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Research Progress and Trends of Green Buildings in China, 2006-2023

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Abstract

China has made notable strides in green building research; however, there remains a need for a comprehensive and systematic analysis. This study leverages data from 2,088 core journals published between 2006 and 2023 as its primary source. Utilizing tools like Excel and Cite Space, it conducts a meticulous examination of content trends, the current state of the industry, and stage characteristics. The objective is to discern growth trajectories and emerging areas, providing guidance for future research endeavors.

Keywords

Green Building; Green Building Technology; Data Visualization.

1. Introduction

In recent decades, the escalating energy consumption in structures due to rising living standards and populations has necessitated the promotion of green buildings to achieve rapid energy conservation and emission reduction targets. Additionally, it is an essential strategy for China to address global energy crises. As a nation experiencing accelerated urbanization, China initiated the promotion of green buildings in 2006, leading to the establishment of the "China Green Building Samsung Certification" green building certification system. In just seven years, more than 3,000 projects have obtained LEED certification and China Green Building Label certification. By 2023, the energy efficiency levels of new buildings in China's urban areas had increased by 20% compared to 2015, with the proportion of green building areas in new urban construction exceeding 50% [1, 2].

This study employs a literature review methodology to assess the evolution and advancement of research fields associated with green buildings. It utilizes data collection, citation space analysis, and bibliometric analysis to identify the primary sources within these fields.

2. Current Status of Green Building Research

2.1 Trends in the Number of Studies

Since China's entry into an aging society in 2000, there has been continuous refinement in the design methods and support services for elderly living and activities. This has led to the emergence of several social problems related to urban elderly care, including issues such as traffic congestion, limited public service resources, and pollution. Consequently, it is vital to consider and evaluate the potential value of suburban elderly care.

The number of articles on green building has exhibited a steady increase from 2006 to 2013. This upward trend was largely stimulated by the introduction of the national standard "Green Building Evaluation Standards" in 2006. The peak in the number of articles occurred in 2014, with a total of 190 articles. However, from 2014 to 2016, the focus shifted towards green building initiatives [3]. The "Green Building Action Plan" emphasized the prioritization of new construction and energy-efficient renovations of existing buildings, with a goal to construct a total of 1 billion square meters of green buildings during the "Twelfth Five-Year Plan" period. Subsequent to 2016, green building

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research entered a stable phase, accompanied by a corresponding decrease in the number of articles. The introduction of the "Green Renovation Evaluation Standards for Existing Buildings" and policy adjustments redirected research towards assembly-based green buildings, which had an impact on the number of related articles [4].

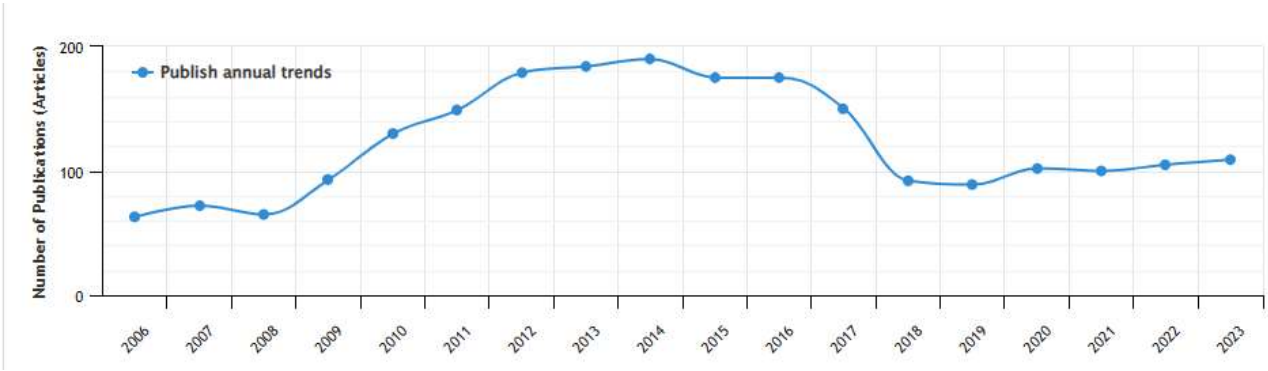

Fig.1 Trend of the number of publications on green building in core journals of Knowledge Networks

2.2 Authors of Literature

Core authors play a leading role in disciplinary research, and the number and influence of papers are large. Price's theory $N = 0.747(N_{max})^{1/2,}$ it is calculated that the number of papers must be greater than N to be called core authors [5]. In the field of green building, $N_{max} = 15$, that is, more than 3 articles are core authors. In the domestic core journal literature, there are 40 authors who have published more than 3 articles and 285 papers, accounting for 13.2% of the total number of papers. Compared with Prime's law of 50%, the gap is large, indicating that the domestic green building has not yet formed a strong core author group in 2023.

2.3 Geographical Distribution Characteristics

The Chinese government has exhibited unwavering commitment to the promotion of green/low-carbon buildings, with considerable advancements made through research conducted by prominent institutions such as universities and academies. Over the past fifteen years, Chongqing, Tongji, Xi'an, the China Academy of Building Sciences, and Tsinghua University have produced a significant number of peer-reviewed publications contributing to the field. However, it is noteworthy that, from 2014-2016, emerging centers of research activity, such as Tianjin, South China, Nanjing, Southeast, and Harbin, began to play a more significant role in the research landscape. From 2017-2023, the research performance of Shandong University of Architecture and Architecture, Beijing Jiaotong University, the China Urban Science Research Association, Peking University, and Tianjin Urban Construction University has eclipsed their predecessors, establishing themselves as the key centers of research activity [6].

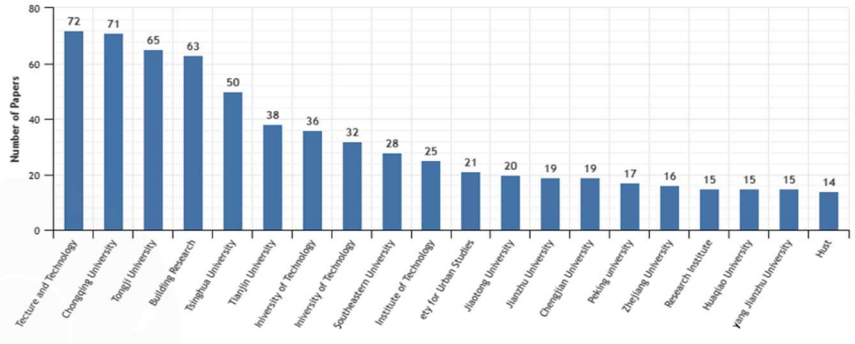

Fig.2 Statistics on the number of core author documents

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Fig.3 Distribution of core author units

In addition to the academic achievements of individual institutions, research collaboration has been instrumental in the advancement of green building theory. Indeed, the scientific backing of research institutions is an essential component in facilitating the progress of green building theory. However, it is vital that the financial support required to sustain these initiatives is not overlooked. The annual growth rate of China's green building initiatives has exceeded 300%, demonstrating the remarkable pace at which these initiatives have advanced and refined the application of green building theory in practice.

2.4 Research Areas

China strongly supports the application and promotion of green building design, and promotes scientific exploration in the field of green building technology. The Ministry of Housing and Urban-Rural Development and the Ministry of Science and Technology implemented the key project of "Green Building Key Technology Research" in the "Tenth Five-Year Plan", forming the first "Green Building Technology Guidelines" in China [7]. The key project of "Modern Building Design and Construction Key Technology Research" during the "Eleventh Five-Year Plan" period includes two major areas of green building research. During the "Twelfth Five-Year Plan" period, green buildings were regarded as a priority theme and development focus in the field of urbanization and urban development, forming seven aspects of the topic.

Gui Zhigang and others analyzed keywords through Cite Space software and concluded that the hotspots of green building research from 2000 to 2018 include sustainable development, library architecture, water conservation, environmental protection, design, energy consumption, green construction, indoor environmental quality, and BIM. A search of 2088 core journals with green building as the theme word and keyword on green building found that green building was the main field of research from 2006 to 2023, followed by green building design and technology. In the period 2017-2023, green building research is gradually carried out under multi-disciplinary interdisciplinary [8,9].

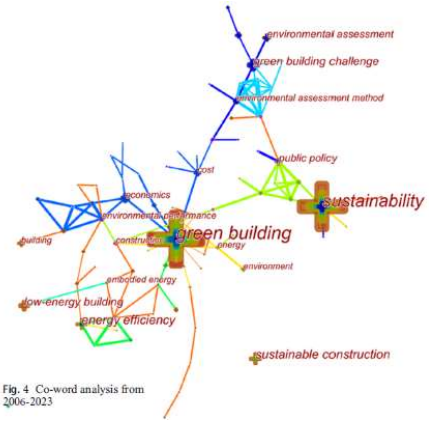

Fig.4 China's green building research priorities from 2006 to 2023

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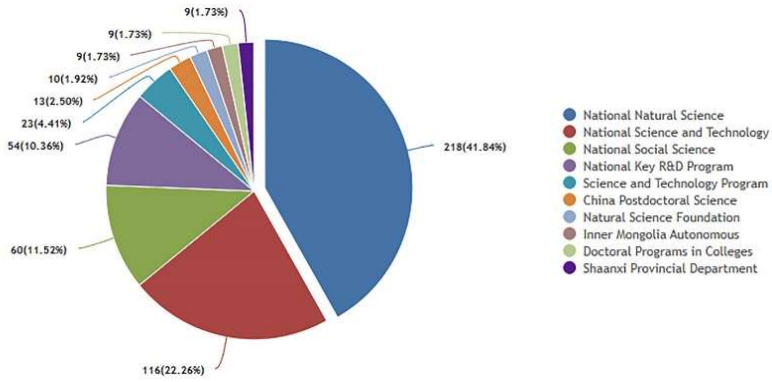

Fig.5 Distribution of green building research funds in China, 2006-2023

2.5 Research Areas

The trend analysis of green building publications in China from 2006 to 2023 reveals a fluctuating trend, with an overall upward trend until 2016. However, the subsequent three years exhibited a plateau in the number of publications, culminating in a significant decline from 2017-2023. This trend could be attributed to the significant increase in support for green buildings after the introduction of the "Green Building Evaluation Standards" in 2006, particularly during the 11th Five-Year Plan and 12th Five-Year Plan [10].

Significantly, the nature of project funding also shows a trend towards national-level project funds since 2006-2023. The majority of these funds are directed towards natural science research, with less emphasis on social science research. This suggests that the domestic research community prioritizes fundamental research, while maintaining a keen interest in the contribution of green buildings to social development.

3. Changes in Research Trends

3.1 Evolutionary Characteristics of the Study Area

From 2006 to 2013, green building research predominantly focused on green building evaluation and building energy conservation. For instance, Qin Youguo scrutinized China's green building evaluation system, Li Zhaojian delved into building energy consumption, and Qiu Baoxing advocated for the development of low-carbon eco-cities. From 2014 to 2016, research shifted towards green renovation of existing buildings and the utilization of underground space. Liu Kaiying streamlined the green building design process, and Qi Baoku demonstrated the application of Building Information Modeling (BIM) technology in the comprehensive life cycle management of prefabricated buildings. From 2017 to 2023, research expanded to encompass post-use evaluation, heat recovery, and other aspects, transitioning towards green credit, green transformation, etc. Yu Yanjie examined the rainwater design of green buildings rooted in the concept of sponge city, and Gao Caifeng evaluated the technical economy of near-zero energy public buildings. In recent years, traditional research has matured, and it is anticipated that computational design, BIM technology, etc. will be integrated with emerging fields. Given the public's emphasis on health, safety, and human settlements, the evolution of green buildings is anticipated to further progress [11].

3.2 Changes in Research Methodology

From 2006 to 2013, China's green building research primarily focused on providing qualitative characterizations of these structures. However, beginning in 2014, there has been a significant transition towards the utilization of mathematical statistics, mathematical models, and environmental simulations, paving the way for more precise analyses. By 2016, the integration of parametric technologies, including Building Information Modeling (BIM) and Grasshopper technology, had been progressively implemented, significantly enhancing the accuracy and efficiency of the evaluation process. The evaluation standards and methodologies employed by China during this

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period experienced the most substantial transformation, transitioning from a primarily qualitative, manual, and simplistic system to a more quantitative, comprehensive, and software-based methodology. This transformation more accurately reflects the scientific evaluation of the building's impact on resources and the environment, enhances the scientific rigor of the evaluation, significantly enhances the efficiency of the building evaluation process, reduces the costs associated with review and consultation, is responsive to market needs, and provides scientifically informed and valuable recommendations for both owners and projects. The diversification of research methods, as the research continues to deepen, has led to the application of interdisciplinary methods in the research of green buildings. This trend is expected to persist into the years 2017-2023 [12,13].

4. Conclusion

4.1 Summary

First, through statistical analysis of journals, authors, institutions, and other perspectives, we have a preliminary understanding and understanding of the overview of green building research. Then, we will sort out the main themes and transformations in the historical process of green building research, and show the changes and development trends of green building research fields, research methods, and core author groups in China over the past 17 years. Summarize them and draw the following revelations [14]:

1) The green building certification mechanism needs to be improved

On the one hand, China's existing green building certification is one-off and lacks tracking of the actual emission reduction and energy saving after the completion of green buildings. On the other hand, China's green building standard system needs to be further improved. Although the system has been revised and improved many times, there are still some problems. For example, the green building evaluation standards in some provinces fail to fully integrate local environmental, economic, social and cultural factors, or are lower than national standards.

2) Green building research and development technology needs to be broken through

Compared with Western developed countries, China has a relatively short history of development in green building energy conservation and emission reduction technologies. At present, China's strength in green building research and development technology is relatively weak, its mastery of environmental protection materials and renewable energy technologies is relatively low, and its dependence on foreign green building materials and energy conservation and emission reduction equipment is relatively high. Therefore, China's green buildings have a higher cost increase.

3) Green building research and development technology needs to be broken through

As the concept and scope of green buildings continue to evolve and technological innovations persistently emerge, there is a growing demand for green buildings in engineering practice. However, the adoption of these green building principles faces challenges due to constraints within management processes, such as the development and approval of national and industry standards. The "ready-to-use" nature of these standards, along with the specific technical regulations they contain, frequently lags behind the dynamic evolution of the field. It is important to note that standards alone are insufficient for delineating the boundaries of green building practices. Additionally, while these standards aim to maintain harmonization, some degree of content duplication is inevitable. [15].

4.2 Future Directions

In addressing domestic challenges and issues in green building research, we outline future directions and prospects for green buildings in China:

1) Prioritizing Green Design for Enhanced Construction Industry Stability

The integration of "Internet+" technology into green building design is poised to reduce construction costs and environmental impact. This trend suggests that the future of green building design in China will be characterized by "informatization+ greening."

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2) Promoting Regional Green Development

Chinese cities striving for 100% compliance with green building standards in new construction projects are catalyzing the comprehensive expansion of regional green industries. This approach broadens the scope of green building applications to encompass "green ecological urban areas." It entails promoting green building development, optimizing urban spatial layouts, adopting resource-efficient urban operations, implementing low-carbon transportation systems, and enhancing ecological systems to achieve regional green development.

3) Ensuring Adaptation of the Standard System

Green building standards play a pivotal role in enhancing building quality, optimizing the market, and fostering green development. They facilitate the transformation of the industrial chain, expedite the integration of ecological considerations, and provide a solid foundation for green development.

4) Transitioning to Sustainable Evaluation of Green Buildings

While China's green buildings have traditionally prioritized energy efficiency in their design, escalating improvement costs and growing concerns regarding carbon emissions across the entire building lifecycle necessitate a shift in focus toward addressing "hidden carbon." This includes emissions associated with materials, transportation, construction, maintenance, disposal stages, and other factors. It is essential to develop coordinated carbon reduction strategies that encompass buildings, industry, electricity, and transportation systems to meet ambitious carbon reduction targets.

These forward-looking initiatives and perspectives highlight China's commitment to advancing the green building sector, ensuring its alignment with contemporary environmental and sustainability goals.

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