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Review Article

Investigating and Explaining the Components of the Green Movement Theory in Designing Green Facades for Third-Millennium Cities

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Abstract

Problem statement: The global need for environmental protection has propelled the green movement worldwide. An emerging management challenge for all organizations in third-millennium cities is to protect natural resources while reducing their negative environmental impact and increasing sustainable performance. Greening is needed in this era to preserve natural resources. Green architecture is examined and evaluated in light of the green movement that took place from the 1950s to 2010. Green architecture describes and evaluates the most relevant architectural projects that integrate the energy systems approach to reduce demand, provide renewable energy supply, and enable energy storage. Studies show that green architecture has evolved significantly and has been given different names depending on the interests or concerns of the time. It has progressed at varying rates depending on the technical, economic, environmental, and political drivers and barriers of each period.

Research objective: The main objective of this paper is to provide a brief review of the relationship between the parameters of the green movement and explain the relationship between architectural design and human health in third-millennium cities.

Research method: The research method adopted in this paper is the comparative study method, which focuses on the fundamental components of the green movement through the use of Bibliometrix and VOSviewer software to analyze and investigate 230 related published articles from 2008 to 2024, and infers the results in relation to thermal comfort.

Conclusion: The most important finding of this research is manifested in three components: thermal comfort, urban green space, and facade design. The main conclusion of this paper can be summarized and stated as devising green facade designs to increase green spaces based on thermal delight.

Keywords: *Green movement, Thermal comfort, Urban green facade, Architectural design, Third-millennium cities.*

Introduction

The dense urban environment increases the comfort of daily life and meets the diverse needs of citizens (Chan & Liu, 2018). However, while urban development in third-millennium cities has created immense economic and social value, it has also had undesirable effects: alienation of people from

nature, noisy and cramped work environments, increased environmental pollution, and fast-paced and stressful urban life that can lead to severe physical and mental fatigue and even a series of social problems (Fu & Xue, 2023). Evidence shows that connection with the natural environment can reduce the incidence of cardiovascular diseases, and greener environments have a more positive

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impact (Hu et al., 2022). On the other hand, urban sprawl leads to an increase in the urban population and a proliferation of construction in third-millennium cities. Similarly, problems such as local climate change hurt the urban heat island effect and human thermal comfort in outdoor spaces (Hami et al., 2019). Urbanization has increasingly drawn attention to thermal comfort in outdoor spaces (Zhang et al., 2020). Large cities experience severe urban heat island problems (Radhi & Sharples, 2013), which is related to the development and expansion of building areas (Ghaffarianhoseini et al., 2019). Buildings account for nearly 40% of global energy consumption, which has a significant impact on non-renewable resources and climate change (Zhang et al., 2020). Furthermore, humans spend more than 90% of their time indoors (Klepeis et al., 2001). Heating and air conditioning systems consume a considerable amount of energy in residential and commercial buildings (about 48%) (Ren & Chen, 2018). Although many studies have been conducted on climate change by adjusting energy consumption structures in buildings (Fabiani et al., 2019; Hwang et al., 2018), their effectiveness is still limited. Therefore, it becomes necessary to encourage people to increase their outdoor activities and shorten the time spent in air-conditioned environments. Given the urban heat island effect, outdoor thermal environments must become more pleasant (Huanget al., 2020; Waietal., 2020). Moreover, improved and delightful access spaces play a vital role in encouraging people to engage in outdoor activities in third-millennium city constructions (Zhang et al., 2020).

Research Questions

1. What are the main trends of the green movement in the research literature, in terms of definitions, terms, countries, and sources in the third millennium?
2. How has the green movement manifested itself in the development of third-millennium cities?

Research Method

• Data identification

This research reviewed and investigated 230 articles on the green movement in architecture published between 2008 and 2024. In this study, Bibliometrix¹ and VOSviewer software were used for bibliometric analysis. Considering the adoption of the comparative research method in this study, after setting the research questions, the next step is to search for documents in the official online database. In this study, the Web of Science database was searched for “title-abstract-keywords” using the keywords “architecture + green movement.” The search in the Web of Science database (on April 28, 2023) identified 230 potentially relevant articles from 97 different sources. The main sources of information are journals, conference proceedings, conferences, and books. The documents cover the period from 2008 to 2024. Fig. 1 contains important information about the identified data using the Bibliometrix software. Fig. 2 shows the prominent keywords and their frequency of occurrence in the selected articles.

• Data analysis

To answer the research question about the main trends of the green movement in the scientific literature, quantitative analysis was performed on the data. Specifically:

1. Co-occurrence of keywords was compared to identify main clusters and related links.



Fig. 1. Overview of main information obtained from Bibliometrix software regarding the green movement in architecture. Source: Authors.

2. Author origin was examined to understand the geographical distribution of manuscripts.
3. Sources of documents, such as major selected journals for publication, were identified.

Theoretical Background

Architecture, the art of designing and constructing buildings, has always been closely linked with the history of art. Not only because many public buildings, especially religious ones, were designed with aesthetics in mind and the services of a wide range of decorative artists and craftsmen but also because many of the exterior and interior facades of these buildings served as canvases for fine art paintings (Bassas et al., 2020). Therefore, most major art movements, such as the Renaissance, Baroque, Rococo, Neoclassicism, and Modernism, influenced architectural movements (Asefi, 2012). The term “green building movement” emerged to reflect social phenomena in 21st-century cities, and technically, the professions of architecture, engineering, and construction responded to the environmental impacts and resources of the built environment (Zhao et al., 2019). This movement advocates methods for creating structures and processes that are environmentally responsible and efficient over a building’s life cycle: design, construction, operation, maintenance, renovation, and demolition (Ahankoob et al., 2013; Kibert, 2016). Ultimately, this movement expanded building design techniques to address economic, functional, durability, and comfort

concerns. Geographically, the green movement spread from a few developed countries to the entire world (Zhao et al., 2019). This research, instead of focusing on art or aesthetics, concentrates on the practical aspect of architecture and its relationship with energy and technology because efforts to preserve the environment, conserve resources, and reduce the exploitation of natural reserves are vital for today’s world. The green movement around the world has led to the concept of green human resource management solutions (Martins et al., 2021). Excessive consumption, exploitation, and depletion of natural resources harm the greening of organizations (Islam et al., 2020). The birth of green architecture in the 20th century resulted from the return of environmental values in developed countries (Ragheb et al., 2016). Different movements have emerged, reflecting momentary concerns and awareness (Bassas et al., 2020). Environmental adaptation solutions are adopted in different parts of the world, but this trend is less common in developing countries (Martins et al., 2021). Many developing countries do not fully implement green practices across their different functional areas (Gupta, 2018). This is while advanced countries have transformed efforts for energy efficiency from the small scale of buildings to the urban scale. The green movement is an evolving phenomenon that has grown from rationalist and performance-based actions in response to specific environmental concerns to highly advanced ecological and systemic actions

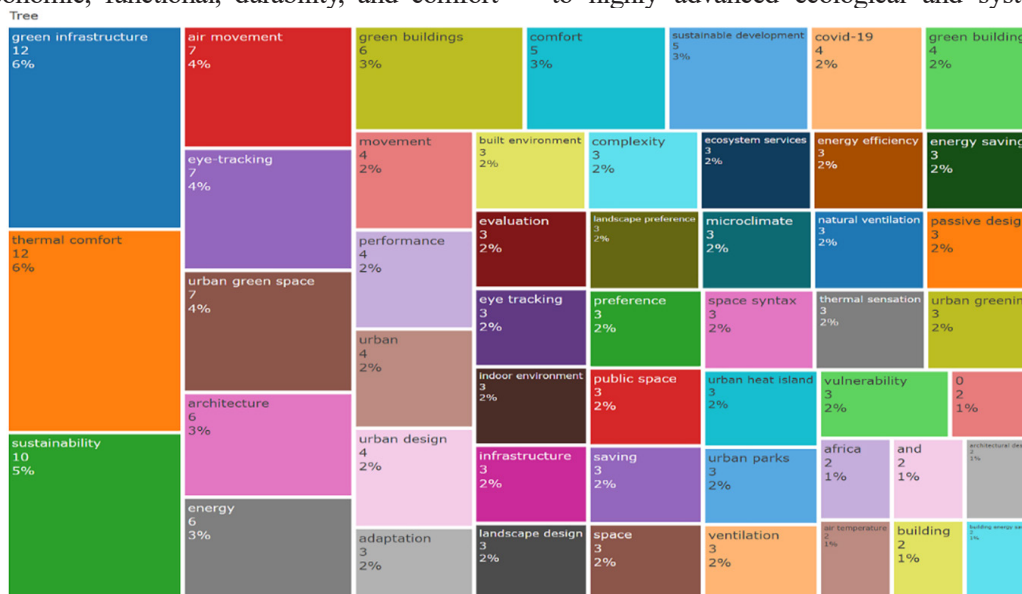


Fig. 2. Most prominent keywords obtained from Bibliometrix software regarding the green movement in architecture. Source: Authors.

aimed at influencing contemporary developed culture (Tabb & Deviren, 2017). A review of the American research literature indicates that research into improving building energy efficiency is now in its seventh decade of activity (*ibid.*). According to Tabb & Deviren (*ibid.*), green architecture became a major issue after the 1950s when European and North American architects began working in unusual tropical locations and became aware of the need to analyze their unfamiliar climate. Research history in Britain indicates that green architecture began two decades later in response to the oil crises of the mid-1970s (Jones, 2012; Wines & Jodidio, 2000).

Research and Findings

• Climate change and urban heat island²

The United Nations predicts that by 2030, 60% of the world's population will live in cities. Modern infrastructure and environmental conditions encourage people to move towards urbanization (Ahmadi et al., 2022). Climate change, the urban heat island effect, and air pollution may cause problems due to rapid growth and industrialization (Goharian et al., 2022). These challenges can directly impact residents' health and thermal comfort and increase demand for air conditioning (Zare et al., 2022). Increased air temperature not only affects outdoor thermal comfort but also increases the heat load on buildings (Wang et al., 2024).

- Cooling

Wang et al. (*ibid.*) propose four green, water-based cooling policies for urban environments: increasing green space accessible to citizens, greening vacant urban lands, promoting green building schemes in architecture, and enacting urban regulations in third-millennium cities.

- Ventilation

Urban morphology significantly impacts surface temperature. Lower surface roughness leads to increased wind speed and, consequently, reduced surface temperature (Wang et al., 2011). Research shows that when urban layouts exhibit a compact pattern, i.e., the urban compactness ratio exceeds 0.15, the intensity of the urban heat island effect becomes more pronounced (Zhao et al., 2016). Wang et al. (2024) propose designing

wind corridors at the city and regional scales at different levels to improve urban ventilation quality, resulting in an urban wind corridor system.

- Energy reduction and greenhouse gas emissions

In response to ongoing climate change, the government is actively promoting the building energy efficiency rating system to assess energy consumption and building benefits and encourage carbon reduction in building design. Furthermore, they are encouraging new building projects to obtain green building labels, increase the proportion of renewable energy in buildings, reduce reliance on conventional energy sources, and further reduce the carbon footprint of buildings (Wang et al., 2024).

• Green infrastructure design for thermal comfort

The increasing uneven development of cities and built environments in third-millennium cities is disrupting the thermal balance and thermal comfort of residents. The geometry and morphology of urban neighborhoods, the orientation and distribution of green spaces, and the mass and space can improve thermal comfort conditions in micro-neighborhood climates (Ahmadi et al., 2022). Recently, numerous studies on thermal comfort in urban parks have been conducted, primarily focusing on thermal perception, thermal criteria, and thermal environment optimization in different regions (Xu et al., 2019). A year-round questionnaire survey in Hong Kong showed that the 1-hour acceptable temperature range is a more accurate method for assessing outdoor thermal comfort than the transient acceptable temperature range (Cheung & Jim, 2019). Xiong et al. (2020) indicated that thermal comfort could be improved by increasing water coverage, reducing building coverage, and optimizing tree coverage. Furthermore, some studies have focused on thermal comfort concerning specific individuals' temperatures (Huang et al., 2021; Ma et al., 2021), surface materials (Bozdogan Sert et al., 2021), and landscape planning and design in urban parks (Adiguzel et al., 2022).

- Design of public squares with green infrastructure for human thermal comfort optimization

Individuals living in third-millennium cities experience summer heat stress conditions with severe health implications, especially under climate change. Urban

planning should address this issue by focusing on areas where people are exposed to heat, such as public squares (Zölch et al., 2019). Various concepts have been proposed to adapt urban structures to severe heat, including modifying the built environment, increasing the share of vegetation cover, or increasing surface material albedo³ (Bowler et al., 2010; Norton et al., 2015; Taleghani et al., 2015). Blue and green spaces have received particular attention as urban green infrastructure due to their potential for urban climate regulation through shading and evapotranspiration and their multifunctionality in simultaneously providing various ecosystem services (Zölch et al., 2016). Zölch et al. (2019) presented a new green design aiming to optimize thermal conditions in both time stages by demonstrating the importance of open lawns for better wind flow and less heat storage, at least for nighttime cooling. Additionally, it added deeper insights into the spatial configuration of these elements (especially depending on wind direction and shading) and quantified differences between the layouts of different scenario designs (Saito et al., 2017).

- Thermal comfort in urban green spaces for health

Gender, age, socioeconomic status, income, religious beliefs, and other factors significantly influence the frequency of individuals entering green spaces for physical activity (Ord et al., 2013). Accessibility (Wang et al., 2019), walking (Kessel et al., 2009), Infrastructure (Schetke et al., 2016), park area (Larsons et al., 2016), and landscape quality (Wang et al., 2019) are objective environmental factors that affect physical activity in the built environment in urban parks. Green space features, such as green space shape (Rodiek, 2008) and landscape diversity (Wen et al., 2018), significantly impact physical activity frequency and psychological perception. However, few studies have focused on the interrelationship between thermal comfort and physical activity in urban green spaces in third-millennium cities (Niu et al., 2022). The thermal comfort of green spaces is one of the most critical factors influencing people's activities (Zeren Cetin & Sevik, 2020). A thermally comfortable environment can reduce individuals' thermal discomfort and heat stress in outdoor spaces. This encourages people to visit green spaces for physical

activity and gathering, improving physical and mental health (Niu et al., 2022).

- Duration of presence in green spaces based on thermal comfort

Thermal comfort in urban green spaces is a major factor attracting people to physical activity (Lai et al., 2014). Microclimate conditions in parks, such as air temperature, relative humidity, wind speed, and solar radiation, can significantly impact people's comfort and behavior (Manavvi & Rajasekar, 2021). The duration of outdoor activity is also significantly related to the sensation of heat, and people spend more time outside when they are within an acceptable thermal range (Thorsson et al., 2007). In terms of activity types, Sharifi & Boland (2018) found that when the thermal environment of green spaces in Australia exceeds the neutral threshold, residents' activities in outdoor spaces change from optional to necessary activities. In summary, the physical factors of green spaces and thermal perception affect the level of presence, duration, and types of outdoor activities.

• Cooling effect of vegetation cover

The environmental quality of urban spaces can have positive or negative effects on the quality of life and physical health of the residents (Perini et al., 2018). In the design of third-millennium urban spaces, three factors – spatial morphology, orientation of elements and spaces, and vegetation cover – are highly important and affect the level of thermal comfort (Yahia & Johansson, 2014). Various urban forms have emerged in third-millennium cities, each of which, by altering the duration of direct solar radiation and average radiant temperature, has different effects on the urban microclimate (Taleghani et al., 2015). The greatest increase in heat in urban environments occurs in spaces where surfaces absorb more impervious materials, where vegetation cover and overall shaded areas are lower (Hertel & Schlink, 2019).

- Thermal behavior of green facades in a warm climate

Population growth necessitates an increase in the construction of buildings and streets whose materials significantly absorb heat, and in response, vegetation cover emerges as a vital

element for improving indoor and outdoor environments (Báez-García et al., 2024). Therefore, the development of environmentally friendly construction methods is the result of the modern ecosystem’s increasing awareness of concerns such as global warming, environmental deterioration, and the destruction of the urban environment (Sharbafian et al., 2024).

• **Current trends in green movement applications: A bibliometric analysis by VOSviewer software**

In this paper, following the various stages defined in the methodology, a bibliometric analysis was conducted to identify current trends in the international scientific literature regarding the green movement in architecture. Then, a quantitative bibliometric analysis was performed on the data. Each map is depicted by nodes (or bubbles) connected by lines. The size of the nodes (or bubbles) indicates the frequency of occurrence or citations, while the lines indicate the connection between two co-occurring keywords, creating a network map. The distance between two nodes represents the relation between them. The closer the nodes are to each other, the stronger their relation is. (Fig. 3).

Based on Fig. 3, three main components – thermal

comfort, urban green space, and design – were identified for thermal design in green movement architecture (Fig. 4), and according to the node sizes, thermal comfort has a higher frequency of occurrence compared to other nodes.

Based on the word frequency over time graph obtained from the bibliometrix software (Fig. 5), thermal comfort has received increasing attention from researchers since 2016. Therefore, this study focuses on analyzing thermal comfort items.

According to Fig. 6, China ranks first, followed by the United States and England, as the countries with the most activity in this topic.

Fig. 7 summarizes all the previous information and describes the relationship between keywords, countries, and journals. The height of the rectangular nodes is proportional to the frequency of keywords, a country, and a journal in the common network, while the width of the lines between the nodes varies with the number of different links (Wang et al., 2022). The results show that the codification of third-millennium cities in China, the United States, and England, as well as Sweden, Korea, and Germany, have the most links with the green movement and architecture. China has the largest share

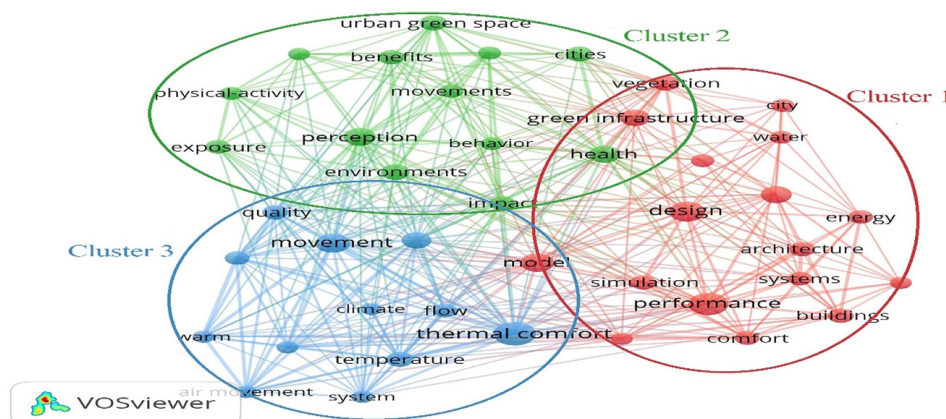


Fig. 3. Network visualization of co-occurring keywords. Node size indicates the frequency of occurrence, and lines between nodes indicate the co-occurrence of two keywords. Distance between nodes represents the relation between two keywords. Identification of three main clusters: Cluster 1 (red): 17 items related to the design topic. Cluster 2 (green): 13 items related to urban green space. Cluster 3 (blue): 12 items related to thermal comfort. Created by VOSviewer software. Source: Authors.

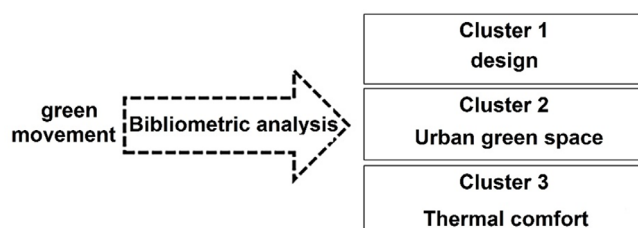


Fig. 4. Components of the green movement based on bibliometric analysis; Source: Authors.

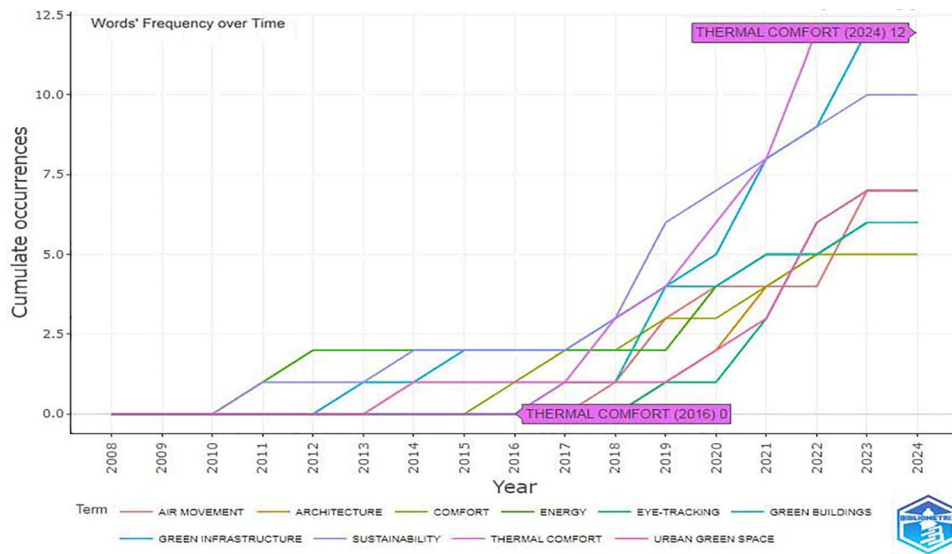


Fig. 5. Word frequency over time obtained from bibliometrix software. Source: Authors.

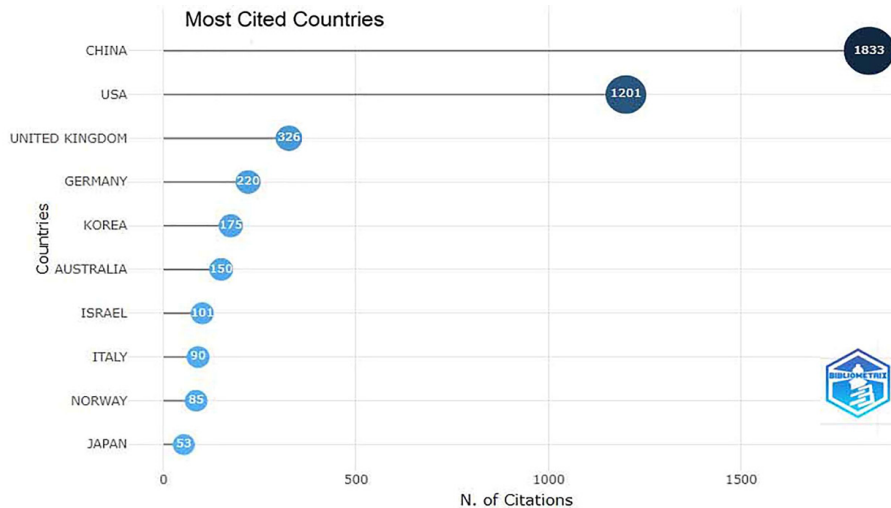


Fig. 6. Countries with high references taken from bibilometrix software. Source: Authors.

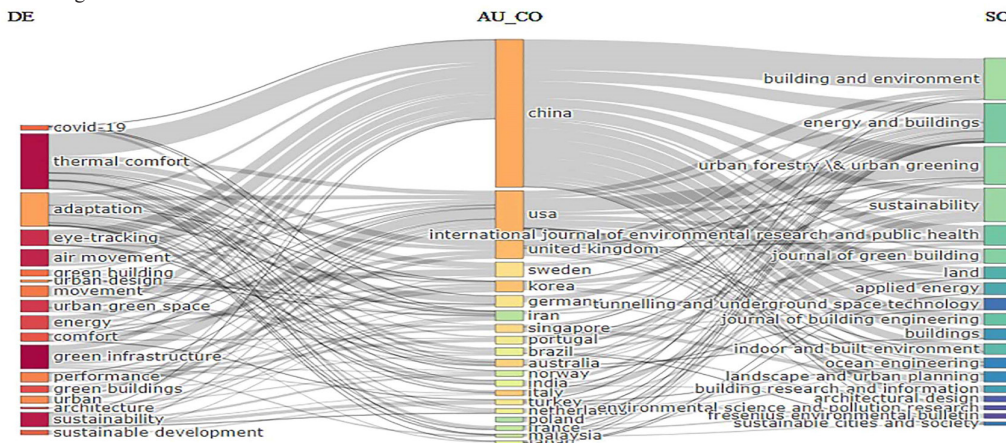


Fig. 7. Keywords (left), countries (center), and sources (right). The height of the rectangles indicates frequency. The thickness of the lines is proportional to the number of links. Generated by the Bibliometrix software. Source: Authors.

in “Building and Environment” and “Urban Forestry and Urban Greening,” while the United States contributes more to “Urban Forestry and Urban Greening.” The bibliometric analysis conducted in the present study

analyzes and measures the scientific literature data using a quantitative research method, which provides an opportunity for discussion about the advantages:

- The analysis of the source of publication allows

researchers to identify the most important journals in this field based on the number of published documents. In this way, researchers can not only stay up-to-date with the latest research but also identify the places where most research is published and target their future participation accordingly (Sommese et al., 2023).

- Identifying the common interaction between keywords in each cluster showed the relationship between different topics in the literature. Understanding these relationships can reveal opportunities for collaborations and new research directions to achieve the goals of the green movement.

- When analyzing the geographical location, it was found that documents from China and the United States received the highest number of citations. This means that these countries are specifically active and involved in research in this field, and the results of their research have a significant impact on the scientific community. Additionally, clustering information improves the understanding of international collaboration among experts.

Overall, the results of the bibliometric analysis conducted in this study provide an overview of international collaborations, the importance of research, and the impact of citations. Researchers can use this information to identify potential partners for collaboration and understand the leading countries in the field of the green movement. Additionally, the present analysis can highlight areas in need of further research and create opportunities for new research collaborations.

Based on Fig. 7, most studies have been conducted on thermal comfort, which, according to Fig. 5, has attracted researchers' attention since 2016 and has seen the highest growth until 2024. Based on Fig. 3, at the intersection of the three clusters, thermal comfort is linked to the urban green space cluster through the keyword "health" and to the design cluster through the keywords "green infrastructure" and "model".

Conclusion

Protecting natural resources and taking preventive measures against environmental degradation is one of the pillars of global management in third-millennium

cities. Considering the position of the green movement theory in scientific and professional discussions of architecture and urban planning in the third millennium, which has established its value in human minds with sustainability approaches, green design, eco-friendliness, and attention to ecosystems, the present study, utilizing internationally published academic documents and through the application of research-facilitating software from around the world, examines and elucidates the components of the green movement theory in the codification (design, planning, and implementation) of third-millennium cities. The most important feature of this article is the use of time-limiting options for high-impact scientific publications and the search keyword "green movement" in the Bibliometrix and VOSviewer software for screening and classifying information. This accelerating approach, while introducing study indicators based on precise analysis, suggests studying important scientific documents and highly cited articles. The scientific findings and the main conclusion of the research have been derived based on this process. In this study, three components: thermal comfort, urban green space, and design are presented as the main concerns of researchers in architecture and urban planning sciences in explaining the position of the green movement in the codification of third-millennium cities. On the one hand, climate change and the formation of urban heat islands are among the major environmental threats affecting human and other living beings' health. On the other hand, the attention of architecture and urban planning thinkers to the design of green infrastructures aims to provide suitable solutions for providing and optimizing thermal comfort in the environment by reducing energy consumption and greenhouse gas emissions. Considering the analysis of scientific documents in this paper, the most important result of this article can be considered the strategy and design of urban green facades to increase urban open green spaces based on providing thermal comfort through vegetation cooling, increasing the duration of presence, and improving the health of living beings, especially humans. In a nutshell, considering the exorbitant costs of providing thermal comfort in enclosed architectural spaces and its adverse

effects on global warming and consequently widespread environmental impacts, it can be concluded that by focusing on the design and inclusion of green spaces in urban areas, which is a vital aspect of environmentally friendly design, thermal comfort can be provided for the long-term presence of citizens in third-millennium cities. Therefore, the design of green facades as a cooling cover and increasing greenery to prevent urban heat islands in third-millennium cities is recommended. With an emphasis on the issue of remote working, the use of internet networks, and individual occupational activities without the need for extensive office spaces, the need for human social interactions, the tendency of humans to be present in open spaces rather than enclosed and confined spaces, etc., this strategy can be suitable for regions with hot and dry environmental conditions.

Conflict of Interest

The authors declare that there was no conflict for them in conducting this research.

Endnotes

1. Bibliometrix is an open-source software with open access, used by Aria and Cuccurullo (Aria & Cuccurullo, 2017) for conducting comprehensive quantitative research analysis and science mapping of the current literature on a defined subject.
2. The urban heat island effect is a phenomenon caused by changes in the balance of the built environment and thermal properties (Ahmadi et al., 2022). Additionally, wind speed, cloud cover, season, city size and population, and time of day affect the intensity of the urban heat island effect (Norouzi et al., 2021).
3. Albedo, refers to the percentage of light reflected from the surface of an object. The values of this quantity can range from zero (absolute darkness) to one (absolute brightness). Albedo is sometimes expressed as a percentage and sometimes as a decimal fraction less than one.

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