IJBES

International Journal of Built Environment and Sustainability
Published by Penerbit UTM Press, Universiti Teknologi Malaysia
IJBES 11(3)/2024, 121-134

Artificial Intelligence and Sustainability in Architecture: Scientific mapping in WoS with Biblioshiny

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ABSTRACT

This paper explores the evolution of academic debate and research in the field of architecture on AI and sustainability up to 2023. It focuses on the quantitative development of scientific publications on AI, the key countries and organizations behind these publications, key research topics and areas, and whether and how these publications address sustainability. A total of 428 international scientific publications (peer-reviewed articles, reviews and proceedings) on AI and sustainability in architecture were identified in the Web of Science database between 2020-2023. It has been noticed that the number of publications on artificial intelligence is increasing rapidly. Since 2021, a significant increase in the number of publications is observed. The countries with the highest number of publications are China (59%), USA (17%) and UK (15%), while the most frequently used keywords in publications are "performance" (13%), "design" (9%) and "model" (8%). The journals with the highest number of publications are Building and Environment (26%), Buildings (16%) and Journal of Building Engineering (14%). In the most cited papers, it was seen that AI is used to achieve goals such as implementing sustainability principles, reducing environmental impacts and increasing energy efficiency. As a result, the concept of sustainability is integrated into research on artificial intelligence as one of the most important concepts of future cities and architecture.

Article History

Received : *15 June 2024*
Received in revised form : *11 July 2024*
Accepted : *24 July 2024*
Published Online : *8 September 2024*

Keywords:

Artificial intelligence, Web of Science, Biblioshiny, Sustainability, Architecture, Bibliometric analysis

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DOI: 10.11113/ijbes.v11.n3.1352

1. Introduction

The world population, which was 1 billion in 1802, reached 6 billion in 200 years. Only in the last 23 years, it has increased by 2.5 billion to approximately 8.5 billion. According to the United Nations, the world population is expected to reach 9 billion in 2037 and 10.4 billion in 2078 (URL-1). In parallel with this increase in the world population, the population projections of cities are also

rising rapidly. According to 2023 data, the populations of cities such as Tokyo, Jakarta and Delhi have already exceeded 30 million. There are more than 100 cities in the world with populations over 5 million (URL-2). The population of the world and cities continues to grow rapidly. This increase leads to the growth of cities with great pressure towards the peripheries, the rapid consumption of resources such as water, food and energy, and the destruction of productive areas (Cohen, 2003). As a solution to these global problems, the phenomenon of sustainability comes to the fore (Praharaj et al., 2018). Within the scope of achieving sustainability goals, artificial intelligence creates a great potential and opportunity.

Although Artificial Intelligence (AI) was first proposed by John McCarthy in the 1950s, it is a relatively new technology that has been introduced into our lives only a few years ago (McCarthy, 2006). In its most general definition, AI refers to machines and computers that mimic cognitive characteristics associated with the human mind, such as learning, cognition and problem solving (Robert & Schalkoff, 1990). Artificial intelligence is the ability of a computer or computer-controlled robot to perform tasks usually associated with smart beings. More specifically, it is a technology that has the ability to learn by acquiring knowledge, make sense of data, derive concepts from data, deal with uncertainty, make decisions and take unsupervised action (Cugurullo, 2020). Artificial intelligence has a very broad content and is in continuous development. Today, although the possibilities and scope of use of artificial intelligence have not been fully explored, it has become a highly effective technological tool in many areas with its data scraping, capturing user behaviour patterns and comments, machine learning, statistical computing and programming capabilities (Pamela, 2018). Artificial intelligence technology increases organisational performance and productivity by automating processes or tasks that previously required manpower.

Ai technologies basically offer three benefits. Firstly, it automates repetitive and time-consuming tasks. This saves time and energy, allowing people to spend their time on more important tasks. Secondly, Ai reveals embedded information in large amounts of non-structured data such as videos, photos, reports, legislation, social media data. Third, Ai integrates computers and other resources to solve the most complex problems. These capabilities of Ai create a potential tool for solving sustainability-related problems (Duan, Edwards & Dwivedi, 2019). With its data capacity and ability to process data, Ai can significantly advance the field of sustainability. AI tools can play an active role in optimising and processing data in the complex and multi-stakeholder process of sustainability. While the pressure of human activities is making the ozone layer and the climate increasingly vulnerable, it is expected to develop measures against climate and environmental change with technologies such as artificial intelligence and the Internet of Things (IoT) (Galaz, 2014). Artificial intelligence technology is expected to produce solutions to climate change and biodiversity loss, effective use of natural resources and achieving Sustainable Development Goals (Campbell et al., 2019).

Ai has the potential to overcome the lack of knowledge and biases that are barriers to developing solutions for sustainability. Ai's ability to process large amounts of data and recognise large-scale patterns provides an opportunity to develop science-based solutions and policies for environmental problems (Cullen-Knox et al., 2017). Environmental sustainability is a highly complex process based on personal relationships. With this feature, it often turns into forms of interaction in which personal gain and self-interest are at play. As a result, the current understanding of environmental sustainability tends to develop irrational solutions (Cox & Raja, 2007). In contrast, Ai provides the opportunity to plan and implement holistic solutions to environmental sustainability and the climate crisis independent of people's individual benefits and reductionism. Decisions made with Ai tools are based on objective data and are free from cognitive biases and emotions. Therefore, the success of Ai technology is related to its ability to disable or redirect the psychological, sociological and organisational factors that currently hinder human progress.

In this context, artificial intelligence is of great importance in the optimisation and development of sustainability processes in architecture. The quality of decisions regarding the future of sustainable cities depends to a large extent on the inclusiveness of AI technologies and associated policy processes (Kontokosta, 2018). Today, the possibilities of using artificial intelligence in architecture, as in other disciplines, are being rapidly explored. Recent studies in the field of sustainability in architecture show that artificial intelligence (AI) is used to improve and optimise the environmental efficiency and performance of smart cities. In order to ensure urban quality of life and sustainability, planners have started to actively use AI tools in areas such as traffic management, security, control of lighting systems, face recognition and waste management (Mark, 2021).

However, it is also predicted that artificial intelligence tools will lead to significant changes in various fields such as climate change, urban development and environmental sustainability. For example, Bibri et al. (2024) systematically examines AI and IoT solutions that can be used for the environmental sustainability of smart ecological cities in a comprehensive manner. Cudzik, Nyka & Szczepańśki (2024), on the other hand, investigate the use of artificial intelligence in architectural education and research on green campus development. Liang et al (2024) present a sustainability-oriented perspective by addressing ethical issues in the field of artificial intelligence and robotics in architecture, engineering and construction industry. Shuford (2024) proposes an interdisciplinary perspective for sustainable solutions by combining environmental sciences and artificial intelligence. Shah & Sahastrabuddhe (2024) examine the effects of artificial intelligence on the architectural profession and the future expectations of architects in terms of sustainability. Bracarense, et al., (2022) and Nishant, Kennedy & Corbett (2020), conducted a bibliometric analysis on artificial intelligence and sustainability in all fields. Adio-Moses and Asaolu (2016) investigated the application of artificial intelligence for the sustainable development of smart buildings. In this study, unlike other studies, a scientific map of the studies

produced on artificial intelligence and sustainability in architecture was created with the Biblioshiny programme. In this context, the studies produced between 2020-2023 were analysed in the WoS database. The data of the studies evaluated by bibliometric analysis are presented in a table and the twenty most cited articles are evaluated by content analysis.

2. Methodology

The methodology of this study includes a systematic representation of the decisions made in the screening and selection of documents, excluded materials, analysis tools and data presentation choices. In addition, it restricted material identification to the WoS database using Biblioshiny software (URL-3), which allows users to perform relevant bibliometric and visual analyses on an interactive web interface.

First, keywords were selected in the context of the data identification process. Data identification can be considered as a series of activities carried out to explain the information processes of a study in an organized manner and to establish clear prioritization criteria (Ali & Faruquie, 2015). From this point of view, a search was conducted in the Web of Science database on 04.06.2024 with the keywords ("Artificial intelligence" OR ai) AND ("architectural design" OR "building design" OR facade OR envelope OR building*) AND ("sustainability" OR "sustainably" OR "environment" OR "sustainable" OR "sustainable development") AND ("sustainability" OR "sustainably" OR "environment" OR "sustainable" OR "sustainable development") in "All fields" in the fields of "Construction Building Technology" and "Architecture" between 2020-2023. The search visualization of this search is presented in Figure 1.

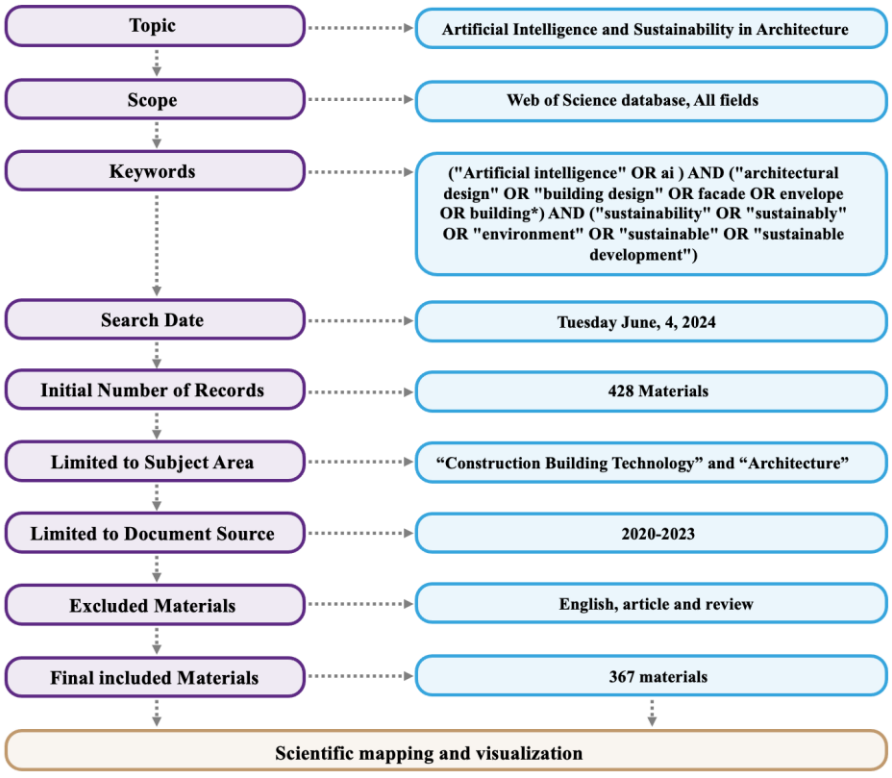

Figure 1 Search in the Web of Science database

After the analysis, a total of 428 publications were reached, 175 in 2023, 123 in 2022, 74 in 2021 and 56 in 2020. The annual scientific production of these publications is shown in Figure 2.

There are 404 studies in "Construction Building Technology" and 27 studies in "architecture" category.

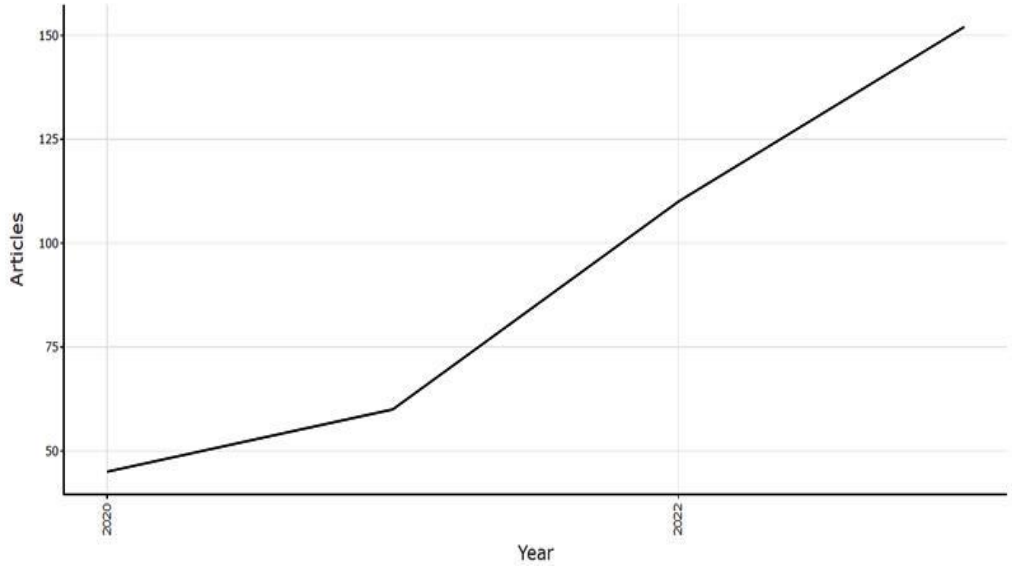

Figure 2 Annual scientific production

3. Results

The main information about the studies performed as bibtex in the search made in the WoS database on 04.06.2024 is shown in Figure 3. Only English language articles and reviews were evaluated in Biblioshiny. In this context, a total of 367 studies were identified. With 1568 authors, the annual growth rate of these studies was 50.04%, author keywords were 1738, and the total number of references was 23,960.

Figure 3 Basic information for all documents

3.1 Three-Field Plot

The three-domain diagram in Biblioshiny 2.0 is used to visually assess the connections between various elements such as sources, nations, relations, keywords, primary authors, works cited and keywords provided by the author. In the rectangular diagrams, the relevant elements are depicted using different colors. The height of each rectangle reflects the connections between various factors such as countries, affiliations, references, author keywords, key authors and keywords provided by the author. A larger rectangle size indicates a greater number of relationships between different components (Kumar et al., 2021). Figure 4 is a diagram of the research on the use of artificial intelligence in sustainability studies in architecture. The statements in the figure show the relationship between authors (left), author keywords (center) and title keywords (right). Accordingly, artificial intelligence, machine learning, deep learning, thermal comfort

and sustainability are the most used keywords. The words energy, building, review, intelligence and learning were frequently used in the titles. This graph provides guidance for academics who want to work on this topic in terms of authors and keywords that they should consider when starting their research.

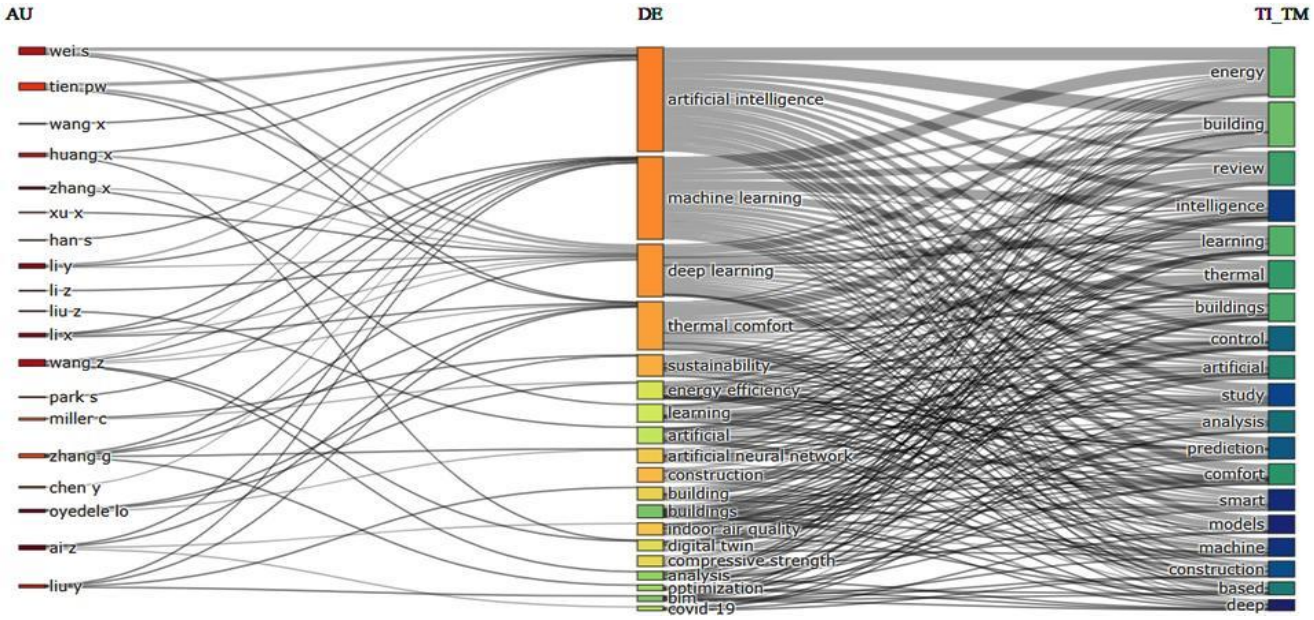

Figure 4 Tree field plot

3.2 Most Relevant Sources

Within the scope of the study, the journals with the highest number of publications on the subject were examined. In this Context, Building and Environment (N=89), Buildings (N=56), Journal of Building Engineering (N=48), Construction and Building Materials (N=36) and Energy and Buildings (N=29) stand out as the most published journals (Figure 5).

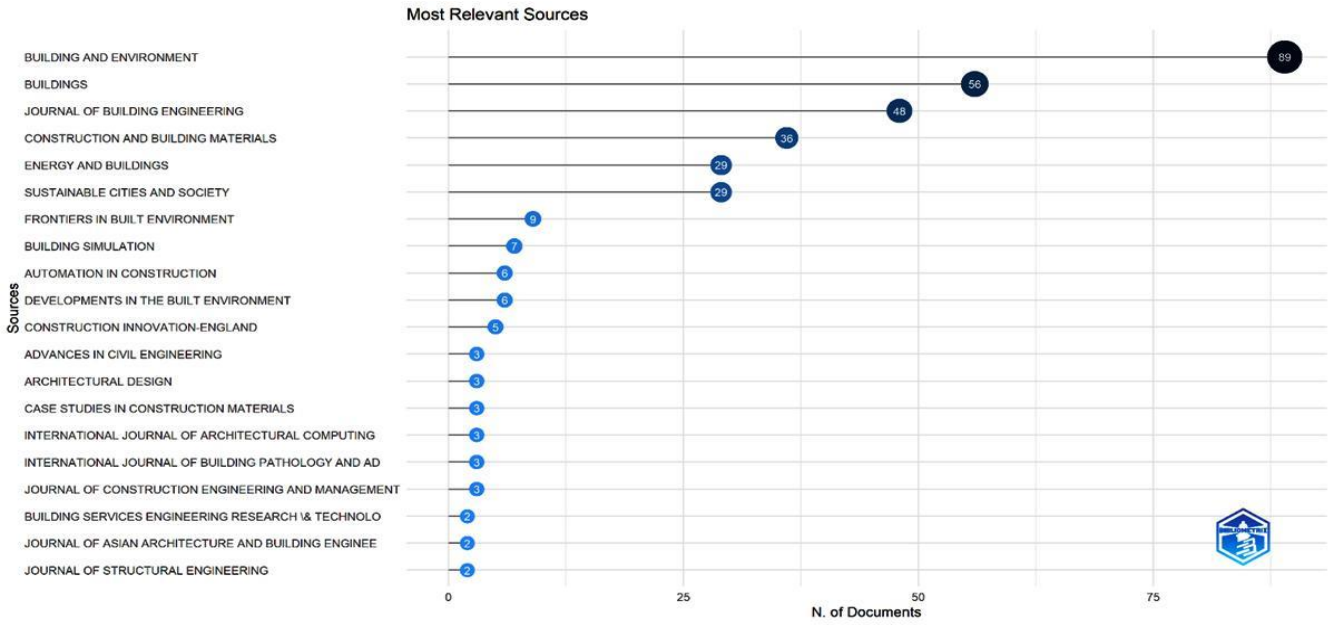

Figure 5 Most relevant sources

3.3 Most Relevant Authors

Figure 6 shows the authors who made significant contributions to the research on "Artificial Intelligence and Sustainability in Architecture" between 2020 and 2023. The top 20 authors out of 1568 authors who contributed to 367 documents on "Artificial Intelligence and Sustainability in Architecture" are listed in the table. In particular, AI Z stands out as the most prolific author, contributing to 13 documents. AI Z is followed by Oyedele LO (7 documents), Zhang X (7 documents), Li X (6 documents) and Li Y (6 documents).

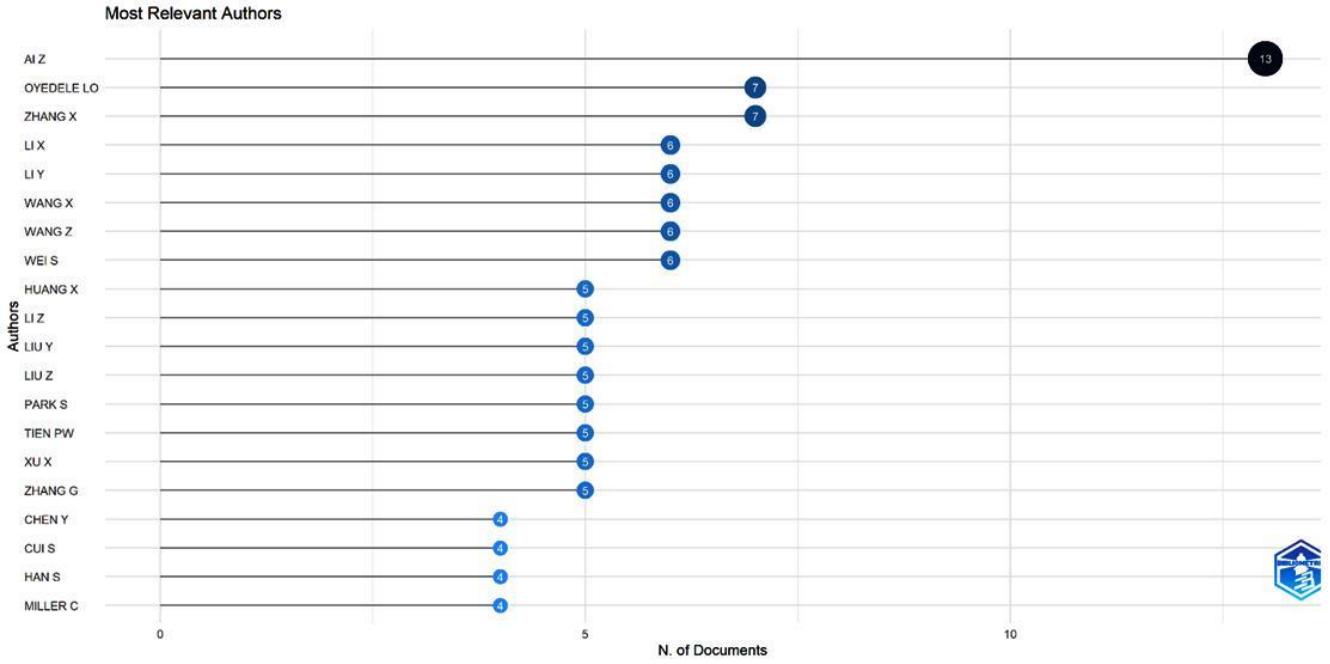

Figure 6 Top twenty most relevant authors

3.4 Most Global Cited Documents

Figure 7 shows the production of authors over time. The diameter of the circles corresponds to the number of articles, while the depth of the blue tone reflects the impact of research as measured by the volume of citations. Figure 7 highlights a significant increase in production over the last decade. Ai Z published the most publications in 2022 (N=6). Chen Y and Cui S have the most publications in 2023 (N=3).

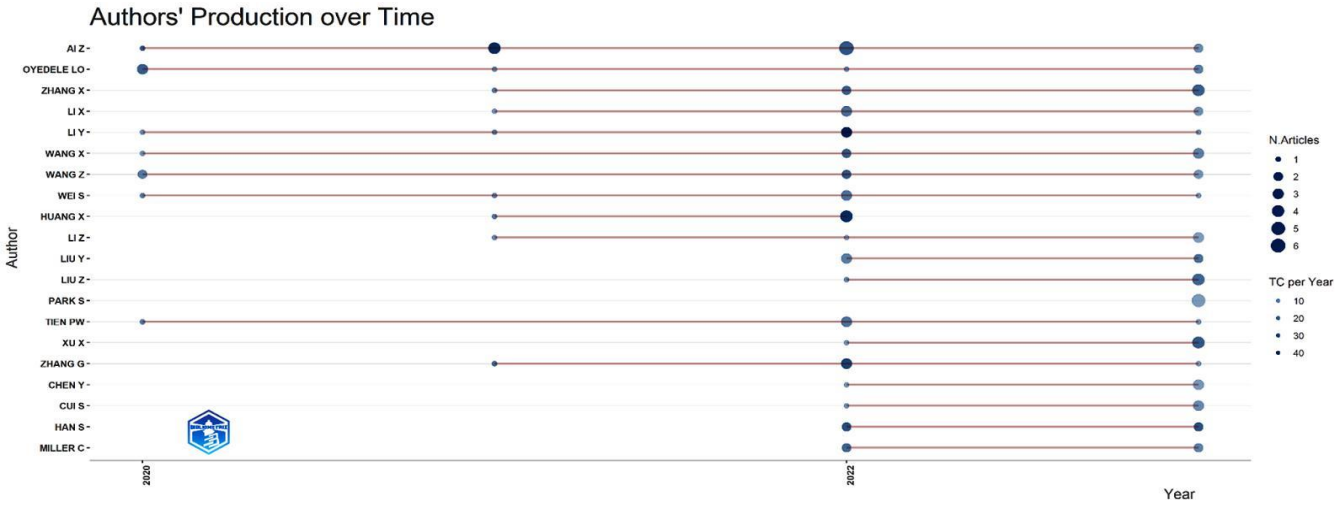

Figure 7 Authors' production over time

3.5 Most Global Cited Documents

When the most cited studies are analyzed, Boje C (N=396) stands out as the most cited author. This is followed by Yan K (N=111), Ashrafian A (N=98), Ai Z (N=98), Sacks R (N=86) (Figure 8).

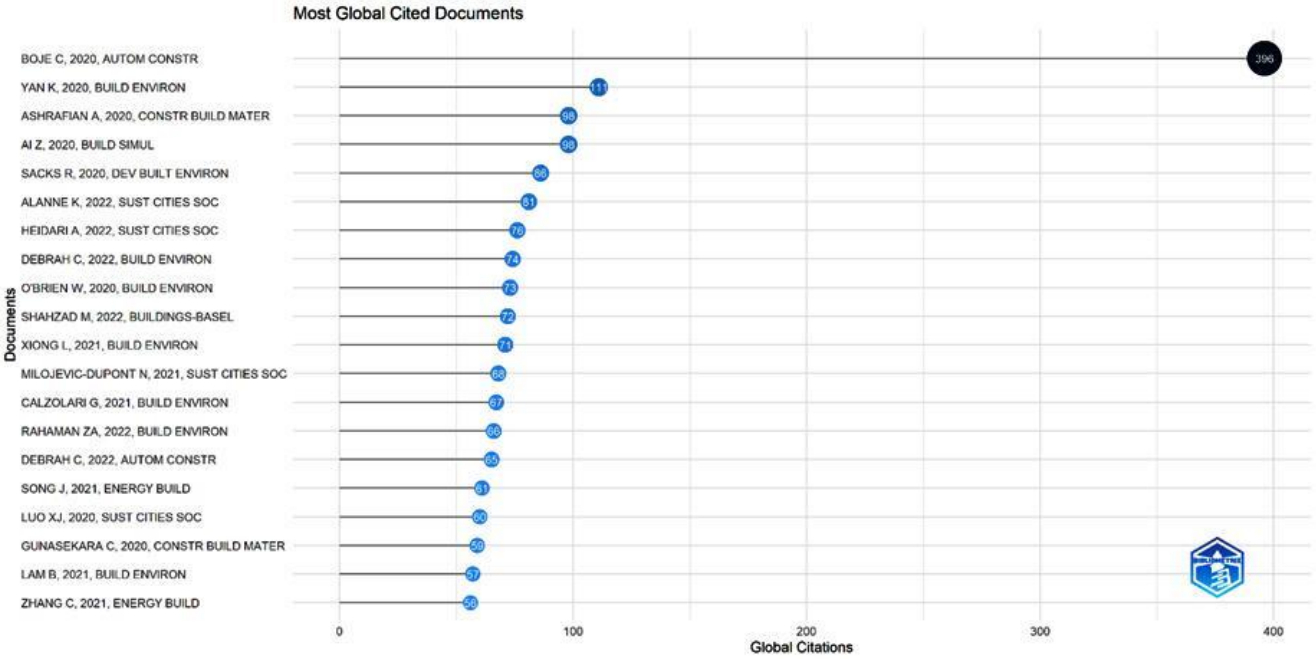

Figure 8 Most global cited documents

3.6 Hematic Map

The thematic map in Figure 9 is frequently used to assess the current status of the topic "Artificial Intelligence and Sustainability in Architecture" and provides a valuable direction for future work. The thematic map (Figure 9) provides a comprehensive depiction of the dominant research areas derived from the analysis of the 250 most frequently used keywords. In this map, clusters representing research themes are organized and categorized according to two key dimensions: centrality, which indicates the importance of a theme in shaping the theoretical landscape, and density, which reflects the internal consistency between the words that make up a theme (Cobo et al., 2011).

According to the thematic progress map shown in Figure 9, the themes in the upper right quarter show significant progress in the area of power analysis and have a significant impact on the evolution of this area. In this quarter, the themes indicated by keywords are strongly interconnected. In contrast, the lower right quarter contains the core themes that are essential to the field of power analysis and revolve specifically around concepts such as statistical power, sample size and dispersion. These themes are of great importance within the research field. The upper left quarter contains peripheral themes that demonstrate their limited influence in shaping the field. In contrast, the lower left quarter contains emerging or declining themes, suggesting that interest in these areas is declining or being explored at an early stage (Güler, 2023).

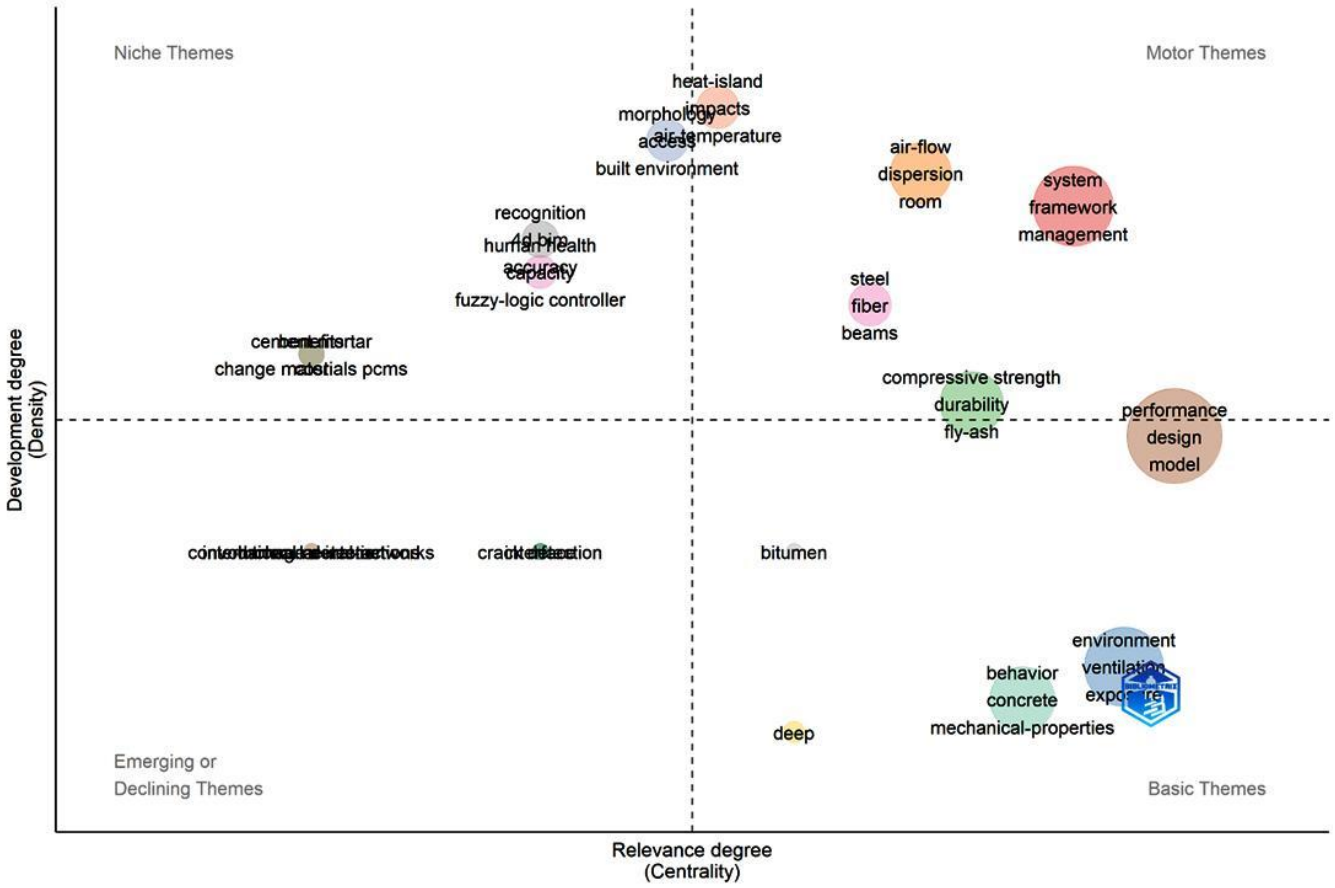

Figure 9 Thematic map formed by the authors' keywords

3.7 Countries' Scientific Production

Figure 10 shows the fields with the highest publication rates on "Artificial Intelligence and Sustainability in Architecture". As the color depth increases, the publication rate also rises. The figure shows that the topic is of widespread interest globally. It can be seen that the topic is of significant importance in countries such as China (483), USA (138), UK (120) and Autralia (84), which are recognized as the most prolific contributors in the selected dataset.

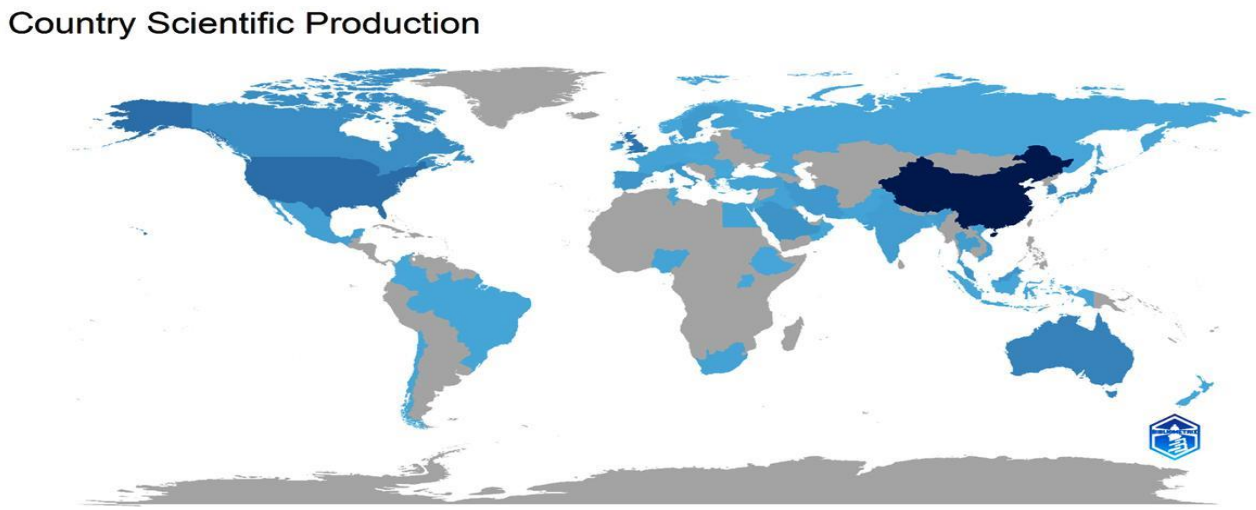

Figure 10 Thematic map formed by the authors' keywords

3.8 Most Frequent Words

The first 20 keywords frequently used in the study are shown in Figure 11. Accordingly, the keywords performance (N=64), design (N=42), model (N=38), simulation (N=30) and optimization (N=28) stand out.

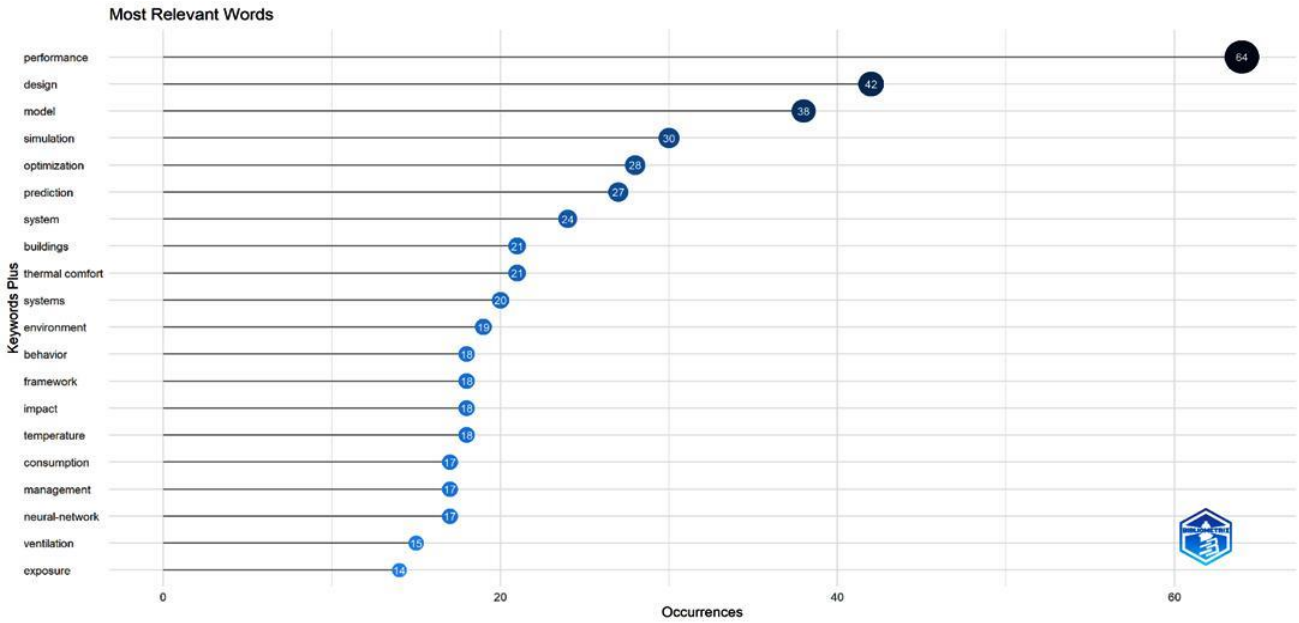

Figure 11 Most frequently used words according to Keywords Plu

Author keywords include artificial intelligence (N=50), machine learning (N=37), deep learning (N=27), thermal comfort (N=19) and sustainability (N=18).

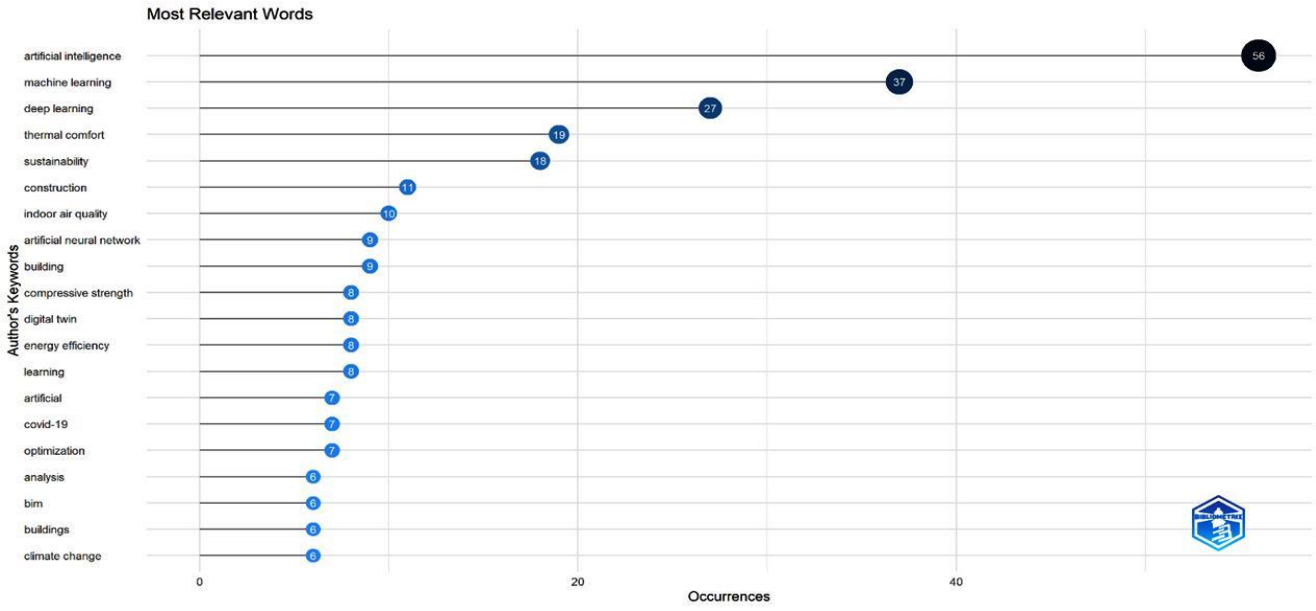

Figure 12 Most frequently used words according to Author's Keywords

3.9 WordCloud

Figure 13 shows the wordcloud with Keyword Plus and author keywords.

(a)

(b)

Figure 13 (a) Keyword Plus and (b) author keyword cloud

3.10 Trend Topics

Trend topics in terms of Word Minimum Frequency (N=5) and Number of Words per Year (N=10) are presented in Figure 14. In 2022, artificial intelligence (N=56), deep learning (N=27), sustainability (N=18) are the prominent trending topics. In 2023, trending topics include the keywords Machine learning (N=37), thermal comfort (N=19), construction (N=11), compressive strength (N=8), occupant behavior (N=5) and sustainable construction (N=5).

Figure 14 Trend topics

3.11 Content analysis of the most cited article

Within the scope of the study, the top 20 most cited articles were analyzed and the data obtained are presented in Table 1.

Table 1 Data obtained as a result of content analysis of the most cited articles

No	Topic	Method	Reference
1	Analyzing the semantic dimension of digital twin technology in the construction industry	Literature review, conceptual framework and examination of potential application scenarios	Boje et al., 2020
2	Fault detection and diagnosis in heating, ventilation and air conditioning (HVAC) system	Fault detection using GAN	Yan, Chong & Mo, 2020
3	Development and performance evaluation of a hybrid artificial intelligence model to simulate the compressive strength of foamed cellular lightweight concrete	Proposal for a new simulation method	Ashrafian et. al., 2020
4	Detection of gas emission in the built environment	Experimental method	Ai et al., 2020
5	Examination and evaluation of the use of artificial intelligence and building information modeling (BIM) in construction technologies	Literature review and use of analytical methods	Sacks, Girolami & Brilakis, 2020
6	Examination of machine learning applications in smart buildings and evaluation of the use of these technologies in areas such as building management and energy efficiency	Literature review and analysis of application examples	Alanne & Sierla, 2022
7	Examination of machine learning and deep learning applications in the management of smart cities and societies and a systematic review of the existing literature in this field	Systematic literature review	Heidari et al., 2022
8	Examination of financing of green buildings	Literature review	Debrah et al., 2022
9	Examination of user-related aspects of building energy codes and standards at the international level	Literature review	O'Brien et al., 2020
10	Examination of the applications and challenges of digital twins in built environments	Literature review and use of analysis methods	Shahzad et al., 2022
11	Investigation and model development of adaptive thermal comfort model with K-nearest-neighbors (KNN) algorithm	Use of experimental and analytical methods	Xiong & Yao, 2021
12	Exploring machine learning to develop strategies to combat climate change in urban areas, taking into account geographical differences	Use of data analysis and modeling methods to set and optimize strategy	Milojevic-Dupo& Creutzig, 2021
13	Examine how deep learning can be used to replace, improve or supplement Computational Fluid Dynamics (CFD) analysis in built environment applications	Literature review	Calzolari & Liu, 2021
14	Assessing the impacts of vegetation loss on surface temperature, urban heat island and carbon emissions in Penang city	Use of satellite data and environmental modeling methods	Rahaman et al., 2022

No	Topic	Method	Reference
15	Investigating the use of artificial intelligence in green building design and construction	Literature review and use of analytical methods	Debrah, Chan & Darko, 2022
16	Investigating the use of a hybrid CNN-LSTM model to predict hourly heating load in district heating system	Evaluating the performance of the proposed model with data analysis and machine learning techniques	Song et al., 2021
17	A comparative study based on machine learning to predict the energy load of multiple buildings	Use of various machine learning algorithms to evaluate the performance of the proposed frameworks	Luo et al., 2020
18	Investigation of data-driven prediction model in building energy prediction	Using attention-based LSTM and fuzzy information granulation methods to build the model	Li et al., 2022
19	Addressing the use of machine learning for risk and durability assessment in structural design	Assessing progress in this area and analyzing future trends	Wang et al., 2022
20	Investigating the integration of BIM and immersive technologies in Architecture, Engineering and Construction	Use of scientometric-SWOT analysis and critical content review methods to assess this integration	Khan et al., 2021

In these articles examined by content analysis, artificial intelligence is often used in data analysis, prediction and optimization processes in energy efficiency, climate change, technology integration, innovation studies, green building design and sustainability studies. It is also used to achieve sustainability goals such as reducing environmental impacts, increasing energy efficiency and implementing sustainability principles.

4. Conclusion

Today, global challenges such as urbanization and climate change have necessitated the search for sustainable and innovative solutions in architecture and construction. In this context, artificial intelligence (ai) technologies play an important role in achieving sustainability goals in architecture. Ai offers groundbreaking solutions in areas such as energy efficiency, material optimization, improving design processes and developing smart building systems. The integration of this technology with architecture has the potential to reduce environmental impacts, optimize resource use and improve quality of life. Therefore, the study of artificial intelligence and sustainability in architecture is of great importance both in academic environments and in practice.

Bibliometric analysis of publications in the field of architecture on AI and sustainability in the Web of Science database is a powerful tool to reveal research trends, new research directions, themes, key authors, influential journals and keywords in this field. In recent years, there has been a marked increase in the architectural literature on AI and sustainability. This increase shows both the growing importance of the topic and the intensity of academic and practical interest in this field. It also shows that international collaborations are increasingly important and there is a trend towards multidisciplinary work.

When the study results are evaluated, it has been noticed that the number of publications on artificial intelligence is increasing rapidly. Since 2021, a significant increase in the number of publications is observed. The countries with the highest number of publications are China (59%), USA (17%) and UK (15%), while the most frequently used keywords in publications are "performance" (13%), "design" (9%) and "model" (8%). The journals with the highest number of publications are Building and Environment (26%), Buildings (16%) and Journal of Building Engineering (14%). In the most cited papers, it was seen that AI is used to achieve goals such as implementing sustainability principles, reducing environmental impacts and increasing energy efficiency. Key themes in AI and sustainability include energy efficiency, green building studies, smart building systems, material innovations and environmental impact analysis. These themes have been identified as important areas for future research.

This study is limited to the WoS database. In future studies, in order to obtain more systematic quantitative results on "Artificial Intelligence and Sustainability in Architecture", it is planned to differentiate and expand the keywords and scan different databases.

In conclusion, the bibliometric analysis on artificial intelligence and sustainability in architecture reveals that this field is becoming increasingly important and has great potential in the field of

research. These findings are instructive for both academic and practicing professionals and will contribute to the direction of future studies.

By conducting a bibliometric analysis on artificial intelligence (AI) and sustainability, this study will also contribute to sustainable development from a broad perspective. In this framework, the research aims to synthesize and analyze academic studies on AI and sustainability, identify the main trends and provide a roadmap for future research. The results show that AI can contribute to the creation of more sustainable buildings by providing innovative solutions in energy efficiency, material optimization and carbon footprint reduction in architecture and can play an important role in the processes of monitoring and improving the life cycle performance of buildings. By identifying research trends and gaps at the intersection of these two fields, the bibliometric analysis will provide strategic directions for academic and practical applications and provide momentum in achieving sustainable development goals.

Acknowledgements

We'd like to thank all the reviewers who took the time to review our article and give us their valuable feedback

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