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Tracing the Evolution of Sustainable Architecture: An Analysis Spanning Five Decades

Sustainable Architecture Evolution

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Abstract

This study aims to reveal the relationship between architecture and sustainability in the approximately half-century history of sustainability. The study reveals bibliographic characteristics such as change, trend, period, country and author in the terminology of sustainable architecture. A systematic literature review was carried out using bibliometric analysis to produce a performance analysis and science mapping of scientific studies in the field. Bibliometric network visualisations were created using VOSviewer software to analyse the conceptual, social and intellectual structure of the field. This study contributes to the literature by deciphering the bibliographic parameters of sustainable architecture studies conducted between 1975 and 2022. It also identifies current trends in the field and provides a chronological perspective on scholarly studies based on environmentally conscious architectural approaches. The scope of the study is limited to sustainable architecture studies in the Web of Science database, taking into account the range of resources and the speed of indexing. The studies were carried out using 15 keywords, which were predetermined for the scope and focus of the research. This study has enabled real and legal researchers to follow the developments and current course in the field. The broad temporal scope of this study, with its unique combination of research and potential to inform practice, underlines its contribution to the discourse on sustainable architecture and firmly establishes its rightful place. The analysis shows that research has gained momentum in recent years. Today, concepts such as sustainable architecture, climate change, sociocultural sustainability and reuse have come to the fore.

Keywords:
Sustainability, Climate change, Socio-cultural sustainability, Reuse, Bibliometric analysis

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INTRODUCTION

Sustainable architecture is an approach to the design and construction of buildings that do not harm the environment and natural resources, are suitable for human health, are economically efficient and long-lasting. This approach considers all processes from design to construction, operation, maintenance and waste management of buildings, taking into account the needs of future generations. Sustainable architecture aims to reduce the carbon footprint of buildings, increase energy efficiency, minimise waste production, and protect natural resources while acting with environmental and social responsibility (Clayton & Radcliffe, 2018). Sustainable architecture can use various technological and design methods to achieve these goals, such as renewable energy sources, green roofs and walls, rainwater harvesting systems, and recyclable materials. Sustainable architecture reflects a sense of social responsibility by protecting the health of the environment and human comfort (Eldardiry & Konbr, 2022; Konbr & Mamdouh, 2022; Owen & Dovey, 2008; Williams, 2007). Therefore, sustainable architecture is an important field contributing to sustainability goals, one of our most important issues.

In this study, which aims to reveal the relationship between architectural thought and production within the framework of environmentally sensitive approaches, the bibliography of representations of environmentally sensitive architectural approaches in the literature has been analysed. It aims to decipher the bibliographical parameters of these studies, such as changes and trends in terminology, chronological existence and relationships between publications. In this way, it ensures that researchers, as well as natural and legal persons who carry out or are interested in studies on the subject, can follow developments and current trends in the field. This study, which is important in showing the extent and evolution of environmentally sensitive approaches in architecture, which have been on the agenda for almost half a century, also offers a chronological perspective. Although a high level of public opinion has been created through various channels on the axis of environmentally sensitive approaches, it is important to analyse some quantitative and qualitative information from scientific studies that have gained a place in the international literature in order to follow the current course. Various bibliometric analysis studies on sustainability in architecture can be found in the literature. These studies are focused on the integration of building information modelling or geographic information systems with a sustainable built environment (Li, Rong, Ahmad, Wang, Zuo, & Mao, 2021; Udomsap & Hallinger, 2020; Wang, Pan, & Luo, 2019), city design (Feng, Gu, Ye, Jia, Zhang, Wang, & Yang, 2022; Xia, Liu, Maria, Liu, & Lin, 2022; Wang, Ho, & Fu, 2019), biomimicry (Varshabi, Arslan Selçuk, & Mutlu Avinç, 2022), material choices and facade designs (Pramesti, Hasan, & Ramandhika, 2021), green buildings (Oguntona, Aigbavboa, & Thwala, 2021; Zhao, Zuo, Wu, & Huang, 2019), and off-site construction (Wuni, Shen, & Osei-Kyei, 2020). However, since these studies focus on specific issues related to

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sustainability, are limited to scientific studies produced in a specific country, and cover limited time intervals on the subject, no study offers a general perspective on sustainability in the field of architecture. Therefore, this study aims to fill this gap by conducting a comprehensive and detailed bibliometric analysis of the field. Following a systematic review of the literature on sustainable architecture and data mining, the study analyses the studies retrieved from the Web of Science database using the VOSviewer program. This study contributes to the literature in terms of raising awareness and interest in how the issue is being addressed scientifically. The Web of Science (WoS) database was used to search for studies on green architecture in the international literature, given its wide range of sources and rapid indexing capabilities. The study is limited to the articles in this database.

LITERATURE REVIEW

On Environmental Sensitivity and Architecture

The increase in the world population and the rapid consumption of resources have raised concerns about the future. The realisation that natural resources are limited in the face of a growing population has put environmentally sensitive approaches on the agenda. Especially in the last quarter of the 20th century, awareness of the need to protect the environment and natural resources has become important (Williams, 2007). Many disciplines have worked on developing self-sufficient systems that minimize environmental and wildlife impacts. On the other hand, the discipline of architecture has been one of the main actors of environmentally sensitive theories and practices regarding its effects on the physical environment (Bennetts, Radford, & Williamson, 2002; Kim & Rigdon, 1998; Sassi, 2006). Architecture, as a production or an idea, has played an important role in the development of environmental and resource-sensitive approaches by being at the centre of various debates.

With the industrial revolution, changes in the way and amount of production, approaches to resource use and evolving patterns of consumption have started to have a negative impact on nature. In society, the protection of nature and the life of living beings has ceased to be valued, and the profit of big capital has become the measure of success. In this process, the reduction, degradation and even destruction of natural resources has become an agenda. The growth of industry and the associated waste problems have made environmentally sensitive approaches controversial on a global scale. Within the scope of the environmentalism movement that deepened and intensified in the 1960s, "sustainability" developed as a concept and various publications were made on the negative effects of human beings on nature (Tekeli & Ataöv, 2017). At the conference held in Stockholm in 1972, the United Nations Environment Programme (UNEP) was established to emphasize the compatibility of economic development with the environment, and June 5 was declared Environment Day. With the Brundtland Report published in the late 1980s, the concept of "sustainability" gained centrality (World

Commission on Environment and Development, 1987). During these years, the European Union's policies on natural resources and environmental protection have also evolved (Aydın & Çamur, 2017). In the early 1990s, 20 years after the Stockholm Conference, after the United Nations Conference on Environment and Development in Rio de Janeiro, the scope of environmental approaches expanded, and issues such as climate change and biodiversity conservation gained importance in the centre of sustainability (Tekeli, 2011). Within the European Union, the Amsterdam Treaty (1999) emphasized the need to address environmental protection sustainably, while the Nice Treaty (2001) emphasized managing water resources, waste, and land use. The Lisbon Treaty (2009) focused on measures on the environment, climate change, energy, and financing of related activities.

In the historical context, while sustainable architecture mainly draws attention to energy efficiency and environmental sustainability, it has gained a more layered and complex dimension over time. Various current concerns such as climate change, resource scarcity, green infrastructure, health, welfare, and social and cultural harmony have started to be addressed. Environmentalist approaches have been addressed in various scopes on the axis of the concept of sustainability and have been supported by various studies that have made a global impact. Many areas, such as agriculture, health, transportation, and construction, negatively impact the environment. Various interdisciplinary proposals and policies have been developed to prevent environmental problems, such as the re-organisation of resource use, the reduction of consumption, the reduction of carbon emissions in built environment applications, and the use of renewable materials (Clayton & Radcliffe, 2018). The discipline of architecture, one of the main actors in the study of the built environment, is one of the disciplines in which these proposals and policies are developed (Konbr, Bayoumi, Ali, & Shiba, 2022). Sustainability, which is discussed in terms of the ability to satisfy human needs without suffering from the depletion of natural resources, is one of the dominant fields of knowledge in today's and tomorrow's humanity within the relations of production and consumption. In particular, it is one of the dominant fields of knowledge in architecture, which is the science of designing and building physical environments (Williams, 2007). Approaches and practices related to sustainability in architecture; ensuring energy efficiency, from land settlement (site location, orientation, building location, size) to the use of climatic data (temperature, wind, air pollution, etc.) and the improvement of indoor quality (comfort level, ambient temperature, humidity, air quality) and from the determination of function in reuse to application methods in a wide range of buildings and cities. In the design of the sustainable architectural built environment, minimizing the negative environmental effects and necessitating a holistic, strategic, and planned construction, on the other hand, it includes social, cultural, and economic infrastructures as well as morphological features (Bauer, Mösle & Schwarz, 2009; Guy & Farmer, 2001; Konbr &

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Abdelaal, 2022; Owen & Dovey, 2008; Sassi, 2006). In this context, all building design activities that consider future generations, are environmentally sensitive and meet users' needs with effective and efficient use of resources are within the scope of environmentally sensitive architecture. The principles of resource management, life cycle design, and design for people are also within this scope. Efficient use of resources such as energy, water, etc., local facilities and building areas resource management, the period from the construction of the building to its demolition/transformation is considered as the life cycle. Design for people is considered within the scope of resource conservation and the provision of appropriate health and comfort conditions (Kim & Rigdon, 1998; Sev, 2009). Approaches that are sensitive to all these environmental challenges in the discipline of architecture, under the umbrella of sustainable architecture; it is represented by different terms such as environmental design, green architecture, ecological architecture, environmentally sensitive architecture, green architecture, and energy-efficient architecture. This diversity in terminology points to architectural practices, ideas, and studies developed on environmental issues (Durmuş Arsan, 2008).

From Data Mining to Bibliometric Analysis

Data mining is defined as transforming meaningless data collection into meaningful data through certain processes; it combines many disciplines, including technology, deep learning, and data science (Han & Kamber, 2006). The common point in data mining, which is used today in different fields such as education, engineering, and health, is that it is a process of knowledge discovery and analysis among the masses of data (Andrés, 2009; Kobayashi, Mol, Berkers, Kismihók & Den Hartog, 2018). One of the topics included in data mining studies is text mining. Text mining is an application area of study made using large volumetric data in the web environment. The whole set of applications preferred in making sense of data, such as clustering and classification, is called text mining. Identification of changing phenomena in any subject and bibliometric analysis is one of the studies in text mining used to identify the transformation in the literature (Artsın, 2020). Bibliometric analysis is a method that has gained importance in recent years to examine the level of development of scientific studies in any field and to determine the transformation in the process (Doğruer, 2022; Donthu, Kumar, Mukherjee, Pandey & Lim, 2021; Güdü Demirbulat & Tetik Dinç, 2017; Heberger, Christie & Alkin, 2010; Park & Lee, 2022).

Bibliometric analysis examines scientific research in a specific field with statistical and mathematical techniques in scientific information-sharing environments such as books, journals, etc. (Borgman & Furner, 2002; Pritchard, 1969). Bibliometric analysis, which is based on analyzing certain characteristics of research, aims to enable a broader perspective on the field of study and to reveal trends in the field (Al & Coştur, 2007; Samiee & Chabowski, 2012). In this way, it reveals the

trends in the field for researchers who are or will be conducting scientific studies in a field and offers the opportunity to discover the structure of the research topic in the existing literature (Verma & Gustafsson, 2020). Bibliometric analysis is both descriptive of the publications produced in a certain region in a certain period on a subject and the relationships between publications and evaluative to determine the extent to which they affect other planned studies. In these analyses, findings on scientific communication are determined by examining research components such as author profile and number of authors, number, type, and language of publications, number of publications by country, topics covered in the field, preferred keywords, number of citations, etc. (Al, 2014; Donthu et al., 2021; Güdü Demirbulat & Tetik Dinç, 2017). Therefore, bibliometric analysis has an important place in performance evaluation for the quantitative and qualitative development of the research field (Al & Soydal, 2012; Van Eck & Waltman, 2010). In addition to identifying the change and transformation in the field, bibliometric analysis also plays an effective role in revealing the insufficient points on the subject and discussing new suggestions (Yılmaz, 2017).

In architectural research, bibliometric analyses provide convenience against various difficulties. Architecture is a broad discipline that includes many sub-disciplines such as interior architecture, landscape architecture, and urban planning. Bibliometric analysis studies help to organize data sets in architectural research, which usually contain large and complex data groups. At this point, bibliometric analyses make it easier to examine topics and trends by classifying research. On the other hand, as in every discipline, it is important to define keywords correctly in architectural studies. Bibliometric analyses guide researchers in the selection of effective keywords. On the other hand, architecture interacts with many different disciplines such as sociology, psychology, and art history. At this point, bibliometric analyses offer the opportunity to examine how the subject under consideration interacts in different disciplines and interdisciplinary connections. From all these points of view, bibliometric analyses in architectural research help to provide a more effective understanding by offering solutions to unique challenges. From another perspective, bibliometric analyses in architecture act as a complement to qualitative evaluations. Comparing the quantitative data obtained through analyses with qualitative data or evaluating them together contributes to more comprehensive and detailed studies. In addition, it provides an opportunity for researchers to better understand their fields of study and to increase the effects in their fields of study.

Bibliometric studies consist of two categories: performance analysis and science mapping. Performance analysis focuses on the contribution of research components to the field by creating metrics associated with titles such as publications, citations, etc. (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011). Science mapping, on the other hand, is concerned with the relationships and interactions between research components such as citations, co-citations, bibliographic matches,

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common words, and co-authorship (Baker, Kumar, & Pandey, 2021; Donthu et al., 2021). In this mapping system, data visualizations are made through science mapping to cluster the data community and research components (Donthu et al., 2021; Özdemir & Selçuk, 2021).

Bibliometric analysis can be done manually or with the help of various software programs. Considering the high number of scientific research conducted today and the rapid advancement of technology, it is advantageous to prefer software programs in terms of both time and scope (Cobo et al., 2021; Oraee, Hosseini, Papadonikolaki, Palliyaguru & Arashpour, 2017; Özdemir & Selçuk, 2021). In addition, software programs also allow the creation of visual relationships and network maps between bibliometric data. In bibliometric analysis, data are obtained from databases such as Web of Science, Scopus, and PubMed (AlRyalat, Malkawi, & Momani, 2019; Chadegani, Salehi, Yunus, Farhadi, Fooladi, Farhadi, & Ebrahim, 2013). VOSviewer, CiteSpace, Gephi, Bibexcel, and Pajek software compatible with these databases stand out in bibliometric analysis with their different capabilities and powerful features (Donthu et al., 2021; Özdemir & Selçuk, 2021). In literature analyses, it is preferred to examine author and institutional collaborations in research field trends (Artsın, 2020; Park & Lee, 2022; Yıldız & Beyhan, 2021). Citespace is another software that provides various graphs, timelines, network maps, and visualizations for scientific network analyses. It allows various uses such as monitoring interdisciplinary studies, scientific collaborations, and identifying research trends. BibExcel is intended for basic bibliometric analyses. Gephi allows visualization by analyzing various networks. Pajek has various capabilities such as complex network analyses, social networks, and information maps (Herrera-Viedma, Santisteban-Espejo, & Cobo, 2020; Pan, Yan, Cui, & Hua, 2018). All these software tools offer visualizations by supporting different aspects of bibliometric analysis. Which software is preferred depends on the objective of the research, the level of complexity of the analysis, and the trend of the research.

MATERIAL AND METHOD

In the following sections of this study, all environmentally sensitive architectural approaches are represented by the concept of "sustainable architecture" to have a common terminology. In this study, which aims to reveal the place of sustainable approaches in architectural thought and production, answers are sought to the following questions:

- What is the distribution of sustainable architectural studies according to years?
- Which country stands out in studies on the field, which is the most productive author, which is the most publishing institution, and which is the most influential journal?
- Which is the most cited article and the most cited journal in sustainable architecture studies?

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- What are the topics covered in articles on sustainability in the discipline of architecture?
- How do the study subjects change chronologically?
- What are the current research topics and trends in the field?

This study was carried out in four basic steps. In the first step of the study, a literature review was conducted. In the literature review, the development of environmental awareness and the emergence of the concept of sustainability and its scope in the discipline of architecture were emphasized. This step was completed with a comprehensive literature review of domestic and foreign publications on bibliometric analysis. The literature review step was used to identify and confirm the study's limitations and determine the possibilities of the analysis method. In the second step, the population and sample were determined. First of all, the Web of Science, an international database containing more than 4 million records covering more than 20.000 refereed and high-quality 2.000 art and humanities journals for more than 50 years from 1975 to the present, has been selected as the universe of the study, taking into account parameters such as its widespread use, range of sources and indexing speed. At the same time, the Web of Science has a widespread network in arts and humanities (Park & Lee, 2022; Web of Science Group, 2022). Web of Science contains in-depth citation and citation data and has a rigorous quality control process for journal selection. It includes old scientific studies in many fields (Web of Science Group, 2022). On the other hand, it includes essential indexes such as the Social Sciences Citation Index, and Arts & Humanities Citation Index, which are at the forefront in architecture.

Determination of the sample was completed in four stages. First, it aimed to reach all publications in the selected database sensitive to environmental problems. In this context, the range of keywords targeted to represent the studies in the literature on different terms was determined. In the keyword selection of the study, bibliometric studies previously conducted in this field were read (Wang, Pan, & Luo, 2019; Xia, Liu, Maria, Liu, & Lin, 2022; Varshabi, Arslan Selçuk, & Mutlu Avinç, 2022; Pramesti, Hasan, & Ramandhika, 2021; Oguntona, Aigbavboa, & Thwala, 2021; Zhao, Zuo, Wu, & Huang, 2019; Wuni, Shen, & Osei-Kyei, 2020). Then, the keywords in the study sample were determined by listing the keywords in various types of publications such as books, articles, and theses on sustainable architecture. In the study, the 15 most prominent keywords were included in a comprehensive literature review that provides a broad overview of the historical and theoretical background of sustainable architecture. The literature review within the scope of "sustainable architecture", "sustainable design", "sustainable building", "green architecture", "green building", "energy-efficient architecture", "energy-efficient design", "energy-efficient building", "ecological architecture", "ecological design", "ecological building", "eco-friendly design", "eco-friendly building", "eco-friendly architecture" and "environmental design" the keyword has been identified. In the selection

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of keywords, widespread use in the literature has been taken into account, and attention has been paid to creating a comprehensive keyword list. As a result of the search in the Web of Science database with keywords, abstracts, keywords, and titles, 485,606 scientific publications were reached. Subsequently, 6.484 publications were identified with research limited to "architecture". There are 3,564 articles, 55 of which are review articles, 2,442 are proceeding papers, 192 are book chapters, 160 are book reviews, and 126 are editorial materials. Finally, the search was limited to the "article" type, considering its widespread effect and active role in directing the academic community, and the research sample was determined to consist of 3,564 articles (Figure 1). In this study, it was assumed that there were no unethical practices such as data confidentiality, double publication, various citation practices (self-citation, inconsistent citation, misleading citation), and potential conflicts of interest in the studies obtained from the database during the data collection phase.

This sample consists of studies between 1975-2022. The database search identified various studies on the bibliometric analysis of sustainable approaches in the architecture category. The bibliometric analysis of sustainability-related articles made in the discipline of architecture between 1975 and 2022 over a comprehensive keyword list constitutes the original aspect of this study (Hu, 2019; Jiang, Liu, Liu, & Liu, 2022; Oguntona et al., 2021; Zhao et al., 2019; Wuni et al., 2020). In the third step of the study, a bibliometric analysis of the determined sample was made. This analysis was carried out in two scopes: performance analysis and science mapping as full-count algorithms. Within the scope of the study, firstly, performance analysis was performed on the relevant sample for year, author, country, institution, journal, and index information. In line with the parameters determined here, sustainable architecture studies were analyzed through numerical data. Then, analyses were carried out with science mapping, frequently used in bibliometrics studies. With these analyses, the relationships between the determined parameters were examined. Within the scope of the study, science maps were created for keywords, prominent journals, authors, and countries with the most publications. In the fourth step, the research results were tested in line with the visualizations, information about the study results was given, and recommendations were emphasized.

Science mapping was created through the VOSviewer program. VOSviewer is a free program widely preferred for creating and visualizing maps based on bibliometric network data. The program is compatible with various databases, including Web of Science, Scopus, PubMed, Dimensions, and Lens (Van Eck & Waltman, 2010). This program can create citation, author, institution, country, and keyword maps based on the data. The VOSviewer program has three different visualization options, namely network, layer, and density visualization, which allow

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reading the relationship, interaction, and data connections between the data.

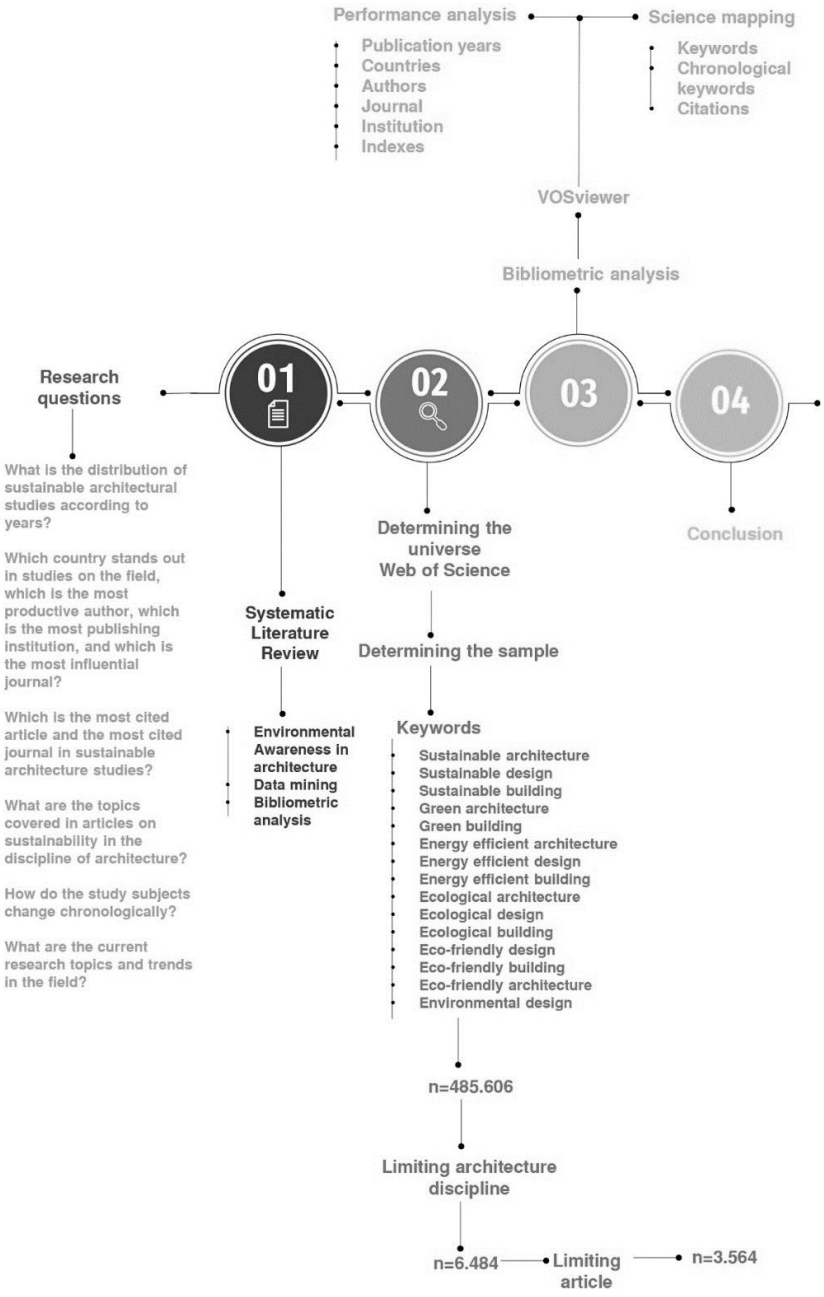

Figure 1. Research design.

In the network visualization, each data in the sample is represented as a circle with its bibliographic information, and the relationships between the data are shown with linear connections. The positions of the circles relative to each other are shaped according to the quantity of the relationship between the data communities, and their sizes are shaped in direct proportion to the density of the data in the sample. Depending on the sample size analyzed, some data whose quantitative values are not sufficient in the network visualization are not visible to avoid confusion of expression. The colour of the data is determined by the data collection to which it belongs. The layer visualization has the same characteristics as the network visualization except for how the elements are coloured. In this visualization, items are coloured according to their density in the

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data cloud, ranging from blue (lowest) to green to yellow (highest). The density visualization is the same as the layer visualization but is visualized as an areal distribution instead of a circle (Van Eck & Waltman, 2010; Van Eck, Waltman, Dekker, & Van Den Berg, 2010). The science mapping in this study is limited to network and layer visualizations. In this study, keyword network visualizations were made to identify the prominent keywords and to show their relationship with each other.

On the other hand, network visualizations of the most cited authors, countries, and journals were carried out within the scope of the study. In addition, layer visualizations were created to analyze the change in keywords over the years. These visualizations reveal the trends in the research field, the change of trends in the process, and their interactions within themselves.

RESULTS AND DISCUSSIONS

The findings regarding the bibliometric analysis of articles accessed from the Web of Science database are discussed under two separate headings: performance analysis and science mapping.

Performance Analysis

The findings obtained at this stage consist of five different scopes: the number of publications by years, the number of publications of countries, the most productive authors, the number of publications of institutions, the distribution of the number of publications according to journals and the most cited authors.

Number of publications by years: Although the publication year of the articles constituting the sample was spread over a wide range of time, it was observed that the number of articles generally increased over the years. This increase parallels sustainability approaches that have been on the agenda with various axioms for the last 20 years. The acceleration as of 2006 can be attributed to the various agreements that came into force within the scope of the European Union, especially in the 2000s. On the other hand, it has been observed that the pioneering studies on the subject date back to the 1975s. This is in line with the years when ideas on environmental problems intensified and the United Nations Environment Program was established in 1972. It has been observed that studies on the field have gained weight in the last 10 years. With 335 studies, the most articles were produced in 2021 (Figure 2). The climate crisis, which stands out within the scope of environmental problems, may be effective in this increase. This year, studies on housing sustainability and adaptation during and after the pandemic period came to the fore (Al Maani, Alnusairat, & Al-Jokhadar, 2021; Peters & Halleran, 2021; Porter, 2021; Saeed, Elkhatib, & Selim, 2021; Spennemann, 2021). In addition, studies on the climate factor in the sustainability assessments of buildings have been another prominent topic (Alawadi, Hernandez Striedinger, Maghelal, & Khanal, 2021; Fantozzi, Bibbiani, Gargari, Rugani, & Salvadori, 2021; Hao, Zhang, Xie, Wang, & Liu, 2021). The

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decrease in the number of articles in 2022 is noteworthy. This situation can be discussed within the scope of the limitations of the study. The first thing that comes to mind can be explained by the fact that the study data was obtained in September 2022. In addition, the effect of changing terminology and keyword selection can also be put forward. On the other hand, another reason may be that researchers focus especially on studies related to COVID-19, publishing institutions or organizations make calls on this issue, and special issues are published.

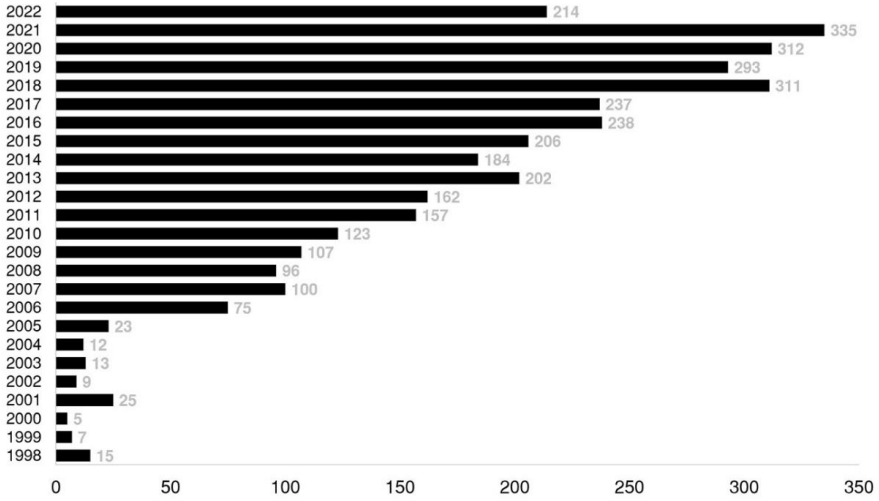

Figure 2. Distribution of publication numbers by years.

Number of publications of countries: According to the United Nations classification, the distribution of articles by country showed that developed countries contributed to the literature by producing more articles than developing and underdeveloped countries. The United States ranked first with 651 articles, followed by Italy with 371 articles, Turkey with 261 articles, China with 254 articles, and the United Kingdom with 225 articles. On the other hand, the fact that a developed country like Belgium is ranked below this ranking should be evaluated in the context of the country's surface area, population, and number of researchers (Figure 3). On the other hand, it should not be ignored that the number of publications is also related to the existence and number of various publication organs operating in the country. In addition to all these, based on the analyses made by the researchers in the database, it has been observed that the publication trends in developed countries have focused on issues such as social and cultural sustainability in recent years, while in developing countries, sustainable architecture is discussed through traditional architecture.

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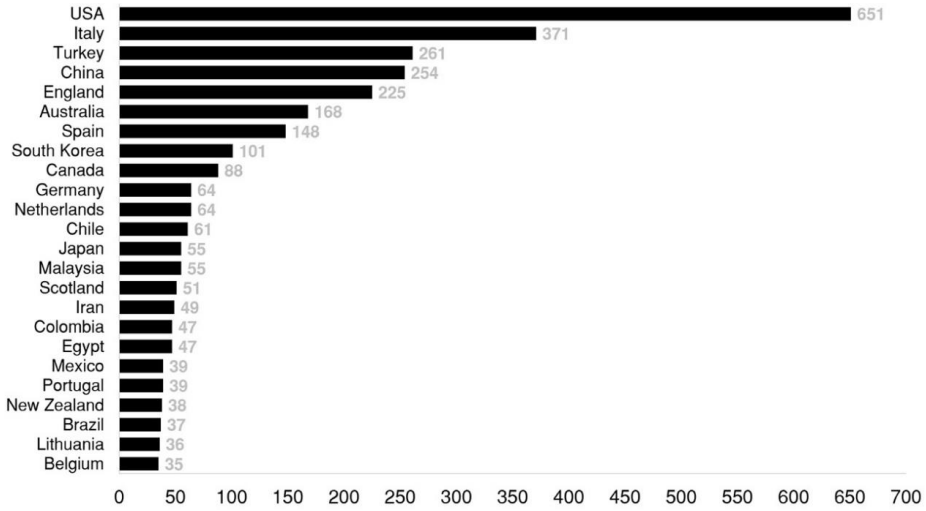

Figure 3. Distribution of the number of publications by country.

Number of publications by authors: Considering the distribution of authors, Kim S. has been the most productive author with 13 articles. Lee J, with 12 articles, Pushkar S, 12 articles, and Lehmann S, 11 articles, are other prolific authors in the field (Figure 4). Kim S's work is mainly related to the sustainability performance and design strategies of buildings (Ahn, Son, Park, and Kim, 2022; Han, Son, and Kim, 2022; Kim, Sanchez, Del Aguila and Kim, 2017; Oh, Lim, Lim and Kim, 2017).

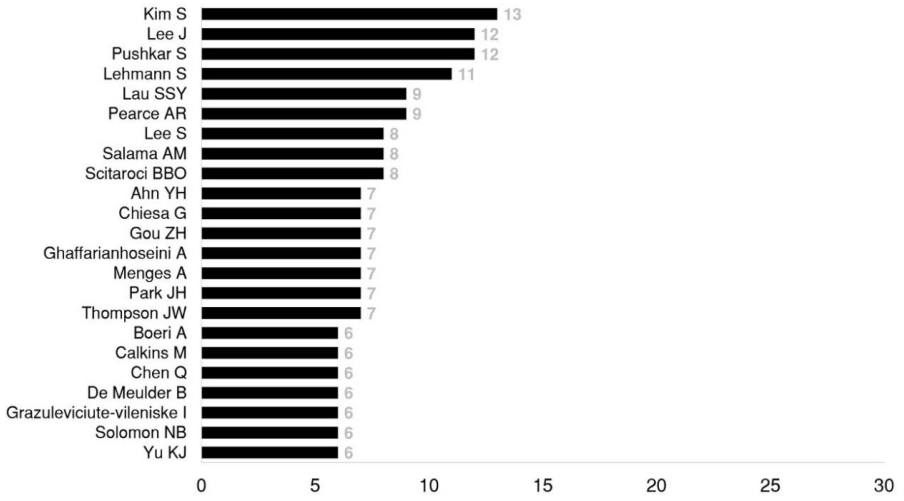

Figure 4. Number of publications by authors.

Number of publications of institutions: In terms of institutional distribution, the Polytechnic University of Milan is the most active institution, with 61 articles. This can be attributed to the fact that the Polytechnic University of Milan is a technical university with research opportunities in architecture and urban studies, architecture, built environment, and civil engineering. Following the Polytechnic University of Milan, Egyptian Knowledge Bank EKB, and Yıldız Technical University with 45 articles each, Polytechnic University Turin with 42 articles, and Sapienza University Rome with 41 articles are the other institutions contributing to the field (Figure 5). The top five institutions hosting the most publications are Italy, Egypt, and Turkey. It is noteworthy that no institution in the USA, the country with the highest number of

publications in this ranking, is included in the list in the last ranks (Figure 3). This can be explained by the fact that the USA hosts a large number of institutions or organizations in the relevant field. The number of publications in institutions and organizations may be related to the number of researchers employed in the institution, as well as the publication organs operating within them.

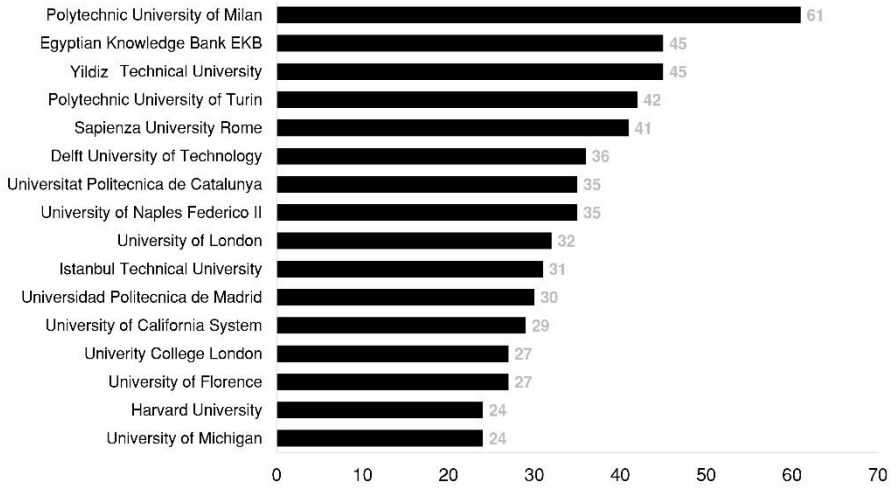

Figure 5. Distribution of publication numbers by institutions.

Number of publications of journals: When we look at the journals in which the studies were published, the Journal of Green Building ranks first with 490 articles, which includes sustainable built environment studies at the building, neighbourhood and urban scale, green building design policies and technological and innovative studies in the field. In addition, Open House International with 238 articles, Landscape Architecture Frontiers with 201 articles, and Techne Journal of Technology for Architecture and Environment with 195 articles are other journals that contribute to sustainable architecture (Figure 6). The number of sustainability-related publications in these publications is related to their tendency towards sustainability studies as well as their publication periods and the number of articles included in each issue. On the other hand, when the publishing houses or publishing institutions and organisations to which the publications are affiliated are taken into consideration, it is seen that the USA, the UK, China, Italy and Turkey stand out. There is a strong correlation between the countries hosting the most publications (Figure 3) and the publications that give the most space to sustainability-related publications.

Most cited publications: When we look at the most cited articles in sustainable architecture research, "Reinterpreting Sustainable Architecture: The Place of Technology," with 124 citations, the article discusses an interpretation of sustainable architecture within the technology framework. The article has been an important reference for other studies on the subject in these years when publications on sustainable architecture started to gain momentum.

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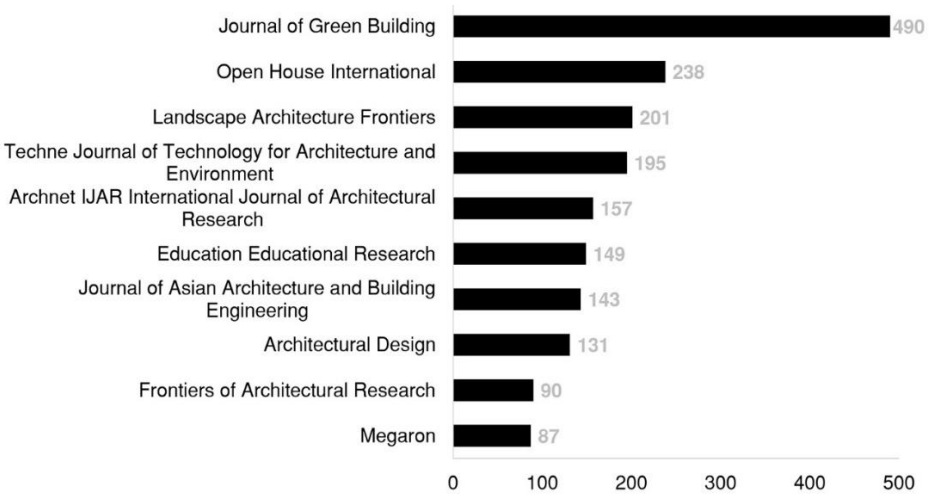

Figure 6. Distribution of publication numbers by journals.

Another most cited article is "A Bibliometric Review of Green Building Research 2000-2016", which presents a 16-year bibliography of green architecture studies. This article has received citations from studies on bibliometric analysis and green architecture. The article "Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. Buildings", which focuses on passive cooling strategies to ensure the energy efficiency of residential buildings, ranks third with 105 citations. It can be thought that the widespread use of energy efficiency studies, especially in the last seven years, has been effective in the number of citations (Table 1). When the publication dates of the most influential publications were evaluated, it was seen that the most influential publications were after 2010. Considering the relationship between prolific authors (Figure 4) and influential publications, Zhonghua Gou, who ranks 12th in terms of number of publications, ranks 4th in the list of influential publications. In addition, Amirhosein Ghaffarianhoseini, ranked 13th in terms of number of publications, is ranked 8th in the list of most influential publications. This shows that there is no direct proportional relationship between productivity and influential publications, while on the other hand, it is clear that there is no relationship between influential publications and publication year.

Looking at the indexes of the journals in which the studies were published, it was seen that 2023 articles were scanned in journals indexed in the Art & Humanities Citation Index (AHCI). This situation can be explained by the fact that the Art & Humanities Citation Index, which is an indexing type for arts and humanities, also covers the discipline of architecture. In addition, the fact that environmental problems are a problem of humanity also supports this situation. On the other hand, it was determined that 1385 articles were included in journals indexed in the Emerging Source Citation Index (ESCI), 300 articles in the Social Sciences Citation Index (SSCI), and 200 articles in Science Citation Index Expanded (SCI-Expanded).

Table 1. List of the most cited journals.

Article Name	Authors	Journal	Citations
Reinterpreting Sustainable Architecture: The Place of Technology	Guy and Farmer, 2001	Journal of Architectural Education	124
A Bibliometric Review of Green Building Research 2000-2016	Chao et al., 2019	Architectural Science Review	123
Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. Buildings	Taleb, 2014	Frontiers of Architectural Research	105
Market Readiness and Policy Implications for Green Buildings: Case Study from Hong Kong	Gou, Lau and Prasad, 2013	Journal of Green Building	87
From Low-energy to Net Zero-energy Buildings: Status and Perspectives	Voss, Musall and Lichtmeß, 2011	Journal of Green Building	84
Decentering the Human in the Design of Collaborative Cities	Forlano, 2016	Design Issues	73
Building Integrated Agriculture: Utilising Rooftops for Sustainable Food Crop Cultivation in Singapore	Astee and Kishnani, 2010	Journal of Green Building	72
Sick Building Syndrome: Are We Doing Enough?	Ghaffarianhosein et al., 2018	Architectural Science Review	70
Thermal Comfort Effects of Urban Design Strategies in High- rise Urban Environments in A Sub-tropical Climate	Yang, Lau and Qian, 2011	Architectural Science Review	68
Planning for multifunctional urban green infrastructures: Promises and challenges	Madureira and Andresen, 2014	Urban Design International	65

Science Mapping

The findings obtained at this stage consist of five maps: keyword relationships, chronological development and relationships of keywords, most cited author, most cited country and citation relationship between countries, and most cited journal and citation relationship between journals.

Keyword relationships: A co-occurrence network was created from the key terms in the sample using the VOSviewer software. The conceptual framework of sustainable architecture and the main concepts addressed in the field were revealed in the co-occurrence network. To increase the readability of the network map, the first 100 concepts related to the field with the highest threshold value of 10 were shown, represented by different colours in eight clusters. The concepts with higher connectivity strength were emphasized as the clusters' main concepts and represented by larger circles. The sub-concepts related to the main concepts were shown in circles scaled according to their frequency of use. Some sub-concepts did not appear on the map due to overlaps. The prominent cluster on the map was the purple-coloured "sustainability" cluster with a frequency of 177, which supports the centrality and inclusiveness of sustainability in environmental issues in architecture. The topic titles related to the cluster are read through the length of the connecting lines. Other main concepts that stand out in the field include urban design, energy efficiency, green building, landscape architecture, built environment, sustainable design, and sustainable

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development (Figure 7). Considering the distribution and grouping of keywords, it is evident that the concept and approach of sustainability discussed in architecture are addressed in a wide range.

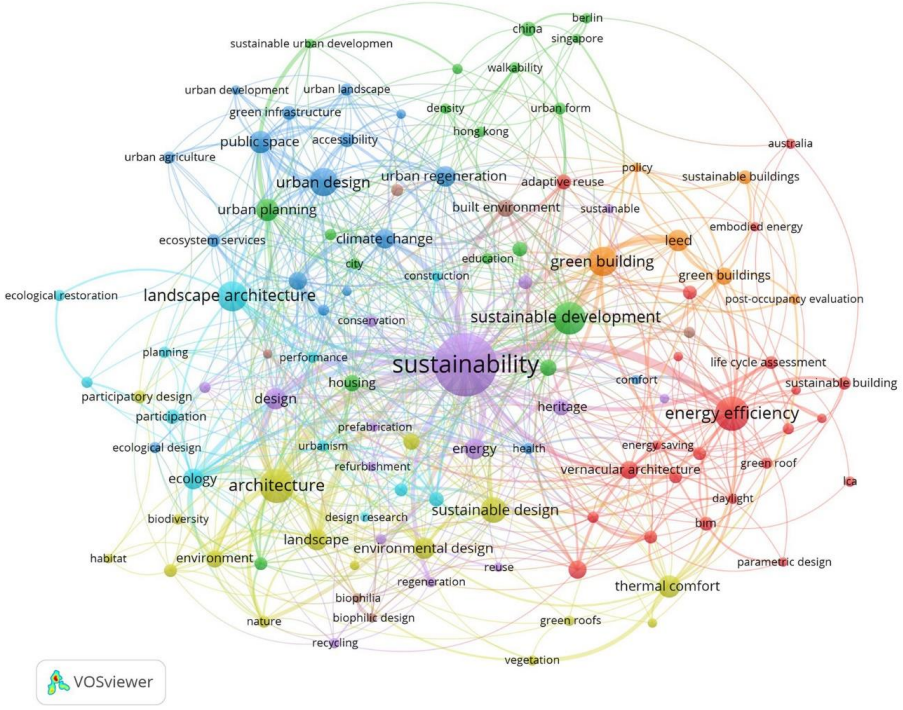

Figure 7. Keyword network visualization.

In the red cluster, energy efficiency is the main concept, with a frequency of 65. Keywords such as thermal comfort, daylight, energy consumption, and natural ventilation are used in energy efficiency studies, also associated with LEED and green building design. The orange cluster, with a frequency of 51, is focused on green building designs. Policies related to building design, post-occupancy evaluation, and environmental design are prominent concepts in articles using this keyword. Another prominent group is the green cluster, with a frequency of 60, which is related to sustainable development. In studies using this keyword, urban planning and building design are emphasized. Cultural heritage, reuse, walkability, and social and cultural sustainability are associated with sustainable development.

Meanwhile, in sustainable architecture, topics related to urban design and landscape architecture, expressed in dark blue and light blue clusters with frequencies of 32 and 31, respectively, are also prominent. Sustainable public space designs and ecology are emphasized in these clusters. The sustainable design cluster, represented by the yellow colour, is dominated by environmental design, comfort, and architecture. The brown cluster, with a frequency of 21, is related to the built environment and focuses on building envelope and environmental psychology (Figure 7).

Chronological development of keywords and their relationships: The chronological evolution of keywords is displayed on the map through colour and tone variations. The map is classified into four colour groups:

navy blue, turquoise, green, and yellow. Generally, it can be seen that changes and developments in the working areas are shaped within the framework of international agreements and various treaties that are common to United Nations or European Union member countries. In the early 2010s, studies related to sustainable environmental policies were conducted, focusing on environmentally friendly and long-lasting designs. In addition, the work during these years mainly highlighted the studies related to the LEED certification, which is very important in rating green buildings. The focus was primarily on the compliance of the identified structures with the criteria in the certification. In addition, studies on life cycle assessment were also among the topics focused on. Looking at the years between 2012-2016, it can be seen that the scope and boundaries of sustainability in the architectural discipline have expanded.

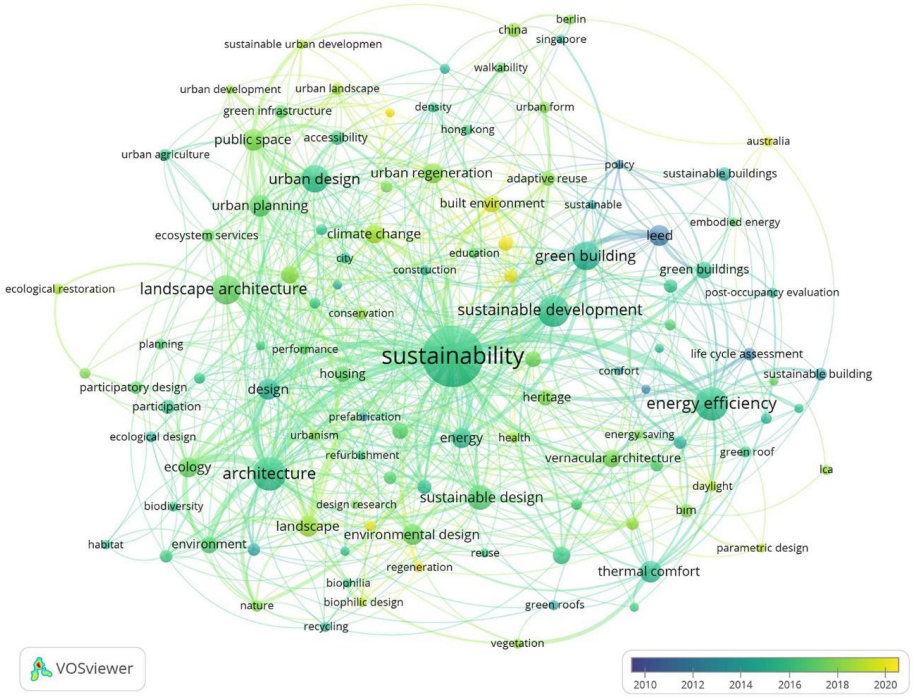

Figure 8. Chronological keyword network visualization.

Regarding subject trends, the sustainability approach in the architecture discipline has been addressed through green building, thermal comfort, natural lighting, water management, energy consumption, and sustainable development. Between 2016 and 2020, sustainable built environment studies focused on vernacular architecture, adaptive reuse, social sustainability, and climate change. Although interest in climate change, adaptive reuse, and social and cultural sustainability continues in current studies, the focus has shifted toward nature-based solutions and regeneration (Figure 8).

Most cited authors: When looking at the most cited authors (with a threshold value of at least 1 document and at least 100 citations) in sustainable architecture research, 17 researchers stand out. Zhonghua Gou is in first place with 7 studies and 257 citations. Amirhosein Ghaffarianhoseini comes in second place with 7 studies and 190 citations,

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while Ali Ghaffarianhoseini ranks third with 6 studies and 184 citations, and Jian Zuo is in fourth place with 4 studies and 175 citations (Figure 9). From this, it can be said that the work of Zhonghua Gou has a widespread impact on sustainable architecture research. On the other hand, when evaluating the citation status of researchers over time, it is possible to say that Xianbo Zhao, Can Huang, and Wu Guangdong's work has received more citations in recent years. This may be due to these researchers' analysis of the current state of their work and the inclusion of new data.

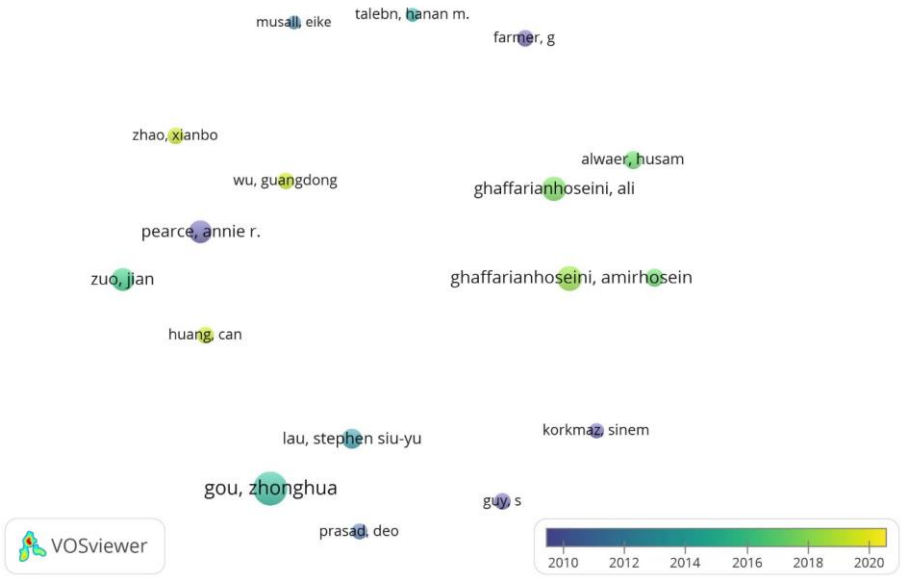

Figure 9. Most cited authors.

The most cited country and the relationship between countries: When looking at the network map of the most cited (threshold value of at least 5 documents and at least 10 citations) countries in sustainable architecture research, a total of 51 countries are included, with 46 countries shown to be interconnected. With 2912 citations, the USA is at the top as the most cited country (Figure 10). The USA mainly received citations from China, the UK, Canada, and Australia. Australia is in second place with 1377 citations, mainly receiving citations from China and the USA. On the other hand, the UK is in third place with a total of 1240 citations, mainly receiving citations from researchers in the USA. China is in fourth place with 1151 citations, mainly from the USA and Australia. From all of this, it can be said that the USA has a significant influence in this field. Furthermore, it is clear that the countries at the top are relatively more economically and technologically advanced and are, therefore, more active in this field. Considering the ranking of the countries with the highest number of publications (Figure 3), it is clear that publications in the UK and Australia have higher impact levels than Turkey and Italy.

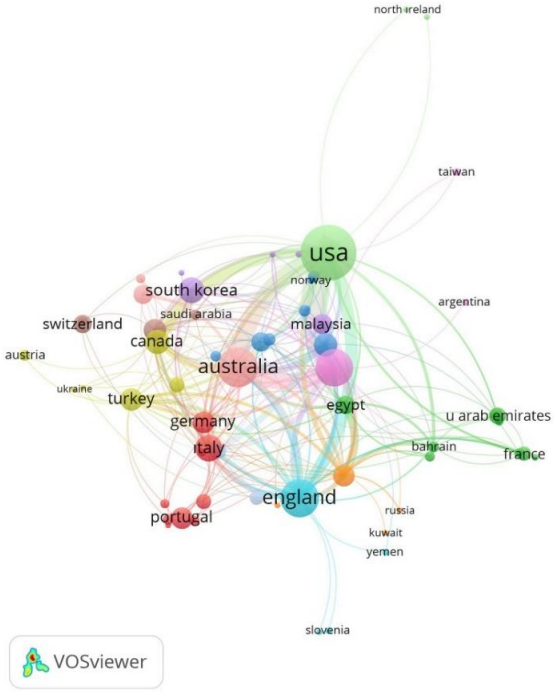

Figure 10. Most cited countries and citation. relations between

The most cited journal and the relationship between journals: When looking at the journals that have been most cited (at least 10 documents and at least 100 citations) from the database of article studies on sustainable architecture, the Journal of Green Building ranks first with 2608 citations. This shows that the Journal of Green Building is highly influential in the field of sustainable architecture, both in terms of hosting the most publications (Figure 6) and the citations it receives. The second most cited journal is the Architectural Science Review, with 1874 citations, followed by the Frontiers of Architectures, with 905 citations (Figure 11). The network relationship between the journals shows that the most citations are between these two journals. On the other hand, Architectural Science Review, which ranks second with the highest number of citations, is not among the journals with the highest number of publications (Figure 6) may be associated with the high impact values of the publications in this journal.

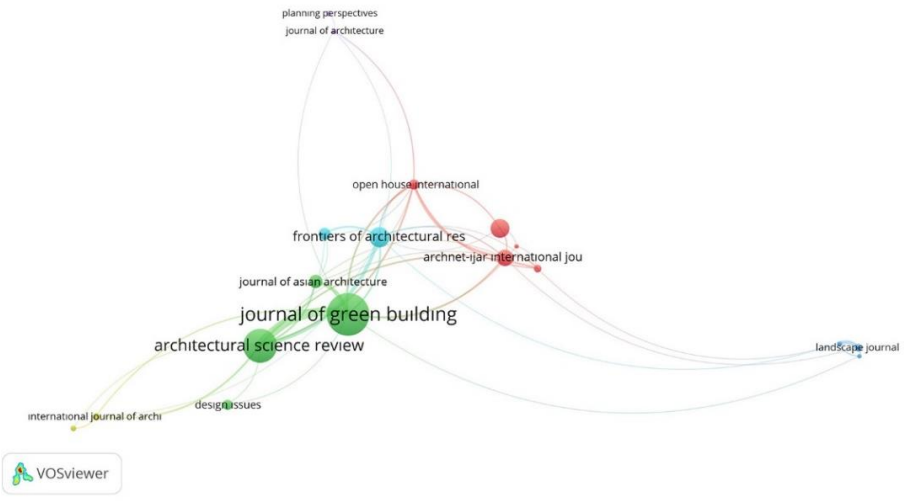

Figure 11. Citations relationship between the most cited journal and journals relations between countries.

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CONCLUSIONS AND RECOMMENDATIONS

Sustainable architectural research, which emerged with environmental problems, has been discussed around various research approaches and strategies, a wide conceptual framework, and various scales. In this study, the emergence, development, and current status of sustainable architectural research has been revealed by numerical and visual analysis. With the bibliometric analysis, which allows a comprehensive analysis and evaluation of a particular field of study, the findings related to the performance analysis of the field and science mapping were deciphered. In the performance analysis, numerical data were emphasized, and the distribution of the number of publications by years, countries, authors, institutions, journals, and indexes was discussed. Thus, prolific authors, the years in which the studies gained momentum, and the journals, indexes, and institutions that supported the subject were determined. In addition, numerical data on the most cited journal and article and the contents of qualified publications are emphasized. In science mapping, visual data is discussed. In this context, the relations between the keywords were deciphered to reveal the areas where the approaches related to the subject are concentrated and the course of development. In the light of the findings obtained from the performance analysis and science mapping regarding the bibliometric analysis, various evaluations, and suggestions are summarized below:

- This study contributes to the knowledge by presenting an overview of the studies on sustainable architecture that have emerged and developed within the scope of environmental problems and focus on various issues. From a theoretical perspective, it can provide ideas for the steps needed to understand the impact of sustainable architectural work on the amelioration of environmental problems and to identify actionable measures. In addition, it can be said that this study can contribute to developing new literature on sustainable architecture specific to environmental problems and the solution to possible future crises.
- The studies have particularly peaked in the last 5 years, and this development can be related to the 2030 Sustainable Development Goals adopted by the United Nations General Assembly in September 2015. At this General Assembly, which saw active participation from heads of state, UN representatives, numerous civil society organizations, and UNESCO from various countries, it is known that consensus was reached on various topics such as preventing climate change, energy, sustainable settlements, and cities. On the other hand, it can be said that the studies in the last few years have been shaped within the framework of the climate crisis and the COVID-19 global pandemic, focusing on the sustainability and adaptation of housing and the climate factor.
- Sunkuk Kim, Joohyun Lee, and Svetlana Pushkar stand out as the most published authors in this field. However, the work of any of

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these authors did not have a similar effect of regarding the number of citations. On the other hand, Zhonghua Gou, Amirhosein Ghaffarianhoseini, and Ali Ghaffarianhoseini, who were among the authors of the most cited articles in performance analysis, were also the most cited authors. This can be explained by the high level of influence of these authors in the literature.

- While countries such as the USA, Italy, Turkey, and China stand out with the number of publications, it is noteworthy that China, New Zealand, and Australia are in first place when the top four most cited authors are considered. Considering the number of publications and citations in performance analyses, it would not be wrong to say that China is influential in the literature.
- Country-based number of publications and country-based number of citations for performance analysis and science mapping were evaluated together. Accordingly, the fact that the USA is the most cited country is directly related to the number of publications. However, after the USA, the most cited publications originated from Australia and the UK. The fact that these countries, which come after Turkey and Italy in terms of the number of publications, rank first in terms of citations can be explained by the production of high-impact publications. In inter-country citation relations, which enable the evaluation of academic communication, it was observed that the USA interacted intensively with China, Australia, and the UK. In addition, China, another country that stands out in the number of publications and citations, has an intense interaction with Australia, which is evidence of the high impact level of Australian publications.
- It can be argued that the prominence of the United States of America in terms of the number of publications and citations is directly related to the productivity of researchers. On the other hand, China and Australia lead in publication impact levels according to the number of author citations. In this comparison, European countries can rank third.
- The fact that journals published in the United States of America and Europe predominantly include studies in this field shows the importance attributed to the subject. On the other hand, the fact that China and Australia host influential publications indicates that researchers from all over the world, from America to Europe and Asian countries, focus on this issue.
- Keyword analyses that provide insight into the research areas, methods used, and evolving approaches demonstrate the scope of the studies. In this regard, the terms "vernacular," which refers to rural local architectural productions, and "biophilic," which points to elements such as natural materials, ventilation, and lighting, are prominent in the chronological decipherment of keywords. Sustainable architecture approaches can be reduced to specific points, such as returning to nature and locality. On the other hand,

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terms such as "energy-efficient," "climate change," "housing," "building use," "design," "green architecture," "physical form of building," "greywater", "cities," and "urban environment," which were on the agenda in previous years, are relatively broad-perspective terms.

- This study will guide researchers or planners working on sustainable architecture in many aspects, such as trends, terminology, reference studies, and dominant research topics on sustainable architecture between 1975 and 2022. Moreover, this study provides a comprehensive perspective on the field by revealing the most effective works, authors, journals, countries, and their relationships, allowing for a comprehensive view of the sustainable architecture field for new studies.
- From a practical point of view, this study enables practitioners working on environmental problems to have an idea of the development of sustainable architecture. Thus, being aware of the different scales and approaches of the subject can help reduce the negative effects and consequences of environmental problems in various decision-making processes. The trends highlighted in this study have provided information on various strategic urban planning decisions, especially planning and infrastructure development, innovations in green building applications, trend-building technology, and material preferences in practice. It is thought that the research results will play an important role in transforming them into practical applications. On the other hand, the study contributed to educational materials and public awareness raising by raising awareness for educational practice.
- Enterprises, universities, researchers, publishing houses, politicians, and governments should work Decisively to balance better the relationship between the effectiveness and efficiency of various theories and practices developed within the scope of sustainable architecture for environmental problems.
- The limitations of this study may be guided in the planning of future studies. A few limitations can be mentioned in this context. The first is the research period (1975-September 2022), and the other is that the data obtained is limited to the WoS database. Therefore, future studies can be built on databases such as Scopus and Science Direct or a combination of these databases. In addition, the inadequacy of the keywords defined for the search in the database may have caused the inability to include sufficient articles on the subject. New studies can be planned with different keywords.

Finally, proposals for the solution of environmental problems such as global warming, increasing population, and rapid consumption of natural resources will continue to be the target and direction that researchers and politicians should strive to achieve in the future.

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