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Visualized Analysis of Research Progress on Green and Low-Carbon Buildings in China Based on CiteSpace

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Abstract: ***To systematically review the research progress of green and low-carbon buildings in China, a bibliometric analysis was conducted on 4,739 documents from the CNKI and Web of Science (WOS) databases spanning the period 2001–2025. Using analyses of publication trends, collaborative networks of core authors and institutions, keyword co-occurrence and burst detection, and keyword clustering, this study yielded the following findings: The number of publications in this field shows a rapid growth trend, yet a core group of authors has not yet formed, and there is a lack of in-depth collaboration among key institutions. Keywords with high betweenness include "energy", "concrete", and "barriers". The burst strength of keywords reveals that current research hotspots in green and low-carbon buildings focus on user behavior, comfort, and low-carbon materials. Keyword clustering results indicate that, at the present stage, the integration of active and passive technologies driven by such technologies as artificial intelligence and digital twins, along with the application of high-performance low-carbon materials, constitute the main research directions in the field of green and low-carbon buildings. Future research should address the existing issue of emphasizing design over operation, promote interdisciplinary collaboration, and attach importance to the supervision of building operation data.***

Keywords: Green building, CiteSpace, Visualization, Low-carbon, Development**.**

1. Introduction

According to the China Statistical Yearbook, China's urbanization rate of permanent residents surged from 36% to 67% between 2000 and 2024 [1], meaning over two-thirds of the population now resides in cities or towns. This rapid urbanization has triggered a substantial increase in energy consumption within the construction industry, shifting the nation's energy focus towards the building and transportation sectors [2]. Statistics from the China Building Energy Efficiency Association (2025) indicate that the construction industry accounts for 22.8% of the country's total energy consumption and a striking 48.3% of its energy-related carbon emissions [3]. This disparity is noteworthy when compared to global figures. State of the Global Construction Industry Report（2024-2025）shows that while the global construction industry consumes 32% of total energy and generates 34% of carbon emissions [4], China's construction sector, despite a lower energy share, contributes a disproportionately higher share of emissions.

This context underscores the critical importance of low-carbon development in construction for achieving China's "dual carbon" goals-carbon peak by 2030 and carbon neutrality by 2060 [5]. Although significant research progress has been made in areas like building energy efficiency and low-carbon materials over the past 20 years, a comprehensive analysis of the research landscape is needed to identify persistent challenges and future directions. Therefore, this paper employs CiteSpace software to analyze and visualize relevant literature from 2001 to 2025 (as of April 30, 2025) [6]. It aims to explore key research foci and emerging trends, analyze implementation challenges, and propose insights for advancing sustainable construction under the "dual carbon" framework.

2. Research Methods

The data sources selected for this study comprise academic journals from the China National Knowledge Infrastructure (CNKI) database and SCIE sources from the Web of Science (WOS) database. The CNKI database was configured with the following themes: 'Zero-Carbon Buildings', 'Low-Carbon Buildings', 'Green Buildings', 'Passive Buildings', 'Low-Energy Buildings', 'Zero-Energy Buildings', and 'Prefabricated Buildings'. The timeframe spans from 2001 to 2025, yielding a total of 3,602 relevant articles. After excluding policy documents, news reports, conference proceedings, and similar materials, and removing duplicates, 2,948 valid data points were identified. The WOS database search terms were 'Zero-carbon building', 'Low-Carbon Building', 'Green Building', 'Passive House', 'Low-Energy Building', 'Zero Energy Building', and 'Prefabricated Building'. The document type was selected as 'Article', with the country set to PEOPLES R CHINA. This yielded 1,794 documents, which were deduplicated to produce 1,791 valid entries. The final sample consisted of 4,739 valid documents. Although 2025 data were included in the analysis of research hotspots (as some journals had already published articles for that year), they were excluded from the analysis of annual publication trends to avoid incomplete representation of the year.

This study quantifies publication volumes from authors and institutions across dimensions including publishing organizations, authors, and relevant keywords, employing annual time slices for analysis. This yields collaborative networks of core authors and research institutions. Keyword co-occurrence and emergence reveal primary research content and hotspots, while cluster analysis combined with literature review stages elucidates developmental phases across different research periods.

3. Results and Analysis

3.1 Number of Published Articles

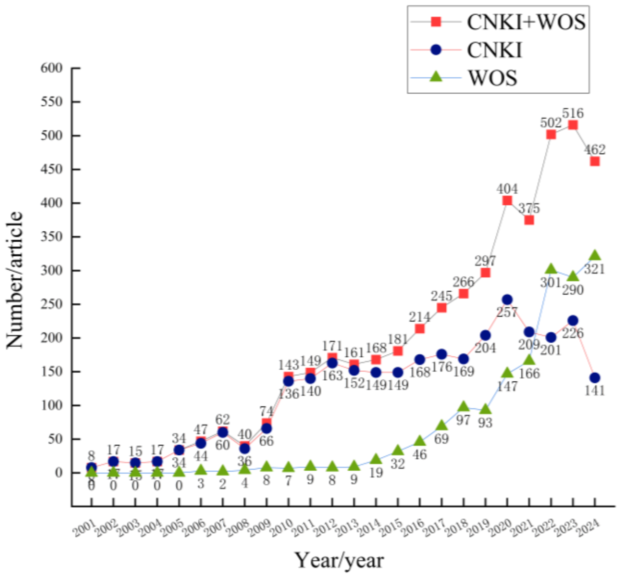

Figure 1: Changes in the Number of Published Papers (2001-2025)

From 2001 to 2009, the total number of publications in both Chinese and English remained below one hundred. Between 2010 and 2019, publication volumes surged significantly, with 2019 seeing an increase of 154 papers compared to 2010. The largest annual increase occurred between 2019 and the present year, amounting to 219 additional papers, as illustrated in Figure 1. The rapid growth after 2020 indicates that green and low-carbon building development has attracted significant attention from the Chinese academic community.

3.2 Analysis of Core Authors

Core author analysis enables rapid identification of authoritative scholars within a field. Calculating core author groups and conducting collaboration network analysis facilitates the identification of academic schools and interdisciplinary collaboration within the domain. Price's Law is frequently employed to determine whether a research core author group has formed within a field. Statistical analysis of data from 2001 to 2024 indicates that Xu Wei, the most prolific author, has published 58 papers across CNKI and WOS. Applying Price's Law formula: M≈0.749(Nmax)1/2, authors with over six publications are identified as core authors, as shown in Table 1. Approximately 154 core authors were identified, constituting 1.25% of the total 12,260 authors. After excluding instances where multiple core authors appeared in the same article, the core authors published 961 papers, accounting for approximately 20.28% (<50%) of the total valid data of 4,739 papers. This indicates that a core author group has not yet formed.

Table 1: Core Authors and Their Research Fields (Top 15, 2001-2024)

Number	Quantity	Author	Research Fields
1	59	Xu Wei	Building Science and Engineering; Highway and Waterway Transportation
2	32	Zhang Shicong	Building Science and Engineering; New Energy Resources; Environmental Science and Resource Utilization
3	25	Sun Yongjun	Building Science and Engineering; Thermodynamics; Energy and Fuels
4	25	Lin Borong	Building Science and Engineering; Computer Software and Computer Applications; Environmental Science and Resource Utilization
5	23	Pan Wei	Building Science and Engineering; Environmental Science and Ecology; Energy and Fuels
6	23	Yu Zhen	Building Science and Engineering; Computer Software and Computer Applications; Power Engineering
7	22	Wang Qingqin	Building Science and Engineering; Computer Software and Computer Applications; Environmental Science and Resource Utilization
8	22	Feng Guohui	Building Science and Engineering; Environmental Science and Resource Utilization; Power Engineering
9	19	Wang, Wei	Building Science and Engineering; Materials Science; Environmental Science and Ecology; Computer Science; Chemistry
10	19	Darko, Amos	Building Science and Engineering; Environmental Science and Ecology; Business and Economics
11	19	Wu Zezhou	Environmental Science and Ecology; Materials Science
12	19	Liu Jiaping	Building Science and Engineering; Inorganic Chemical Engineering; Chemistry
13	19	Liu Meng	Building Science and Engineering; Power Engineering; Environmental Science and Resource Utilization
14	17	Gou Zhonghua	Building Science and Engineering; Environmental Science and Ecology; Energy and Fuels
15	17	Chen Wei	Building Science and Engineering

Based on the number of core authors as well as the number of publications, the author cooperation relationship was analyzed by the g-exponential function (k = 25), and the top 4 most connected and active components were obtained to make a high-productivity authors' cooperation mapping, due to the difference of author names in Chinese and English literature, the largest two components are connected, but there is no connecting line to show that, see Figure 2. The node size indicates that Xu Wei, Zhang Shicong, Sun Yongjun, Lin Borong, and Pan Wei are among the most published scholars annually. Based on Table 1 and Figure 2, we found that the high-yield authors cooperate with each other more closely, and their research fields are more concentrated, although most of the other scholars also have cooperative relationships with each other, but they still have not formed a core group of authors, so we should strengthen the communication and cooperation between different groups of authors and different disciplines in the future.

3.3 Analysis by Research Institutions

Analysis of research institutions and their collaborations can reveal the advantages and differentiation of institutional research, identify the status of cross-institutional cooperation, and help understand the technological integration situation in the industry. Match the English names and Chinese names of institutions in the WOS database, integrate the contributing institutions and their affiliated units, and use the g-index function to obtain the collaboration map of research institutions in the field related to green and low-carbon buildings, as shown in Figure 3.

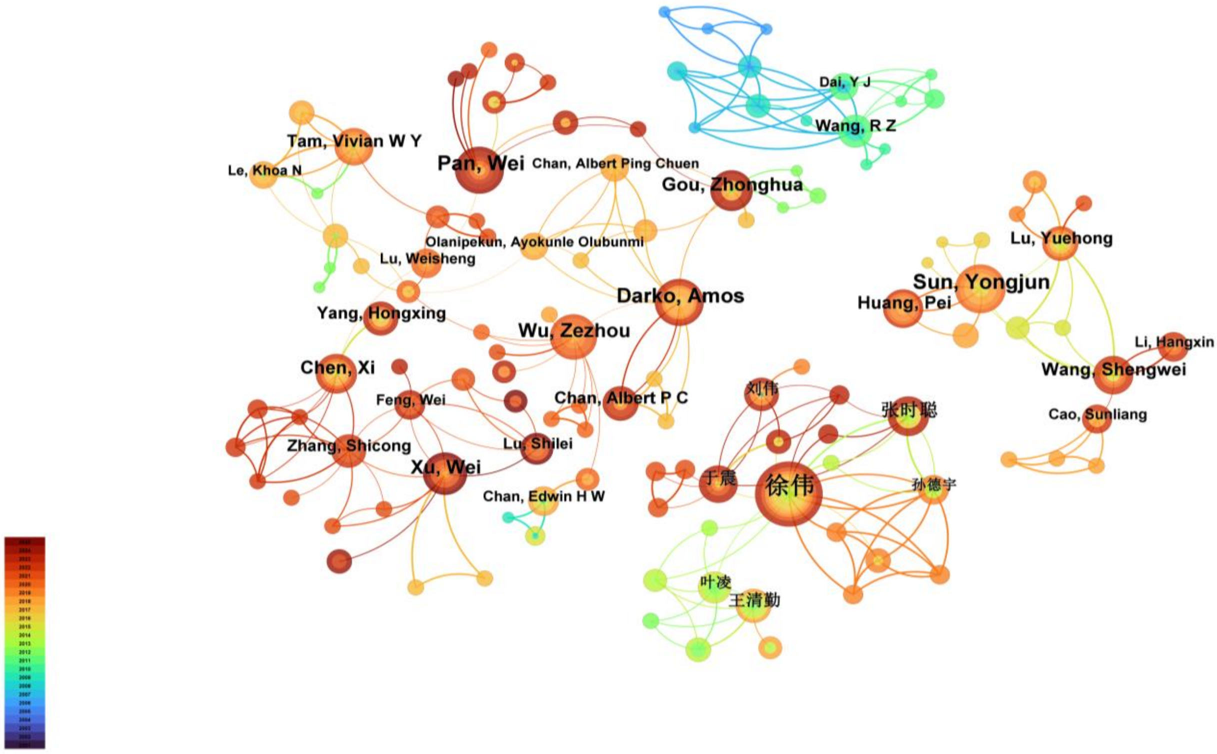

Figure 2: Collaboration Network of Authors (2001-2025)

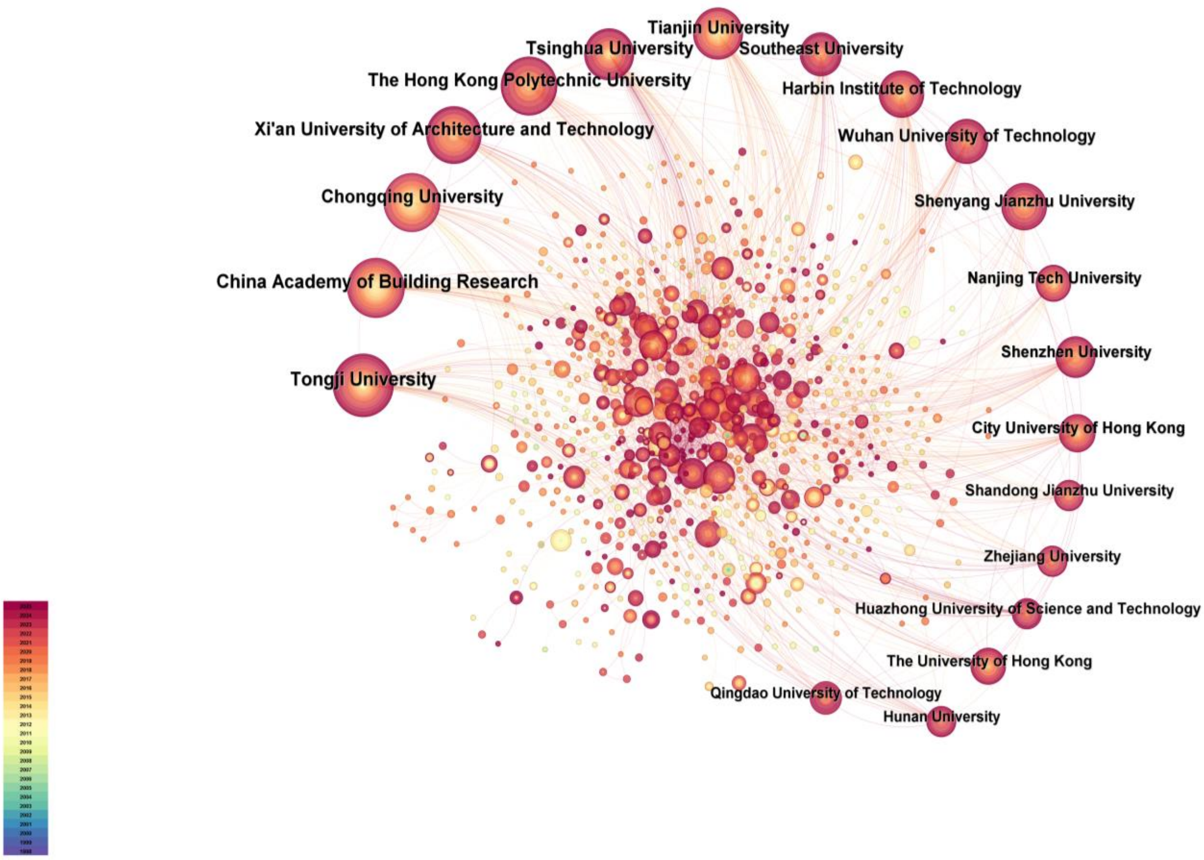

Figure 3: Collaboration Network of Research Institutions (2001-2025)

As can be seen from Figure 3, according to the size of nodes, Tongji University, China Academy of Building Research, Chongqing University, and Xi'an University of Architecture and Technology are the core research forces with the most prominent contributions in this field. Combined with literature reading, it is known that Tongji University focuses on the construction of indicator systems and building energy-saving design; Chongqing University pays more attention to green building evaluation, building energy-saving technologies, and carbon emissions; China Academy of Building Research takes green building evaluation, building energy conservation, and residential buildings as its main research objectives; Xi'an University of Architecture and Technology concentrates its research on green building design. The connecting lines between nodes reveal a cooperation model centered on universities or research institutes. However, collaboration between core institutions remains limited, preventing effective integration of their strengths.

Table 2: Research Institutions by Number of Publications (Top 15, 2001-2025)

Number	Quantity	Institution Name	Location
1	175	Tongji University	Shanghai
2	160	Chongqing University	Chongqing
3	157	China Academy of Building Research	Beijing
4	155	Xi'an University of Architecture and Technology	Xi'an
5	132	The Hong Kong Polytechnic University	Hong Kong
6	129	Tsinghua University	Beijing
7	122	Tianjin University	Tianjin
8	107	Southeast University	Nanjing
9	96	Harbin Institute of Technology	Harbin
10	91	Wuhan University of Technology	Wuhan
11	86	Shenyang Jianzhu University	Shenyang
12	75	Nanjing Tech University	Nanjing
13	70	Shenzhen University	Shenzhen
14	67	City University of Hong Kong	Hong Kong
15	58	Shandong Jianzhu University	Jinan

Table 2 lists the top 15 research institutions in terms of the number of publications in the field of green and low carbonization of buildings, indicating that Tsinghua University, Southeast University, Tianjin University, Tongji University, Harbin Institute of Technology, Chongqing University, and Xi'an University of Architecture and Technology are the backbone of research on the green and low carbonization of buildings, as the development of the architectural disciplines of these universities has been developed earlier and their strengths are strong.

According to the location of the institutions, the regional ranking of the number of research institutions in the field of green and low carbonization of buildings is counted (Table 3), of which Beijing has 48 research institutions, indicating that the talent reserve and resource investment in the region provide a good foundation for the development of scientific research, Shanghai, Guangdong and Jiangsu have more than 10 research institutions, and the rest of the regions, such as Hunan and Sichuan, have different numbers of research institutions, which indicates that the development of building green and low carbonization has received widespread attention nationwide.

Table 3: Regional Ranking of the Number of Research Institutions (2001-2025)

Number	Region	Number of Institutions	Number	Region	Number of Institutions
1	Beijing	48	17	Fujian	7
2	Shanghai	37	18	Jilin	6
3	Guangdong	31	19	Heilongjiang	6
4	Jiangsu	26	20	Anhui	5
5	Tianjin	18	21	Gansu	5
6	Hubei	15	22	Yunnan	4
7	Shaanxi	13	23	Shanxi	4
8	Zhejiang	12	24	Jiangxi	4
9	Shandong	11	25	Guangxi	3
10	Chongqing	10	26	Xinjiang	3
11	Hunan	9	27	Inner Mongolia	3
12	Sichuan	9	28	Macao	3
13	Liaoning	8	29	Ningxia	2
14	Hebei	8	30	Hainan	2
15	Hong Kong	8	31	Guizhou	1
16	Henan	7			

3.4 Keyword Co-occurrence Analysis

Table 4 shows that the highest frequency of keywords is "green building", with a frequency as high as 1,028 times, and other high-frequency words such as "performance", "design", "construction", etc. indicate that under the requirements of the strategy for the transformation and development of the building industry, the green and low-carbonization of buildings requires joint efforts from design to operation of the whole life cycle, The other high-frequency words "performance", "design", "construction", etc. indicate that under the requirements of the transformation and development strategy of the construction industry, the green and low-carbon building needs to make joint efforts from design to operation of the whole life cycle, and through the simulation operation of the building design, we can understand the actual operational performance of the design scheme, and seek for the optimal solution of the passive energy-saving design, and at the same time, combine with active optimization technology of the energy consumption of the building, so as to achieve the sustainable development of the construction industry. Achieve sustainable development of the construction industry. In addition, the optimization of construction management plays an important role in resource utilization, dust reduction, noise reduction and cost optimization, which is an inevitable requirement for green development. Centrality is a measure of the importance of the node network, reflecting the probability of co-occurrence with other keywords, and key nodes are generally nodes with centrality greater than 0.1. As shown in Table 4, the centrality of "green building", "energy", "concrete" and "barrier" are all greater than 0.1, indicating that the centrality of these keywords is higher than 0.1. The centrality of "green building" is ranked first, indicating that it is the cornerstone of the transformation of the whole construction industry and the main line of the industry's evolution. "Energy" ranks second in terms of centrality, with a frequency of only 107, which is not a high frequency, but is a cross-sectoral link. The evolution of energy in buildings began in 2008, when China was promoting the use of solar buildings, and the subsequent digitalization provided powerful tools and instruments that pushed energy research towards multidisciplinary integration. Nowadays, research on decarbonization of energy, such as BIPV and regional energy networks, is at the heart of the future transformation of the energy system. [7] “Concrete” ranks third in centrality, the only high centrality building materials keyword, and is one of the main sources of implied carbon emissions [8], The high-frequency keyword with strong relevance is “mechanical properties”, which first appeared in the context of overcapacity in the cement industry in 2012, and the relevant standards put forward mandatory requirements for green building materials to promote the transformation of high-performance and low-carbon concrete. “Barriers” is ranked fourth in terms of centrality and is a key node connecting multiple development bottlenecks. It first appeared in 2015 when green buildings were promoted on a large scale under digital empowerment, indicating that there are multiple barriers to the transformation of the construction industry in terms of economy, technology and social awareness.

Table 4: Keyword Co-occurrence (2001-2025)

Number	Frequency	Centrality	First Appearance Year	Keyword
1	1028	0.21	2002	Green Building
2	336	0.04	2001	Performance
3	228	0.05	2006	Design
4	202	0.05	2006	Construction
5	202	0.07	2008	System
6	184	0.05	2009	Model
7	147	0.02	2006	Management
8	127	0.04	2012	Optimization
9	114	0.08	2003	Energy Conservation
10	113	0.01	2011	Impact
11	107	0.12	2008	Energy
12	106	0.09	2007	Simulation
13	97	0.05	2014	Behavior
14	96	0.11	2015	Barrier
15	95	0.04	2005	Building
16	92	0.05	2004	Building Energy Conservation
17	92	0.03	2014	Mechanical Properties
18	88	0.01	2010	Low-Carbon Building
19	87	0.04	2009	Sustainability
20	85	0.12	2012	Concrete

3.5 Keyword Emergence Analysis

Keyword bursts can indicate an active timeline for that type of research. The sudden activity of the research indicates that the research has made breakthroughs or received widespread attention, and analyzing the keyword occurrences can help to identify the research frontiers. As can be seen from the keyword emergence (Figure 4), the top five in terms of emergence intensity are “green building”, “green construction”, “energy saving”, “low-carbon economy”, “building energy efficiency”, “low carbon economy”, “green building”, “green construction”, and “low carbon economy”. According to the timeline of emergence, 2016 is a key year for the research shift, “Green building”, “building energy efficiency”, and “green construction” all came to an end around 2016, indicating that the industry is no longer focusing only on the energy and water saving indicators of green building itself, but is gradually focusing on the whole life cycle of the building. It shows that the industry is no longer focusing only on the energy saving and water saving indicators of green buildings, but is gradually paying attention to the operation of the whole life cycle of buildings, seeking solutions to the problem of more design labels and fewer operation labels through the research of “evaluation standards” and “indicator system”. at the same time, it pays more attention to urban ecology and low-carbon development, forming a more systematic research system for sustainable development of buildings, and the release of the Green Building Evaluation Standard (GB/T 50378-2019) is a sufficient proof of this shift. The low-carbon development of buildings is later than the green development, the earliest attention in 2008, related to the development of “solar energy”, accompanied by photovoltaic technology advances, cost reductions, photovoltaic integration of the launch of the building energy consumption to further reduce, so that low-carbon operation of the building becomes possible, but due to the problem of solar energy conversion efficiency, did not really promote the low-carbon transformation of buildings. Currently, under the constraints of the new standards, previously unappreciated comfort issues such as ventilation, user energy behavior and low-carbon materials research have become a research hotspot in recent years.

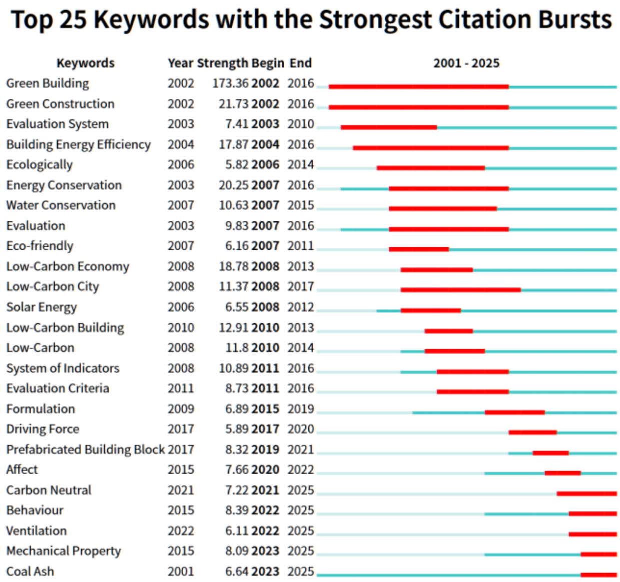

Figure 4: Keyword Burst Detection Graph (2001-2025)

3.6 Keyword Clustering Analysis

Combining the changes in the number of articles and the emergence of keywords, the research development can be divided into four phases: the start-up phase in 2001-2009, the comprehensive promotion phase in 2010-2014, the full-life-cycle transformation phase in 2015-2019, and the “dual-carbon” target-driven phase in 2020-present. Keyword clustering analysis can help researchers quickly understand the main body of the research field, research hotspots, and track changes in research topics. The smaller the number of labels in the cluster diagram, the more keywords are included in the cluster [9]. In order to sort out the research themes of each stage and explore the future development direction, the four stages were analyzed by keyword clustering.

Figure 5: Keyword Clustering Graph (2001-2009)

As can be seen from the clustering figure 5 for the first phase, the first three numbers are “green building”, “countermeasures” and “Energy conservation”. This stage is the embryonic period of basic technology exploration and policy framework centred on “green building”. In terms of policies and standards, in 2002, the Ministry of Construction officially issued the Administrative Regulations on Building Energy Efficiency, which marked the shift of green buildings from concept to practice. The policy characteristics of this period were based on administrative mandates, supported by technical guidelines, and focused on basic energy-saving areas such as building envelope insulation and heating system efficiency; in 2006, the Ministry of Construction released the pilot version of Green Building Assessment Standard (GB/T 50378-2006), which systematically defined the concept of green building; in 2007, the Three-Star Green Building Assessment System was formally implemented. With the “four energy-saving aspects and one environmental protection aspect” (energy conservation, land conservation, water conservation, material conservation, and environmental protection) as basic constraints, it realized guidance for technical routes. At the technical level, the core focus of this phase is to solve the practical problem of “how to build green buildings”. The practice of green building is explored through the establishment of different types of demonstration projects covering schools, residences, office buildings, etc. On the energy side, the use of renewable energy sources such as solar energy and ground-source heat pumps is taken as the main breakthrough, and the study on the integration of energy systems is shifted from energy saving to energy conservation in buildings; on the energy-saving side, thermal insulation systems are promoted in the envelope, and the use of polystyrene panels (EPS), extruded plastic panels (XPS), etc., is adopted to improve the thermal insulation performance of buildings, reduce the energy demand for winter heating, and reduce the energy demand for heating in winter.

At this stage, green buildings are regarded as high-cost, high-technology demonstration projects, with insufficient market impetus, relying on policy subsidies and land grant concessions, while exposing their high incremental costs, complex processes, and technological fragmentation.

Figure 6: Keyword Clustering Graph (2010-2014)

As can be seen from the clustering figure 6 in the second stage, the first three numbers are “green building”, “green construction” and “low-carbon building”. This indicates that the concept of low carbon has been widely promoted and integrated in the construction field, and the green building evaluation system and standards have been further improved. In terms of policies and standards, the Building Energy Efficiency Design Standard (JGJ 26-2010) proposed new standards for envelope structures and energy efficiency; in 2011, the “Twelfth Five-Year Plan” for the first time explicitly proposed that "the construction industry should promote green buildings and green construction", which brought green building into the national strategic level; in 2012, the Building Lighting Design Standard (GB/T 50033-2013) strengthened the requirements of the window-to-ground ratio, and the lighting of the building is gradually moving towards standardised governance; and in 2014, the Green Building Evaluation Standard (GB/T 50378-2014) was promulgated, with the addition of new indicators such as construction management, innovation, etc., and the lighting is also included in the certification system. The introduction and implementation of new policies and standards have made the development of green building from demonstration to full promotion, and from standard exploration to mandatory specification. On the technical level, assembly construction has risen rapidly to become the core of building industrialization, and lighting design technology has made breakthrough progress. Standardized production and assembly construction effectively reduce energy consumption, save consumables and shorten the construction period, while the low-carbon concept is integrated into the transformation and development of the construction industry, and building energy efficiency and transportation and energy systems form a linkage carbon reduction system; the first professional lighting software "DALI2014" passed the assessment of the Ministry of Housing and Construction, which has significantly improved the modelling efficiency. In addition to this, the introduction of LEED certification and the simultaneous adoption of dual standards provides a platform for international alignment and expands the breadth of evaluation system research [10].

Design over operations and incremental costs become the biggest bottlenecks at this stage, and the problem of technology stacking for rating purposes continues to grow [11], difficulty in landing the whole life cycle concept and failure to get a real systematic solution to the light problem [12].

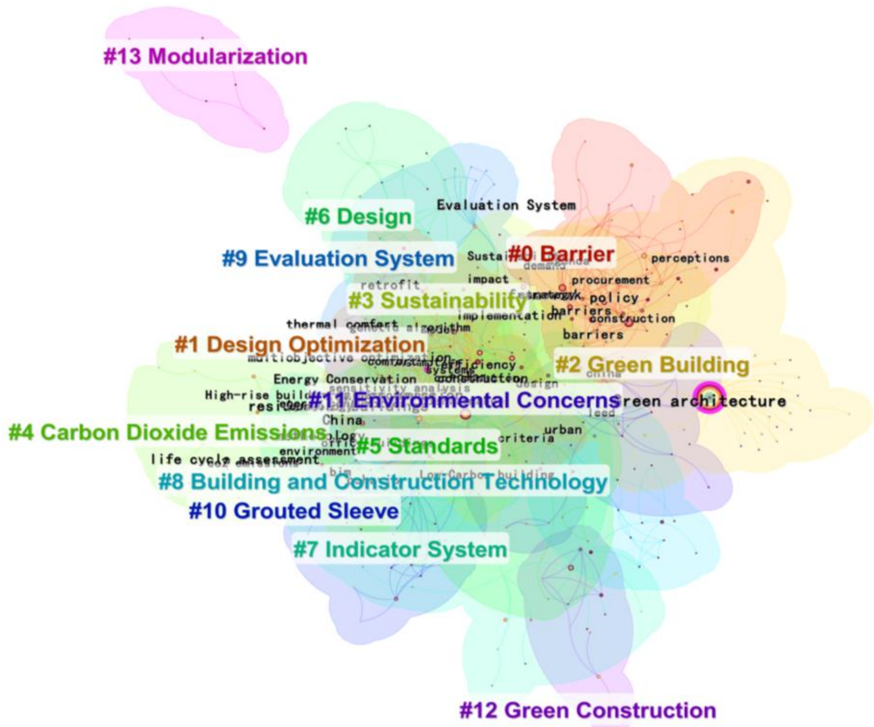

Figure 7: Keyword Clustering Graph (2015-2019)

As can be seen from the clustering figure 7 of the third stage, the first three numbers are "Barrier", "design optimization" and "Green Building". Digitalization has initiated a technological change for the development of green buildings, and relying on the maturity of technology and large-scale application, incremental costs have been reduced significantly. At the level of policies and standards, national and local governments have intensively introduced incentive policies for digital buildings. In 2016, the Ministry of Housing and Construction issued the Guiding Opinions on Promoting the Application of Building Information Modelling, which encourages enterprises to apply BIM in green building projects; in 2019, in order to adapt to the development of green and low-carbon development in the whole life cycle, and reverse the situation of focusing on design but not on operation, it issued the Evaluation Standard for Green Buildings(GB/T50378-2019), cancelling the design evaluation and reconstructing the evaluation system by combining the requirements of low carbonization of the whole life cycle with a "people-oriented" approach [13]; The release of the Technical Standard for Near-Zero Energy Consumption Buildings (GB/T 51350-2019) has solved the problem of the lack of local standard support for enterprises exploring "near-zero energy consumption" technologies. At the technical level, photovoltaic power generation technology has gradually matured, the cost of components has dropped significantly, and passive energy-saving technologies have gradually replaced high-cost active technologies. Meanwhile, BIM, as a full-process management tool, has become an important technological support under the inevitable trend of "industrialization" [14], realizing the standardization of the process from design to operation, and creating an opportunity for the next stage of "zero-carbon buildings".

Incremental costs are controlled at this stage, but the threshold of BIM technology is higher, the requirements for construction management are more cumbersome, the coverage of energy consumption monitoring in the building operation stage is insufficient, and the building operation data have not formed a unified regulatory system, and the problem of design over operation has not been effectively solved.

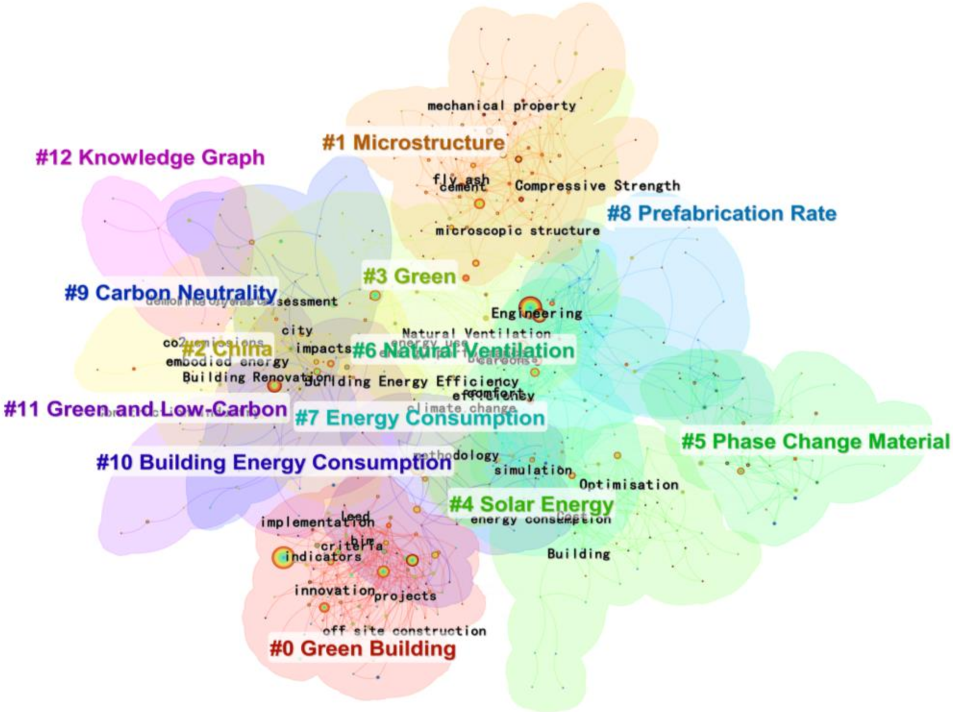

Figure 8: Keyword Clustering Graph (2020-2025)

As shown in Figure 8, the first three clusters in the fourth stage are “green building”, “microstructure” and “China”. In 2020, China proposed the “dual carbon” target for the first time, and the low-carbon transition in the construction field accelerated. Under the constraints of the “dual carbon” target, “zero carbon” has become the core direction of technological innovation. In terms of policies and standards, in 2021, the Ministry of Housing and Urban-Rural Development issued the Guiding Opinions on Accelerating the Promotion of Green and Low-Carbon Development, emphasizing the promotion of zero-energy buildings, near-zero-energy buildings, and the development of “zero-carbon buildings”. In 2023, the General Office of the Ministry of Housing and Urban-Rural Development released the Zero-Carbon Building Technical Standard for public comment, planning a three-level evaluation system of low carbon, near-zero carbons and zero carbon; in 2024, the Green Building Evaluation Standard (GB/T 50378-2019) was partially revised, highlighting the performance requirements of green buildings in terms of carbon emission reduction. At the technical level, the development of “zero carbon” takes energy and materials as breakthroughs. In terms of energy, the combination of renewable energy and energy storage technology enables the building energy system to have flexible adjustment capability [15], and through the dual technology overlay of passive design to reduce energy consumption and active energy efficiency optimization, as well as green power replenishment [10], it starts from ultra-low-energy buildings (50% reduction in energy consumption) and gradually upgrades to near-zero energy consumption (energy saving of 70% or more) [16], and eventually achieves the zero energy consumption target where renewable energy completely The goal of zero energy consumption is covered by renewable energy; in terms of materials, the rapid development of assembled buildings [14] is driving the materials research to high-performance, intelligent, green direction of in-depth innovation to form a multidisciplinary cross-fertilization of the innovation pattern.

At present, China is in the stage of full implementation of green building, gradual promotion of ultra-low energy building and zero energy building, and research and development of “zero carbon building” and assembly building technology. technologies such as BIM [17], artificial intelligence [18], and digital twin [19] are being deeply integrated into the whole process of design, construction, and operation and maintenance. However, the initial cost of assembly building is high [20], long-term benefits are not reflected, the development of enterprises is polarized [21], the carbon emissions of existing buildings have not been valued by the market [8], the theoretical basis of building design is lacking [22], and the performance of low-carbon materials is defective, etc. relying on the advancement of intelligent technology cannot be completely solved.

4. Conclusions and Prospects

Based on CiteSpace software, this paper explores the development lineage and current research status of green and low-carbon transformation in the construction industry. The study finds that:

(1) The number of published articles shows a trend of continuous growth. The high density and tight connection of the co-operative network of highly productive authors indicate a strong research connectivity among highly productive authors, but lack of interdisciplinary co-operation. In terms of

literature publishing institutions, architecture and urban planning related higher education institutions and research institutes are the main ones, while the dense collaborative networks among these institutions suggest strong cross-institutional and cross-disciplinary cooperation, facilitating the integration and utilization of innovative resources. However, core institutions have not yet achieved deep integration and efficient complementarity of their strengths, and regional development disparities remain evident. Keyword co-occurrence shows that energy, materials, and barrier solutions are the gathering points of research in various aspects; keyword emergence shows that low-carbon materials, user energy behavior and comfort issues such as building ventilation are the current research hotspots.

(2) China's building green low-carbon transformation and development has gone through four stages, each stage is guided by policy, standards as the cornerstone, to achieve continuous innovation of green low-carbon technology. 2001-2009 is the budding stage of industry transformation, accompanied by the first set of standards and policies, the formation of the four sections of the environmental protection framework, to explore how to build a green building, only to stay in the demonstration phase; 2010-2014 is a period of promotion of green and low-carbon development of buildings, the concept of low-carbon has been promoted, the evaluation system and standards have been improved, a number of regulations and plans have clarified the status and development goals of green buildings, assembly building and daylighting design technology has made progress, the implementation of the domestic green building evaluation system and LEED certification dual-track model, but the problem of technological stacking is prominent; 2015-2019 digital transformation to lay the foundation for the "zero carbon", the cost of photovoltaic modules decreases, the application of passive energy-saving technology makes the incremental cost drop significantly, and BIM becomes a full-process management tool, but it has a high threshold and fails to be comprehensively promoted, and the problem of focusing on design but not on operation is aggravated; 2020-present is the "zero carbon" technology research stage, digital twins, artificial intelligence and other technological development and active-passive dual technology superposition drive the whole life cycle carbon reduction to refinement.

In the future, ultra-low-energy and zero-energy buildings will be gradually and comprehensively promoted, and the research on green and low-carbon buildings should focus on the practice of fusion of intelligent technologies and various links, the research and development of high-performance low-carbon materials, and the overall greening of building design to operation. In terms of the integration of intelligent technology, technology R&D should pay attention to improving compatibility, paying attention to data security, and cost control for intelligent systems; material R&D should take full account of the actual needs and design characteristics of the building, and improve the performance of the material in terms of durability, seismic resistance, and compression resistance. In terms of building green design and operation, interdisciplinary training and cooperative research in architecture, material science, information technology and other fields are needed to improve the basic theories and design methods of green building design, enhance the level of green and low-carbon building design, and solve the problem of focusing on design rather than operation.

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