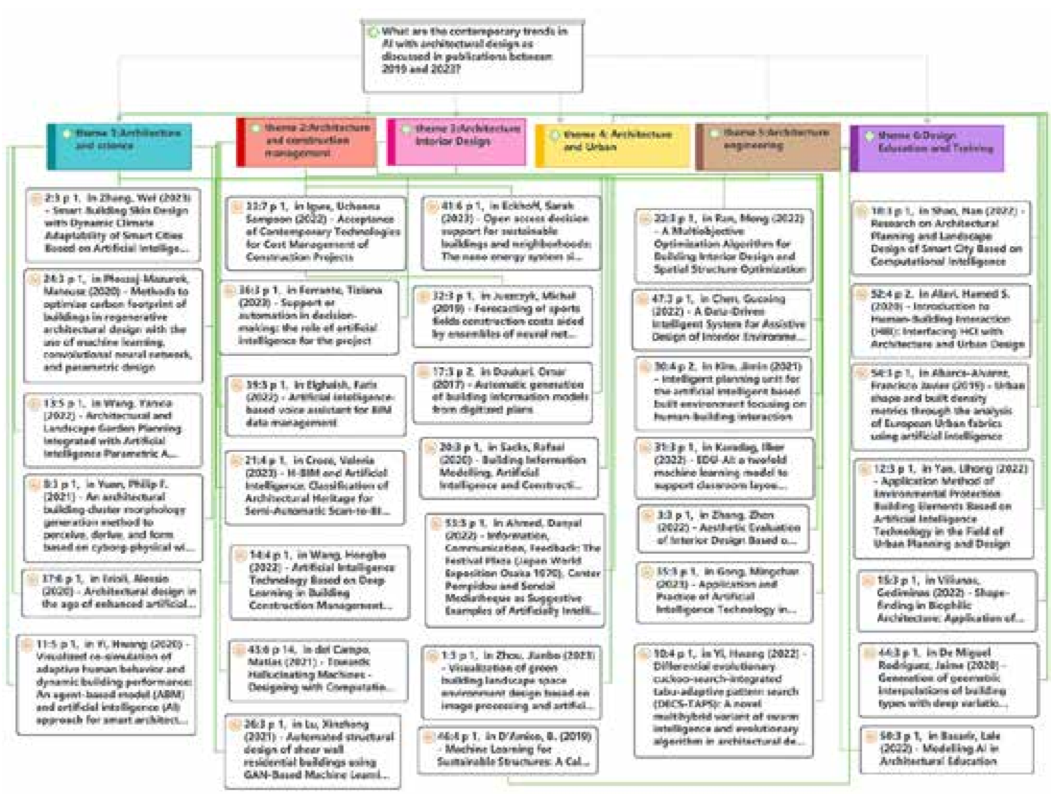

Figure 7 Overall network for AI and architecture design

The author has classified the research papers into six themes based on the literature from 2019 to 2023 and prior coded content:

Theme 1: Architecture and Science

Research in this field explores the potential impact of AI on the construction industry. Various researchers (Trabucco, 2021) have evaluated recent advancements in automating architectural design and forecasted AI's potential impact on architects' tasks. Although achieving complete automation is challenging due to the diverse tasks architects undertake, specific aspects, such as design, are more vulnerable. Economic aspects such as cost estimation are highly susceptible to AI influence; meanwhile, areas like building physics and law exhibit uncertainty due to the successful performance of algorithms. Interestingly, critical architectural aspects, such as design, demonstrate significant implications (Trabucco, 2021).

Smart Buildings:

Zhang (2022) intelligent architectural design has been gradually developed. At the present stage, the design of intelligent system in architecture has become a systematic design project, which is widely used in the field of architecture. The rapid development of artificial intelligence has not only brought new opportunities but also new challenges to the field of architectural design. On the one hand, digital architecture can share some of the functions of traditional architecture in its advantageous application areas, but inevitably new building function requirements and building design types will be formed. On the other hand, the depiction of building plans, elevations, and renderings, daylight adjustment, and volume calculation, as well as the transfer of text and graphic files via the Internet, are all closely related to digital architecture, regardless of which application software is used. In the current digital era, where real and virtual environments will coexist, digital transformation also has a lasting impact on intelligent building design, drawing out a new development model.","archive":"2023/07/18","archive_location":"0 citation(s delineates the shared functionalities between digital and traditional buildings and the transformative impact of digital technology on the design of smart buildings. Moreover, Almusaed and Yitmen (2023) concentrate on AI simulation modeling and digital twins in the design of smart buildings. A digital twin replicates a building's performance, emphasizing the importance of smart building design and indicating the need for further exploration of AI and digital twin integration (Almusaed & Yitmen, 2023).

Architectural Skin:

The study of architectural skin (Yuan et al., 2021) emphasizes responsive and adaptive design to overcome limitations in building skins in cold regions, utilizing AI to design dynamic climate-adaptive smart building skins. The study discusses using a multi-Pareto evolutionary algorithm to enhance building skin performance and integrate it with smart building devices. Conversely, Zhang (2023) building skin plays an important role in indoor environment regulation and effective utilization of outdoor environmental resources. The traditional fixed skin of residential buildings in cold regions lacks the ability to respond to the external climate, so it is difficult to meet the dual requirements of building energy efficiency and indoor comfort. In the long river of architectural development, the most important thing of architectural design is how to meet the climate adaptability. Traditional architectural forms have long been unable to meet the current social development, climate conditions, and user needs. Based on the basic theory, this paper establishes a systematic understanding of inlay, studies the design method of complex skin with geometric algorithm as the operating tool, discusses the application of this method in architectural design in combination with practice, more systematically and comprehensively studies the building skin with dynamic climate adaptability, and makes a physical model of building skin with dynamic climate adaptability. The contrast experiments under different control modes were carried out using the climate chamber experimental system. This research focuses on taking geometric principles as the prototype, trying to break the common design idea of generating skin by overlapping cells, and providing a systematic skin design method with strong operability and modular structure, hoping to help expand creative thinking.”,”archive”:”2023/07/18”,”archive_location”:”0 citation(s primarily concentrates on indoor environments, using AI to design and optimize dynamic, climate-adaptive building skins. Additionally, it addresses the use of phase change materials and soft polymer biomimetic materials in the design process. The former study offers a more comprehensive approach compared to the latter.

Architectural Generation:

Architectural generation, a pivotal area in AI architectural design, provides numerous research avenues. For example, Zou et al. (2023) used plus-cover technology for the digital preservation of cultural heritage, identifying architectural forms in the Hubei region using image recognition technology, and contributing to research, preservation, and architectural design. This study specifically concentrates on cultural preservation. In contrast, Wang & Chen (2022) employed AI parametric analysis for architectural landscape design, emphasizing parametric and landscape design. (Li, 2022) extracted building information from plans to create 3D models, using deep learning to automate building construction scenes, enhancing construction progress management. Meanwhile, Huang et al. (2021) investigate the use of Generative Adversarial Networks (GANs) and Natural Language Processing (NLP) in construction, proposing a method that combines GANs and NLP to create meaningful architectural designs. Although each study under architectural generation differs, their collective focus is on exploring and applying AI in architectural generation.

Architectural generation, a crucial domain in AI architectural design, offers various research opportunities. For instance, Zou et al. (2023b) which reflects regional architectural features to some extent. However, most of the existing methods for architecture form belong to the field of qualitative analysis. Accordingly, quantitative methods are urgently required to extract regional architectural style, identify architecture form, and to and further provide the quantitative evaluation. Based on machine learning technology, this paper proposes a novel method to quantify the feature, form, and evaluation of regional architectures. First, we construct a training dataset—the Chinese Ancient Architecture Image Dataset (CAAID utilized plus-cover technology to digitally preserve cultural heritage, identifying architectural forms in the Hubei region through image recognition technology, thereby contributing to research, preservation, and architectural design. This study specifically focuses on the preservation of cultural heritage. In contrast, Wang and Chen (2022) utilized AI parametric analysis for architectural landscape design, with a focus on parametric and landscape design aspects. Li (2022) extracted building information from blueprints to generate 3D models, employing deep learning to automate construction scenes, thus improving construction progress management. Meanwhile, Huang et al. (2021) investigated the utilization of Generative Adversarial Networks (GANs) and Natural Language Processing (NLP) in construction, proposing a methodology that integrates GANs and NLP for meaningful architectural design generation. Although each study in architectural generation differs, they collectively focus on exploring and implementing AI in architectural design.

Sustainability:

In architectural design, researchers investigate the utilization of machine learning and AI for eco-friendly development, energy conservation, and emission reduction. Early design stages should prioritize environmental protection and energy efficiency (Płoszaj-Mazurek, 2020). The study also delves into optimizing a building’s carbon footprint, formulating regenerative design principles, training machine learning models, and developing an application for estimating carbon footprints, demonstrating the impact of building parameters on carbon footprints and the potential for optimization during the design phase (Li et al. 2022b). Moreover, a blend of BIM models and genetic algorithms is employed to enhance energy efficiency in small high-rise office buildings, underscoring the significance of energy-efficient building design and the potential for BIM models and genetic algorithms to optimize design procedures and energy efficiency.

Semantic Segmentation:

In architectural design, semantic segmentation is frequently employed to identify and label elements and spaces in architectural drawings consistently improving identification and labeling accuracy (Seo et al., 2020b) in order to develop architectural design automation technology using artificial intelligence, the characteristics of an architectural drawings, that is, the architectural elements and the composition of spaces expressed in the drawings, were learned, recognized, and inferred through deep learning. The biggest problem in applying deep learning in the field of architectural design is that the amount of publicly disclosed data is absolutely insufficient and that the publicly disclosed data also haves a wide variety of forms. Using the technology proposed in this study, it is possible to quickly and easily create labeling images of drawings, so it is expected that a large amount of data sets that can be used for deep learning for the automatic recommendation of architectural design or automatic 3D modeling can be obtained. This will be the basis for architectural design technology using artificial intelligence in the future, as it can propose an architectural plan that meets specific circumstances or requirements.","archive":"2023/07/18","archive_location":"5 citation(s. This study employs Atomic convolution, a semantic segmentation technique that surpasses prior methods through model training (Li et al., 2023). An intelligent assistance system for architectural space design based on AI was developed by analyzing the semantic network and architectural spatial structure. Both studies greatly contribute to the intelligent digital transformation of architectural spatial design.

Building Design Optimization:

Due to the iterative nature of architectural design, optimizing this process attracts significant attention from scholars. For example, Yi and Kim (2022) utilized a Rhino Grasshopper and Python-based design simulation platform that integrates real-time occupant response, ambient building manipulation, and space optimization, demonstrating the potential of this integrated approach to improve building design and simulation intelligence. Moreover,Ekici et al., (2021) expanded the spatial scope of the study, suggesting a multi-region optimization approach for sustainable high-rise buildings in densely urbanized areas, employing parametric modeling, simulation, machine learning, and optimization techniques to address various performance aspects.

The introduction of DECS-TAPS, a novel meta-heuristic optimization technique for Architectural Design Optimization (ADO), aimed to resolve the slow convergence issue caused by high-dimensional and multi-scale variables. Pan (2022) and Ekici et al., (2021b) the differences related to the impact of the dense surroundings are not taken into consideration. Part 1 of this study presents a multi-zone optimisation (MUZO both utilized this technique across various architectural design domains, whereas Yi and Kim, (2022) and Ekici et al., (2021b) the differences related to the impact of the dense surroundings are not taken into consideration. Part 1 of this study presents a multi-zone optimisation (MUZO focused on integrating technology. Erioli (2020) examined the role of architects in the technological era, exploring machine and algorithm involvement in the design process and the potential symbiotic relationship between humans and intelligent systems.

In contrast, Dortheimer et al. (2023) in larger-scale public architecture projects, the client is frequently represented by a community that embraces numerous stakeholders. The scale, social diversity, and political layers of such collective clients make their interaction with architects challenging. A solution to address this challenge is using new information technologies that automate design interactions on an urban scale through crowdsourcing and artificial intelligence technologies. However, since such technologies have not yet been applied and tested in field conditions, it remains unknown how communities interact with such systems and whether useful concept designs can be produced in this way. To fill this gap in the literature, this paper reports the results of a case study architecture project where a novel crowdsourcing system was used to automate interactions with a community. The results of both quantitative and qualitative analyses revealed the effectiveness of our approach, which resulted in high-level stakeholder satisfaction and yielded conceptual designs that better reflect stakeholders' preferences. Along with identifying opportunities for using advanced technologies to automate design interactions in the concept design phase, we also highlight the challenges of such technologies, thus warranting future research. © 2023 by the authors.","archive":"2023/08/15","archive_location":"0 citation(s introduced crowdsourcing systems and AI from the perspective of users and designers of public buildings, aiming to involve stakeholders in large-scale building projects, potentially enhancing user satisfaction. Both studies explore human-AI relationships, with one focusing on the designer-AI dynamic and the other incorporating perspectives from designers, users, and AI. Additionally, particular studies investigate safety monitoring (Akanet al., 2023), semiotics (Brunetti, 2023), visualization (Zhou, 2023), and biophilic architecture (Viliunas & Grazuleviciute-Vileniske, 2022).

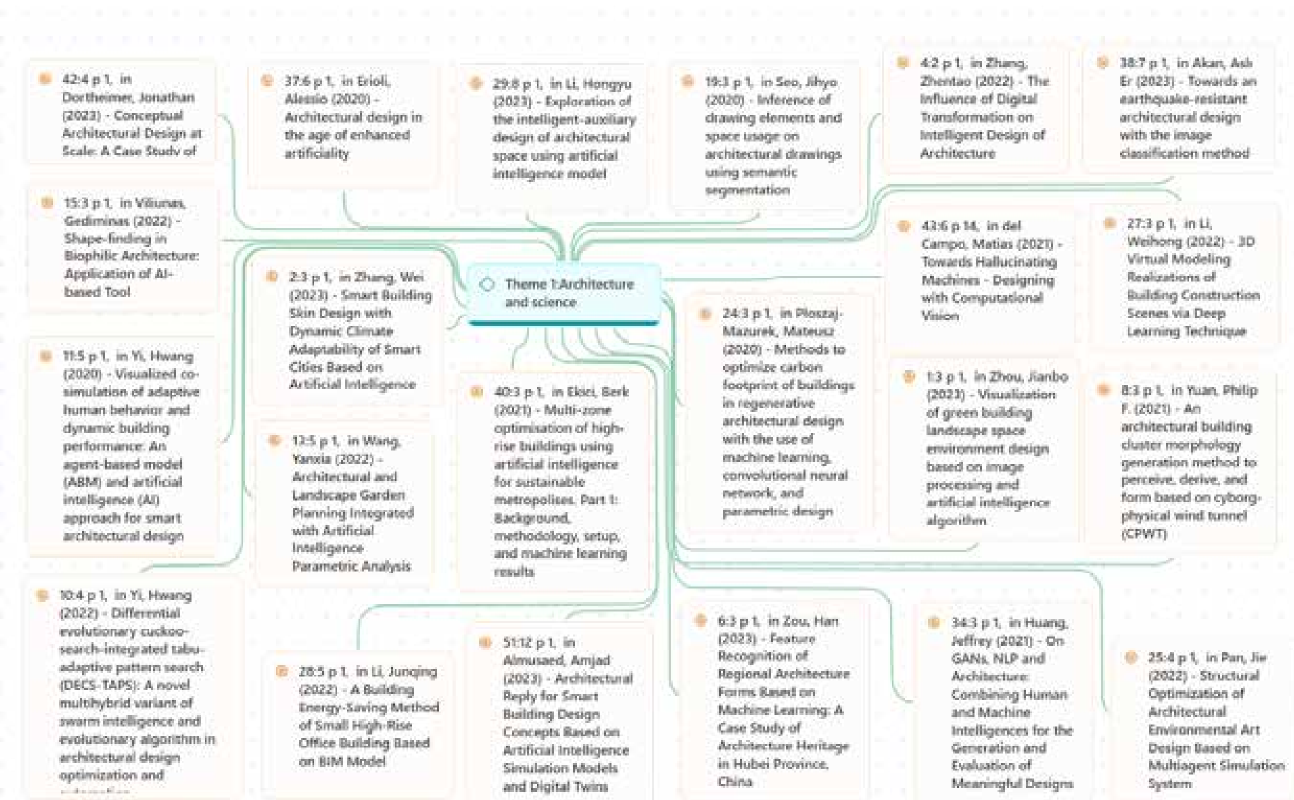

Figure 6 Network of the architecture and science theme

Theme 2: Architecture and Construction Management

The second theme of this report centers on construction and project management. Building Information Modeling (BIM) is acknowledged as crucial for research advancement. The International Organization for Standardization (ISO) defines BIM as a digital database that stores information on constructed assets, representing a building's objects and functional traits (ISO 29481-1:2016(En), Building Information Models — Information Delivery Manual — Part 1: Methodology and Format, n.d.). Zhao (2017) observed a notable rise in discussions and utilization of BIM over the past decade, highlighting the collaborative effort required among modeling teams to create BIM models, as supported by multiple studies (Ji et al., 2013;H. Kimet al., 2013;engineering, and construction industries have had rapid technological advancements over the last decade, particularly in the area of building information modeling (BIM S. Kim et al., 2017).

BIM has a significant impact on the construction sector, streamlining collaborative information sharing and integration among designers, engineers, and contractors. It meets various requirements, ranging from cost analysis to structural and energy simulations, thereby improving project management and design quality (Wang & Hu, 2022; Yu et al., 2022) the author proposed the application of a deep learning-based AI technology in construction management system modeling. The 3 D reconstruction deep learning model is first introduced, and then the model idea of the construction progress reliability control system is designed based on BIM (building information model. The integration of BIM with AI is a key research focus aimed at optimizing construction processes. The incorporation of AI into BIM serves multiple purposes, including automated decision-making, design optimization, infrastructure system defect detection, and architectural heritage data classification (Croce et al., 2023; Elghaish et al.,2022; Zeng et al.,2022) making the most of Artificial Intelligence (AI. The intersection of AI and BIM has been the predominant research trend in this field for the past five years.

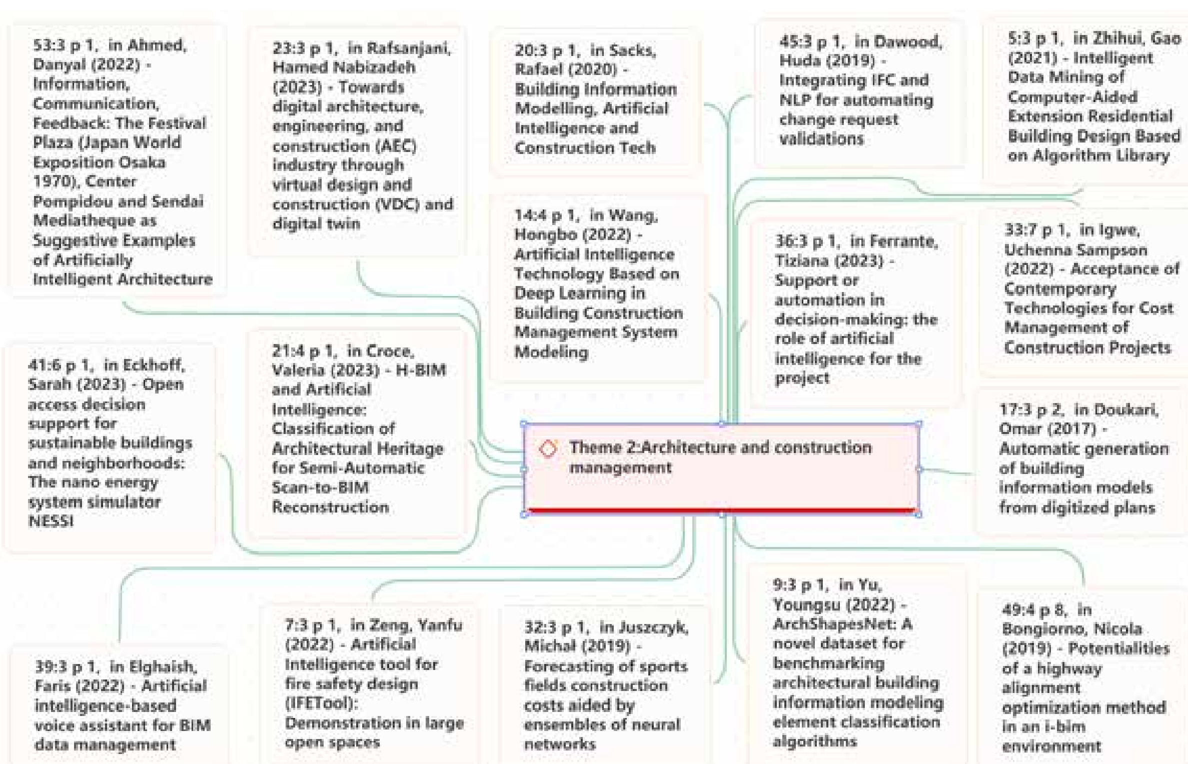

Figure 7 Architecture and construction management theme

Theme 3: Architecture Interior Design

Analysis of the interior design theme demonstrates AI's versatile application across various research perspectives in this field (Refer to Figure 8). An increasing number of researchers acknowledge AI's potential to enhance the interior design process . Several researchers (Gong, 2023; Ran & Dong, 2022) have investigated AI's potential to enhance interior design and emphasized the need for further research in this area. Ran and Dong (2022) validated a multi-objective optimization algorithm for building interiors and spatial structures using AI decision-making, as demonstrated by a library in a cold climate. Gong (2023) employed visual information design to optimize indoor shape and contour characteristics, achieving 3D visual feature reconstruction for comprehensive interior design scheme optimization.

Nevertheless, scholars' research in this area extends beyond design issues, as evidenced by proposals for an intelligent framework for interior design evaluation using machine learning and mobile digital devices focused on aesthetic assessment. Additionally, some scholars focus on extending the scope of ML algorithms in architectural design through algorithm refinement. For example, Karadag et al. (2022) introduced a dual machine learning model, EDU-AI, developed to generate classroom layouts in educational buildings, adaptable to various floor plans, and assisting in multiple building design tasks.

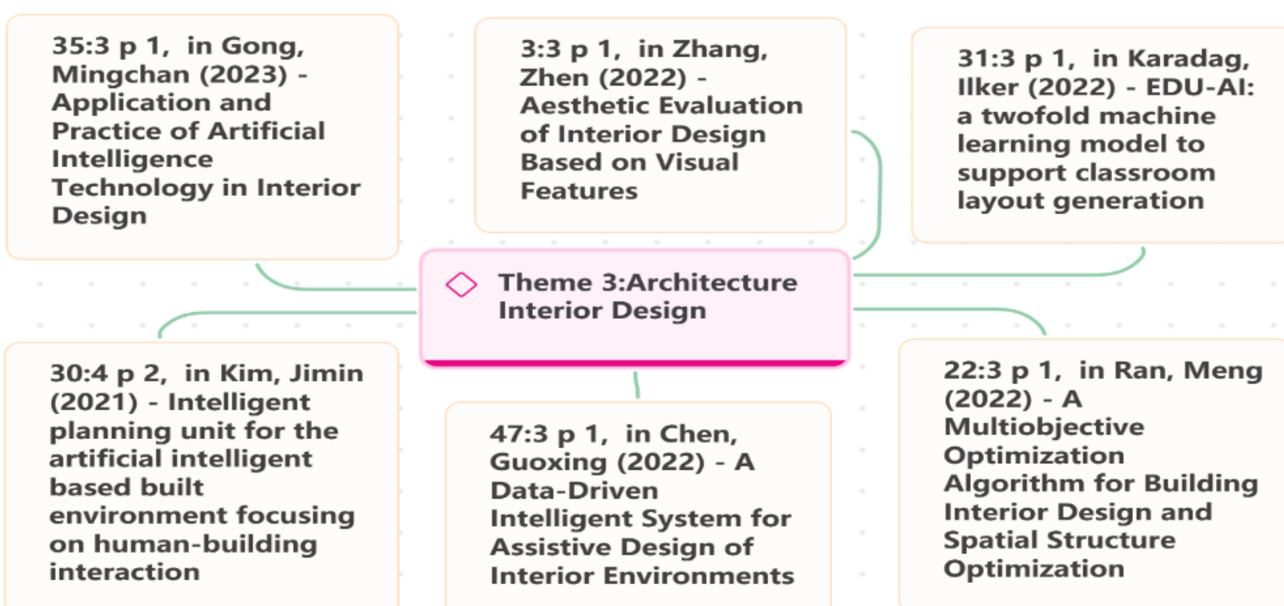

Figure 8 Architecture Interior design theme

Theme 4: architecture and urban

Urban planning and design are prominent research topics in AI applications. While the focus is on AI's role in urban planning, the perspectives diverge but converge on issues related to human-building and environmental interaction. Shao (2022) utilized algorithms such as Ant Colony, Particle Swarm Optimization, Genetic, and Improved Ant Colony Algorithms to improve architectural planning and landscaping design for smart cities. The study underscores the importance of safety research and advocates for the Improved Ant Colony Algorithm as the preferred choice for planning and design.

In contrast, Yan (2022) presents an AI-based approach to urban planning and design utilizing reinforcement learning to improve efficiency and reduce construction waste. This approach employs agents to learn environmental interactions and develop road network designs, aiming to help planners create more efficient urban layouts and integrate behavioral intelligence in road network planning. Likewise, other researchers have applied AI to analyze the structure and density of European urban areas. This analysis highlights the significance of measuring building density for urban planning and sustainability. The research identifies Self-Organizing Maps (SOMs) as a powerful tool for analyzing and visualizing urban data, providing valuable insights for urban planning and development.

In summary, researchers mainly use AI in urban design to navigate the complex interactions among human society, architecture, buildings, and cities. Some apply AI to develop road network solutions, targeting energy conservation and emissions reduction in urban development processes to tackle this multifaceted challenge. Others utilize AI to analyze city structure and density, providing insights for rational future urban planning. Implementing computational intelligence in architectural planning and landscape design for smart cities requires a multidisciplinary approach and considerations of human-building and building-city relationships. By leveraging big data, integrating AI techniques, addressing uncertainty modeling and ethical computing, and evaluating economic and social impacts, designers and planners can establish sustainable and efficient smart city environments.

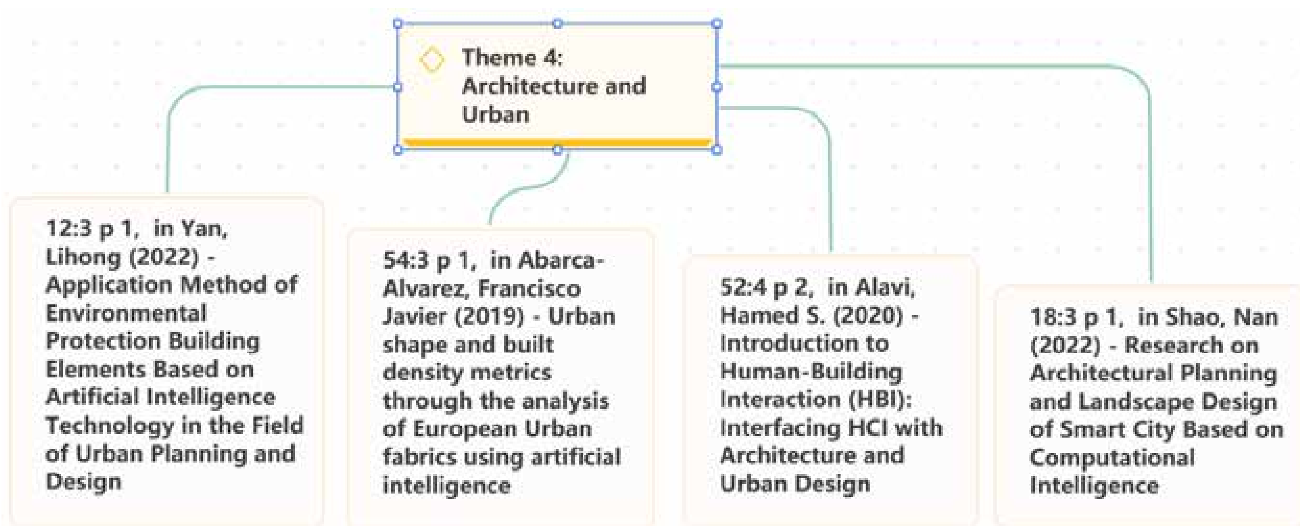

Figure 9 architecture and urban theme

Theme 5: architecture engineering

AI applications have profoundly impacted architectural design in multiple facets. In architectural engineering, structural design has garnered significant attention from researchers, primarily due to the underexplored applications of AI in this field. Lu et al. (2020) employed the StructGAN model to develop a comprehensive automated design system for shear walls, harnessing Generative Adversarial Networks (GANs) for efficient and intelligent design.

Likewise, De Miguel Rodríguezet al. (2020) introduced a technique for creating innovative 3D wireframe building structures using deep variational autoencoders (VAE), broadening the scope of machine learning applications in the design sector. A comparative analysis of these studies indicates that D'Amico et al. (2019) greenhouse gases (GHG primarily address the sustainability of building structures. The study encourages professionals to provide structural designs for a broad and diverse dataset while exploring the possibilities of employing machine learning and neural networks in sustainable structural engineering.

Sustainability has long been a central concern for architectural researchers and has been a recurring theme in earlier studies, including those on architecture and urbanism.

In the field of building engineering design, AI research has focused on both micro and macro-level structural design. The study investigates the potential use of AI techniques such as machine learning and neural networks on sustainability datasets about building structures.

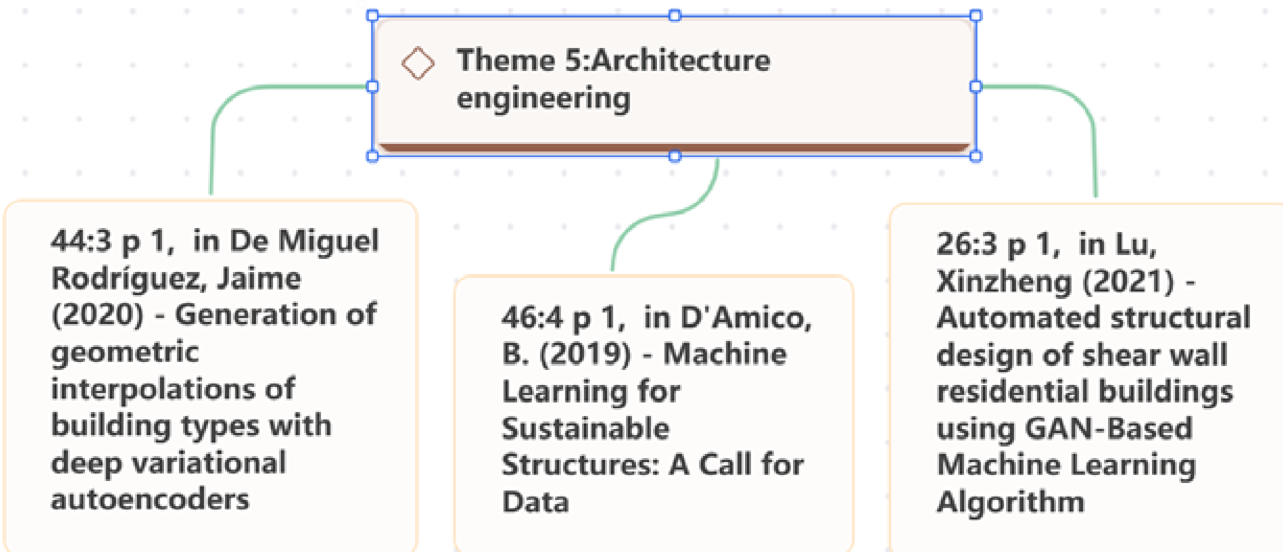

Figure 10 architecture engineering theme

Theme 6: Design education and training

A single paper in the Education and Training category is separately addressed due to its specificity. The research introduces an AI-based undergraduate research course in architectural education, which explores the potential benefits and challenges of integrating AI into architectural design. The course covers AI tools and techniques, their roles in architectural design, and their presence in architecture. The authors discuss the obstacles and future directions of AI integration into architectural education, emphasizing the need for continuous updates in architectural education to keep pace with technological advancements and the fundamental theoretical knowledge required for architects in the AI era. The article cites various sources that explore the intersection of AI and architecture, addressing AI's impact, machine learning, and AI's role in architectural style and aesthetics. The conclusion suggests additional improvements for integrating AI into architectural education (Basarir, 2022) part of the domain knowledge and hard skills become either irrelevant or insufficient by the time the students graduate. This paper suggests that integrating AI in the architectural design curriculum is beneficial for raising designers' awareness of all areas of architectural design, in the form of input, process, and output. The study views consecutive learning experiences in a continuum and explores the potentials of integrating AI applications and techniques in architectural education, and how architectural design practice may benefit from it. Consequently, it provides insights into how architectural design education may transform itself considering the future impact of AI on the Architecture Engineering Construction (AEC.

However, future education and training require a comprehensive approach that includes practical implementation, specific skill sets, ethical considerations, industry feedback, and a balanced curriculum. This approach will enhance robustness and applicability in addressing the educational and industrial demands of the AI era. The integration of AI, as a distinct theme in architectural education, requires thorough individual study to understand its complexities and significance. The introduction of an undergraduate research course based on AI highlights the evolving nature of architectural education, necessitating the incorporation of AI tools and techniques into the curriculum. This study confirms the growing need for educational programs to adapt to advancements in AI, ensuring that students acquire both theoretical knowledge and practical skills to meet future challenges. Besides presenting AI as a bridge between technology and humanity, supporting evidence from multiple sources discussing its impact on architecture and machine learning strengthens the writer's argument and lays the groundwork for future advancements in architectural education.

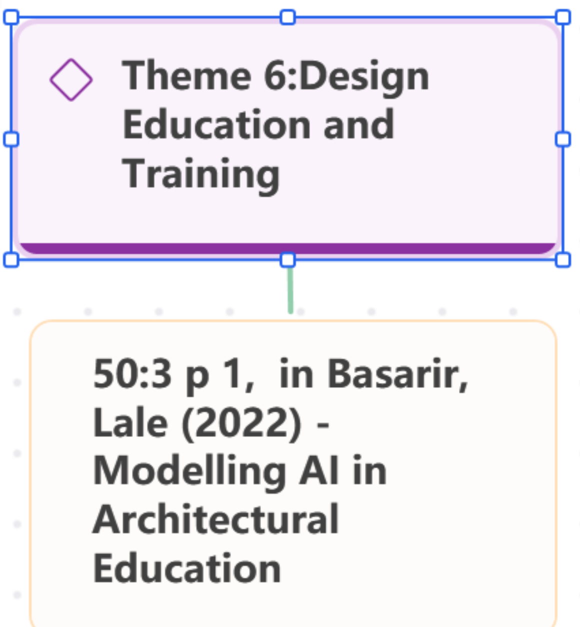

Figure 11 Design education and training theme

Conclusions and Future Research

The paper reviews 54 articles published between 2019 and 2023, focusing on Artificial Intelligence (AI) and Architectural Design, employing two review methods. The results provide insights into the application areas and research trends of AI in Architectural Design during the specified period. Quantitative research, using ATLAS.ti23 data, emphasizes a limited number of articles that explore collaborative design efforts between AI and humans, despite the growing interest in this area. Qualitative research emphasizes a focus on algorithm optimization and the integration of AI with Building Information Modeling (BIM). However, these studies demonstrate fragmented concepts, a lack of theoretical frameworks and research methods, and a predominant focus on practical applications over theoretical exploration, potentially leading to the scarcity of AI-generated architectural design research. The paper suggests that future trends in AI research for architectural design will include refining AI algorithms, integrating AI with BIM in project management, and optimizing architectural design. Theoretical research on AI-generated designs presents a significant research gap for exploring architectural design from an AI-generated perspective.

The analysis of 54 articles from 2019 to 2023 provides valuable insights into the current state and future trajectory of artificial intelligence (AI) in architectural design. In addition to identifying major themes such as algorithm optimization and AI-BIM integration, the article also highlights significant flaws. Consequently, the conclusion of the paper advocates for a more comprehensive refinement and discussion of the findings, outcomes, and conclusions. Future efforts aim to delve deeper into Theme 1 to generate innovative ideas and shape the future of architecture and design. Future research should focus on elucidating the complex relationships between artificial intelligence (AI) and architectural design, exploring collaborative design efforts between AI and humans, and integrating theoretical frameworks for practical applications. Researchers can enhance their understanding of AI's role in architectural design and stimulate creative developments in the field by addressing these gaps. Furthermore, theoretical exploration of AI-generated designs offers a promising direction for future research, enabling the integration of theoretical frameworks with practical applications in AI-driven architectural design.

Analysis of various topics in AI-driven architecture reveals that Theme 1, focusing on its impact on the construction industry and associated references, has received the most citations. There is increasing interest in the impact of AI on architecture and the underlying conditions affecting architectural construction processes and practices. This may involve optimizing building performance, enhancing sustainability, and improving efficiency. Despite the critical role of Theme 1 and its ability to address architectural issues, researchers may prioritize it because of its broad scope and potential to address the points raised. Future efforts aim to delve deeper into Theme 1 to generate innovative ideas and shape the future of architecture and design. Furthermore, the multifaceted nature of Theme 1, coupled with AI's system-based design approach and complex technologies, facilitates not only interdisciplinary collaboration but also the integration of AI with architectural advancements to cultivate "smarter" and "more sustainable" cities. refer to Table 3

Table 3: Potential future research

Potential Future Research Directions	
1	Refining AI algorithms for better design optimization, improving construction efficiency, and advancing the field of construction management.
2	Enhancing the user experience in architectural design through the refinement of AI algorithms, focusing on better design optimization and improving construction efficiency.
3	Improving AI algorithms for structural design to enhance their accuracy and efficiency in optimizing building structures.
4	Optimizing AI techniques for energy efficiency in smart buildings, aiming to develop more effective and sustainable energy management solutions.
5	Developing AI-driven tools for interior design algorithms, focusing on enhancing the efficiency and effectiveness of interior design processes.
6	Integrating AI with other emerging technologies to create more sustainable and efficient architectural solutions, particularly in smart buildings.
7	Foster interdisciplinary collaboration to explore innovative approaches that integrate AI with other emerging technologies, leading to more sustainable and efficient architectural solutions.

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