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Review

A Comparative Review of Recent Research Progress in Prefabricated Buildings in China and Other Countries

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Abstract: Prefabricated building construction has emerged as a transformative technology in construction engineering and the building industries. However, owing to its research characteristics, the relevant literature on prefabricated buildings is diverse and fragmented. This study offers a comparative review of relevant 21st century literature on prefabricated buildings using VOSviewer1.6.18 software. The research progress and future opportunities about prefabricated buildings were comprehensively analyzed, which provides recommendations for its subsequent development. Through keyword searches on the Web of Science, 3214 documents were identified, and an overall analysis of co-citations and co-authorship was conducted. Additionally, a comparative co-occurrence analysis highlighted the differences between China and other countries. Further elaboration of research hotspots is provided, and three future research directions are proposed: (1) energy conservation and reducing the environmental impact of prefabricated buildings, (2) improving the performance of prefabricated building components, and (3) deepening the understanding of the behavior of prefabricated structures under seismic and dynamic conditions. This study provides practitioners and scholars in the field of construction engineering with a comprehensive overview of the literature on prefabricated buildings and paves the way for future advancements in the industry. The findings of this study can be used to promote prefabricated buildings in the architecture, engineering, and construction industries.

Keywords: prefabricated building; energy conservation; VOSviewer; performance of prefabricated building components; behavior of prefabricated structures

Citation: Wu, X.; Han, J.; Cui, H.; Li, T.; Bai, X.; He, Y.; Liu, N. A Comparative Review of Recent Research Progress in Prefabricated Buildings in China and Other Countries. *Buildings* **2024**, *14*, 1062. https://doi.org/10.3390/buildings14041062

Academic Editor: Mizan Ahmed

Received: 18 February 2024
Revised: 24 March 2024
Accepted: 8 April 2024
Published: 10 April 2024

1. Introduction

Prefabricated building, which is emerging as a groundbreaking architectural trend, is rapidly advancing to the forefront of the construction industry. This innovative methodology not only redefines traditional architectural modalities but also presents viable solutions for the urgent requirements of modern society. However, despite these advancements, prefabricated building faces challenges, such as design inflexibility, inadequate joint performance, elevated transportation expenditures, and sustainability lacunae.

In recent years, the prefabricated building sector has undergone substantial evolution, effectively augmenting construction efficiency [1,2] and concurrently reducing the carbon footprint [3,4]. Consequently, there is a compelling need for widespread dissemination and endorsement of prefabricated building practices to promote societal advancement.

In recent years, there have been several comprehensive reviews of the research progress in the field of prefabricated building [5–9]. For example, Masood et al. [5] analyzed the

themes and key terms in supply chain management in prefabricated housing construction and identified key concepts such as lean, modular, customization, integration, and collaboration. Li et al. [6] provided a thorough understanding of the knowledge domain in the domain of risk management concerning prefabricated construction. The study summarized the current research content on five major knowledge themes including supply chain and industry, decision-making and optimization, safety and health, environment and overheating, investment and cost, and proposed demand and feasible risk management strategies for future research. Li et al.'s [7] study indicated that there is a need for further exploration and improvement in various aspects of prefabricated construction, including policy formulation, performance management, sustainability, design optimization, and technological applications. Khan et al. [8] summarized the technological development and adaptability of prefabricated industrial steel buildings. Serving as a more efficient and sustainable construction method, the prefabricated industrial steel buildings can shorten project duration, reduce overall costs, and minimize resource waste. Emphasized the ability of prefabricated industrial steel buildings to withstand adverse conditions such as earthquakes, wind, fire, explosions, and impacts, as well as the advantages of prefabricated industrial steel buildings in terms of efficiency, sustainability, and reducing environmental impact. Satheeskumar Navaratnam et al. [10] discuss various aspects of prefabricated construction, including its application in different countries, cost and time benefits, environmental advantages, safety considerations, fire and acoustic performance, and structural response to earthquake and wind loads.

Guaygua et al. [11] conducted a comprehensive and systematic review of research on improving the seismic safety of precast concrete buildings. This study utilized VOSviewer1.6.18 software for bibliometric analysis and the generation of scientific maps, including co-occurrence analysis of keywords and impact analysis, among others. It covered a qualitative evaluation of the literature, considering the quality of the documents and their relevance to the research topic, to identify knowledge gaps in the field and suggest directions for future research. Xie et al. [12] provided a comprehensive study on the application of Building Information Modeling (BIM) technology in the Chinese construction industry by analyzing policies, applications, barriers, and future trends of BIM technology in the fields of sustainability and informatization of Chinese construction. They summarized the formulation of China's BIM technology policies, the latest applications, and developments from 2011 to 2021, while also highlighting the widespread application of BIM technology in the design of commercial, industrial, office, and residential buildings in China, as well as the issues encountered in its application.

According to the analysis of the available literature, it is indicated that the current research on prefabricated buildings is diverse and fragmented, lacking statistical studies. Given the dispersed distribution of extant scholarly works, this investigation strived to present a comprehensive analysis of the literature pertaining to prefabricated construction. A bibliometric analysis of the preceding 15 years was conducted. Commencing with an assessment of impact across journals, authors, and countries within this domain, the subsequent sections of this paper delineate a comparative examination of research emphases in China juxtaposed with those in other nations. Through this, the research focal points in the realm of prefabricated building for both China and other nations were identified. Our findings provide valuable guidance for the development of prefabricated buildings in China and other countries, but also propose future research directions and serve as a contemporary reference for researchers in the prefabricated building industry.

The remainder of this document is structured as follows. Section 2 presents a summary of the methods and data collection procedures employed in this investigation. Section 3 delineates the developmental trends observed in the realm of prefabricated construction and identifies notable journals and influential authors within this domain. Section 4 describes focal points within the domain of prefabricated construction in China and other nations. A comparative analysis was conducted to discern the differences between China and other countries in this field. Lastly, Section 5 encapsulates the main discoveries.

2. Methodology

Previous studies have highlighted the objectivity and reliability of bibliometric reviews [7,13]. This study employed a bibliometric analysis to scrutinize retrieved articles. Figure 1 illustrates the research framework. Initially, the relevant literature was collected from designated databases, followed by meticulous screening based on predetermined criteria. Subsequently, a thorough bibliometric analysis of the refined literature was conducted by constructing co-citation and co-authorship networks to encapsulate the research landscape. The current research status was then evaluated, and the disparities between China and other nations were analyzed through a comparative assessment. Finally, the current research hotspots in prefabricated construction were summarized, and suggestions for future research directions in the field of prefabricated buildings were proposed. Figure 1 outlines the approach adopted for this research.

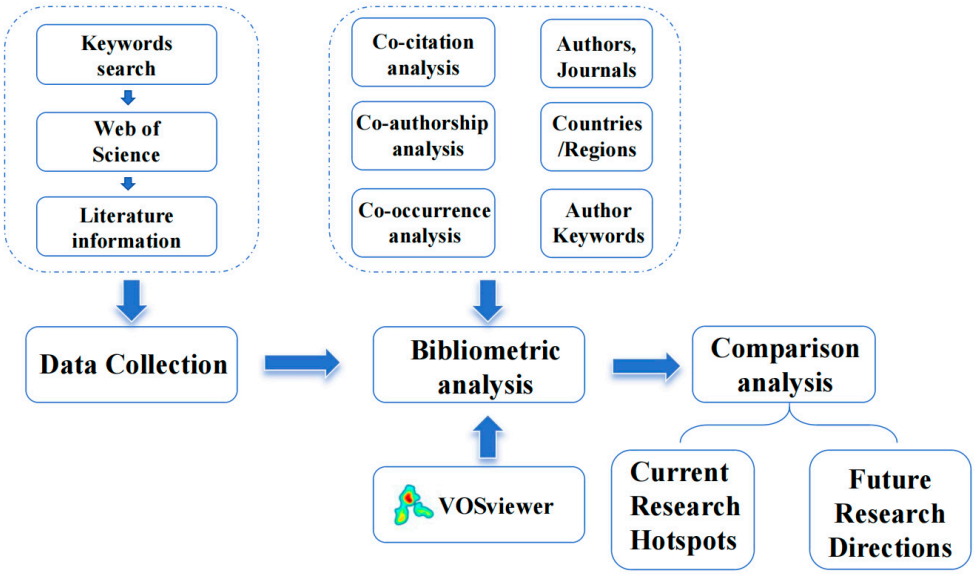

Figure 1. These schemes follow the same format.

2.1. Data Collection

To derive more significant research findings, this study uses the Web of Science (WOS) core collection database, which comprises the most pivotal and influential literature globally [14,15]. The selection of documents from this database ensured robust support for this study.

Aligned with the definition of prefabricated buildings delineated in Section 1, we initially formulated the list of search keywords, incorporating "prefabricated", "fabricated", and "assembly" to encompass the concept of prefabrication. Meanwhile, "building" was selected to represent the architecture, engineering, and construction (AEC) sector. This deliberate selection of keywords holds paramount significance in procuring relevant and authoritative literature, thereby establishing the groundwork for the foundational research of this study.

Thus, the query we used was as follows:

(TS = (prefabricated building OR fabricated building OR assembled building *))

"TS" denotes the article subject, encompassing the title, abstract, and indexing, while "*" indicates a fuzzy query.

Despite the strategies employed, a significant proportion of the retrieved documents contained irrelevant content unrelated to prefabricated building. To address this challenge, an initial screening of journals was conducted. Our selection guidelines were influenced by pertinent review studies of prefabricated building that focused on notable civil engi-

neering journals. Subsequently, any papers considered irrelevant to the AEC industry were excluded from the remaining documents. This meticulous selection process resulted in a dataset comprising 3214 documents for bibliometric analysis. Among these documents, 1157 were authored by Chinese researchers, whereas the remaining 2057 originated from other countries, thereby offering a diverse international perspective for the study.

2.2. Bibliometric Analysis

In this study, we used VOSviewer, a widely recognized tool for literature investigation, to conduct a bibliometric analysis. VOSviewer is a software tool for constructing and visualizing bibliometric networks. These networks may for instance include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations. VOSviewer is renowned for its ability to conduct extensive literature analyses and visualization on a large scale [16], encompassing co-citation/citation, co-occurrence, and co-authorship analyses [17]. This section offers an overview of the analytical methods employed in this study.

Co-citation analysis: An integral part of this study, co-citation analysis, involves identifying two papers that are frequently cited together in other studies, thereby establishing a co-citation link. This method allows us to discern which journals or authors are commonly cited in tandem, thereby shedding light on influential contributors in the field. Such an analysis reveals prominent journals and authors, aligns them with specific research trends, and facilitates a structured categorization of literature within the field. Co-citation analysis, especially when executed via VOSviewer, outperforms traditional citation analysis by efficiently grouping journals and authors based on research direction [13]. This was achieved through a cluster analysis of documents based on their mutual citation frequency, with those having more co-citations likely forming a cluster in the analysis.

Co-occurrence analysis: Co-occurrence is a key technique in this study and focuses on evaluating keywords in scholarly literature. It quantifies the frequency of individual keywords and tracks their co-occurrence with other keywords. Each instance of a keyword in a document contributes to its overall count, and the simultaneous appearance of two keywords in a single article increases their co-occurrence. Similar to co-citation analysis, this analysis categorizes keywords based on research directions. Keywords with higher occurrences garner more attention in the field and those with frequent co-occurrences align closely with primary research themes, often forming identifiable clusters. Utilizing VOSviewer's capabilities, this study employs a co-occurrence analysis complemented by an analysis of author-recommended keywords [13,18].

Co-authorship analysis: Co-authorship analysis examines the collaborative relationships among authors. In this method, stronger collaboration is indicated by a higher number of articles published jointly by the authors. This approach differs from co-citation analysis, as it primarily identifies and clusters countries or regions based on the intensity of their collaborative relationships. Although it does not delineate research directions, it effectively highlights influential countries or regions in the domain. VOSviewer's co-authorship analysis function quantifies the volume of publications, citations, and international collaborations per country or region. Classifying documents according to the affiliations' locations assists in identifying countries with significant contributions to the field of prefabricated building, thereby providing strategic insights for future research and collaboration.

3. Overview

3.1. Number of Papers

After gathering data and preprocessing, trend analysis takes precedence as the primary step. The volume of articles serves as a barometer of fluctuations in research interests within a particular domain. Hence, our initial comparison focuses on the annual publication output concerning prefabricated building in China and other nations. Figure 2 shows the trajectory of articles published over the past 15 years and reveals some differences between the two items, yet with a notably similar overall trend. Since 2015, there has been rapid growth in

the number of documents pertaining to prefabricated building in China, surpassing the total number of documents in other countries by 2022.

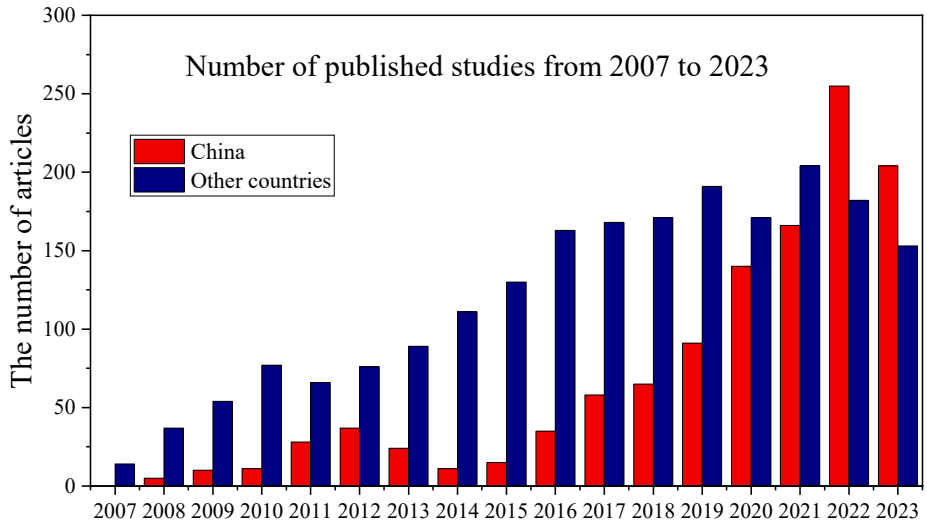

Figure 2. Number of published studies from 2007 to 2023.

3.2. Publication Sources

Co-citation analysis can reveal clusters that are more closely interconnected in a research field and possess greater influence [19]. To identify the most influential publication sources concerning prefabricated buildings, we performed a co-citation study in which the minimum citation threshold for a journal was set at 200. Fifty-seven journals met this requirement, as illustrated in Figure 3. Figure 3 shows the co-citation network of publication sources. The circle size reflects the citation frequency and the line width between two circles denotes the extent of co-citations between articles from the respective journals. Additionally, the color and spatial proximity of the circles signify the relatedness of the journals' research areas and provides a visual representation of the closeness of research directions.

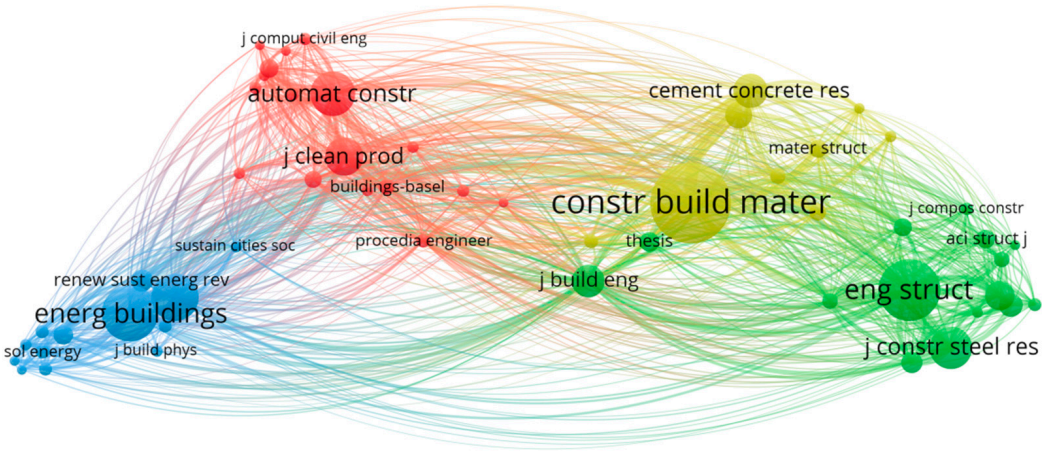

Figure 3. Co-citation network of publication sources.

Figure 3 shows that all journals are categorized into four clusters, denoted by yellow, green, blue, and red. The largest number of items appears in *Construction and Building Materials*, which primarily publishes articles related to construction materials in the AEC industry, while other journals in this cluster (yellow) also feature articles concerning materials. The green clusters are predominantly focused on scrutinizing structural aspects and methodologies for extracting pertinent information from them. Publications within the blue cluster are dedicated to advancing the sustainable development of construction

projects by delving into the intricate interplay between structures and the environment. The red cluster predominantly publishes articles related to the application of prefabricated building and its construction method.

Table 1 provides a comprehensive summary of key influential journals. The table is organized into columns with headings such as Documents, Citations, Total Link Strength, and Citation/Documents. The Documents column represents the number of published documents in the journal. The Citations column includes the cumulative citations of the journal's published documents. The Total Link Strength column represents the total co-citation frequency of the journal's publications. The Citation/Documents column presents the proportion of citations to the quantity of published papers. It is crucial to recognize that co-citations between two journals (e.g., Journals A and B, and Journals A and C) may overlap, potentially inflating the total link strength. The Journal Title and related data in Table 1 are arranged in descending order by Total Link Strength.

Table 1. Journal publications versus citations related to prefabricated building.

Journal Title	Documents	Citations	Total Link Strength	Citation/Documents
Journal of Building Engineering	329	2666	26,535	8.1
Buildings	227	1220	24,401	5.37
Construction and Building Materials	420	9125	17,104	21.73
Automation in Construction	136	5585	14,014	41.07
Energy and Buildings	183	5728	12,134	31.3
Journal of Constructional Steel Research	98	1800	7956	18.37
Building and Environment	135	3884	7580	28.77

The journals listed in Table 1 include notable publications, such as *Journal of Building Engineering*. These journals epitomize those with the highest average citation rates (citations/documents). The number of papers published across these journals demonstrated considerable variability, ranging from 36 to 420, while the number of citations ranged from 347 to 9125. These data illustrate a significant disparity in both the count of published papers and volume of citations garnered. Notably, ranking in terms of publication volume does not always align with citation frequency. As an illustration, the number of documents from *Automation in Construction* is nearly 40% less than that in *Buildings*. However, the number of citations for *Automation in Construction* is approximately 80% higher than that for *Buildings*.

Overall, despite minor variances in the data, scholarly works featured in the journals listed in Table 1 are invaluable resources, offering substantial guidance for research in the field of prefabricated buildings.

3.3. International Collaboration

In our study, we utilized the co-authorship analysis feature of VOSviewer to quantitatively examine the collected literature. We set a minimum publication threshold of 20 articles per country and region. Of the 97 countries from which documents were retrieved, 34 met this criterion. This threshold was established to balance network readability while preserving essential information. A lower threshold results in a denser graph with more items and links, consequently diminishing the clarity [20].

The co-authorship network in the prefabricated building research domain is illustrated in Figure 4. Unlike Figure 3, the circle size in Figure 4 indicates the number of papers published by authors from various countries, the width of the lines represents the volume of co-authored papers between two countries. Countries/regions sharing the same color on the graph belong to the same cluster, suggesting a higher level of collaboration within these groups compared with others. The graph categorizes the countries/regions into six distinct clusters: purple, green, yellow, blue, fluorescent blue, and red.

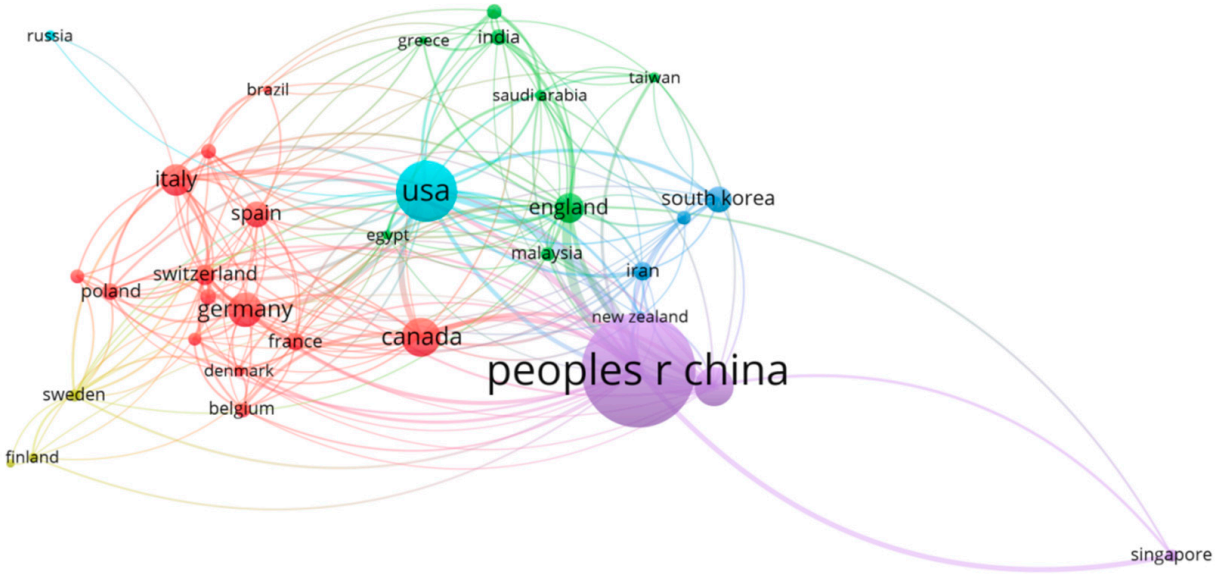

Figure 4. Co-authorship network in the prefabricated building research domain.

It is noteworthy that despite the substantial collaboration between China and the United States, they are identified as separate clusters. This distinction occurs because the volume of publications from each of these countries is both equal to and significantly surpasses that from other countries.

Table 2 provides pertinent details for the top nine countries with the greatest volume of publications, including China (1155 documents; 13,011 citations), the United States (436 documents; 7716 citations), and Australia (208 documents; 4962 citations). The number of documents from these countries/regions varied from 17 to 1155, while the count of citations ranged from 295 to 13,011. As the same with Table 1, the Journal Title and related data in Table 2 are arranged in descending order by Total Link Strength.

Table 2. Top ten countries with the highest number of publications.

Country	Documents	Citations	Total Link Strength	Citations/Documents
China	1155	13,011	86,479	11.26
Australia	208	4962	56,208	23.86
The United States	436	7716	42,254	17.69
England	141	2372	31,660	16.82
Italy	155	2013	23,287	12.98
Canada	209	2885	21,802	13.8
New Zealand	28	708	19,608	25.28
Chile	17	295	11,937	17.35
Singapore	36	954	9742	26.5

When examining the volume of research articles issued by various countries, we find that the extensive contributions of Chinese scholars in recent years have led to a relatively high output of prefabricated building research. To further advance prefabricated building in China, it is crucial to define the developmental direction of this field. To facilitate this, we performed a keyword co-occurrence analysis on the literature from countries where the ratio of cited references to total references exceeded 15. This was compared with a keyword co-occurrence analysis of Chinese literature to provide meaningful insights.

3.4. Co-Cited Authors

Through a co-cited author analysis of the gathered literature, this study identified key influential authors in the prefabricated building sector. A minimum citation criterion

of 50 was established for each author, and 62 authors met the threshold. Figure 5 shows the co-citation network of authors. In Figure 5, the circle size indicates the number of papers published by various authors, and the width of the lines represents the volume of co-citation papers between two authors. Figure 5 categorizes the authors into four distinct clusters. The research themes among authors within the same cluster are related. To delve deeper into the connections among authors within each cluster, we examined their most-cited works, summarizing their research focus in Table 3. From Table 3, it can be observed that the research focus on prefabricated buildings primarily concentrates on four aspects: 1. Seismic assessment of concrete structures, 2. Building and energy control, 3. Optimization of assembled building in construction, 4. Information on joint of assembled components. Table 4 lists the publications from the authors with the highest number of citations, providing insights into the leading voices in prefabricated building research. Co-cited author analysis indicates a correlation between research themes among authors within the same cluster.

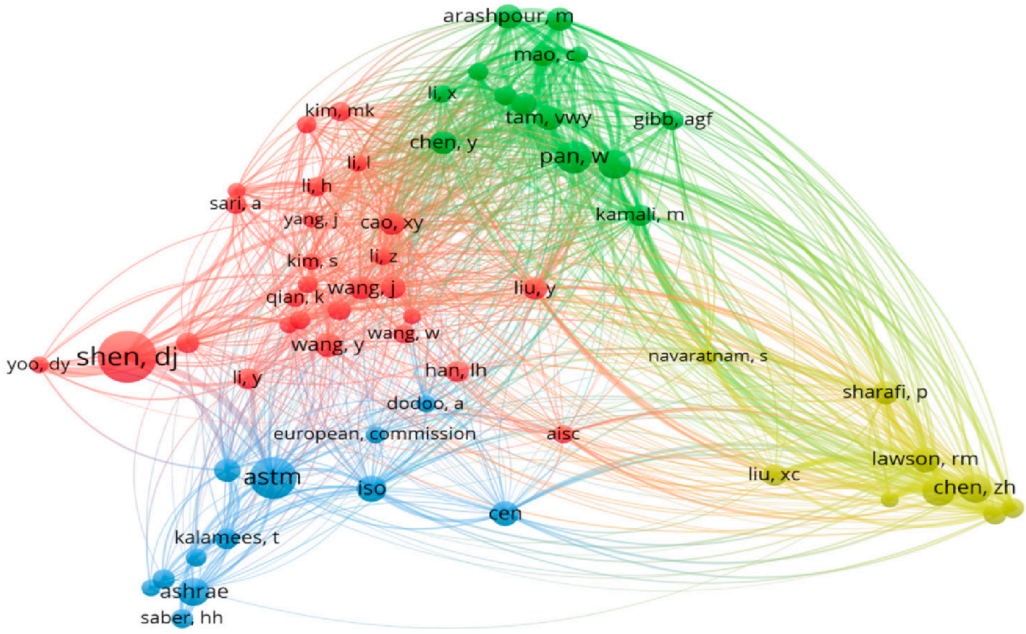

Figure 5. Co-citation network of authors.

Table 3. Representative works of other authors.

Research Direction	Reference	Cluster Color
Seismic assessment of concrete structures	Li et al., 2019 [21], Wang et al., 2018 [22], Shen et al. [23], Shen et al. [24], Priestley et al. [25]	Red
Building and energy control	Chen et al., 2010 [26], Saber et al. [27], Kurnitski et al., 2011 [28]	Blue
Optimization of assembled building in construction	Tam et al., 2007 [29], Li et al., 2022 [7] Chen et al., 2022 [9]	Green
Information on joint of assembled components	Chen et al., 2021 [30], Chen et al., 2017 [31], Chen et al., 2017 [32] Yang et al., 2022 [33]	Yellow

Table 4 summarizes the most-cited authors across different clusters, highlighting the tendency of authors within the same cluster to demonstrate more frequent co-citations and indicating interconnected research themes. The authors receiving the most citations in each cluster are Shen Dejian, Kalamees Targo, Chen Zhihua, and Pan Wei. Shen Dejian is

renowned for contributions in reinforced concrete structures, diagnosis of early-age cracks, seismic performance of prefabricated buildings, and fiber-reinforced polymer technology. Kalamees Targo focuses on energy-saving building materials, building ventilation, and heat preservation in buildings. Chen Zhihua researches steel structures, space structures, and composite structures. Pan Wei specializes in sustainable construction, zero-carbon buildings, modular integrated construction, advanced prefabrication, and smart technology.

Table 4. Representative works of the representative authors in each cluster.

Cluster Color	Most Influential Author	Citations (All Scopes)	Masterpiece	Source
Red	Shen et al., 2016 [23]	112	Effect of internal curing with super absorbent polymers on autogenous shrinkage of concrete at early age	*Construction and Building Materials*
Red	Shen et al., 2014 [24]	94	Influence of curing temperature on autogenous shrinkage and cracking resistance of high-performance concrete at an early age	*Construction and Building Materials*
Blue	Kalamees et al., 2011 [28]	193	Cost optimal and nearly zero (nZEB) energy performance calculations for residential buildings with REHVA definition for nZEB national implementation	*Energy and Buildings*
Blue	Kalamees et al., 2009 [34]	152	The effect of combining a relative-humidity-sensitive ventilation system with the moisture-buffering capacity of materials on indoor climate and energy efficiency of buildings	*Building and Environment*
Yellow	Chen et al., 2017 [32]	147	Experimental study on interior connections in modular steel buildings	*Engineering Structures*
Yellow	Chen et al., 2017 [31]	101	Experimental study of an innovative modular steel building connection	*Journal of Constructional Steel Research*
Green	Pan et al., 2014 [35]	254	Major Barriers to Off-Site Construction: The Developer' s Perspective in China	*Journal of Management in Engineering*
Green	Pan et al., 2012 [36]	145	Strategies for integrating the use of off-site production technologies in house building	*ASCE Journal of Construction Engineering and Management*

4. Research Cluster Analysis

4.1. Bibliometric Analysis of Documents from China

In this study, we employed VOSviewer to conduct a keyword co-occurrence analysis of the Chinese literature pertaining to research on prefabricated building, as shown in Figure 6. By analyzing 1157 Chinese documents, we identified 39 key terms that occurred frequently, including synonymous keywords representing similar concepts, which were manually consolidated by experts. In Figure 6, the size of each circle reflects the frequency of occurrence of each keyword in the literature. The connecting line widths indicate the frequency of co-occurrence between pairs of keywords, illustrating the interconnectedness of these concepts within the research domain. Cluster 1 introduced advancements in seismic resilience research. Cluster 2 explored prefabricated construction processes, and Cluster 3 introduced performance research on prefabricated building components.

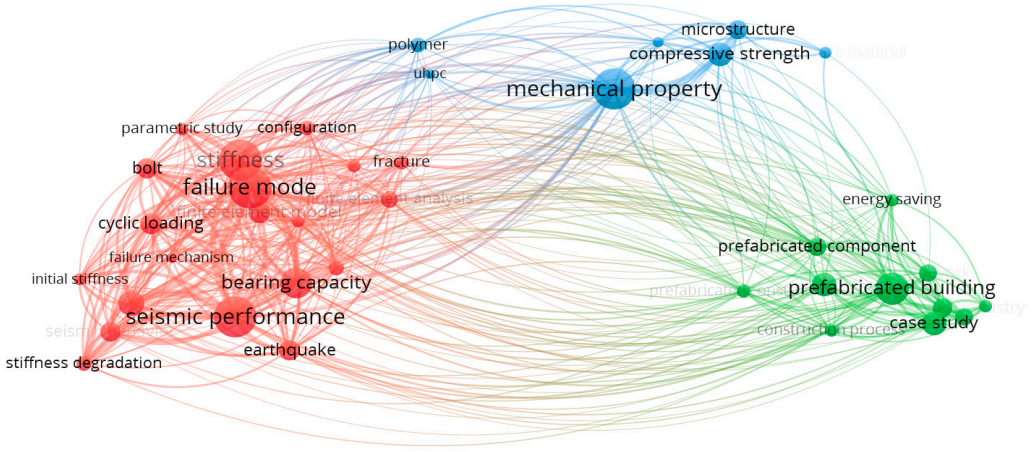

Figure 6. Network of co-occurrences of author keywords in the Chinese literature.

4.1.1. Introduction to Advancements in Seismic Resilience Research

In the evolving landscape of structural engineering, the exploration of seismic risk assessment and innovative design strategies for prefabricated building structures has become a focal point of scholarly research. Li's [37] pioneering work lays the foundation for a quantitative framework aimed at evaluating and monetizing seismic failure risk in prefabricated structures. By seamlessly integrating vulnerability and building depreciation theories with seismic hazard analysis, Li presented a robust method for comprehensive risk assessment. The practical application of this framework in a residential prefabricated building case study not only demonstrated its feasibility but also underscored its effectiveness in enhancing risk management, decision-making processes, and disaster prevention and mitigation efforts. Li's research represents a significant contribution to the quantification of the seismic risk associated with prefabricated structures.

Yang's [38] focused on the seismic performance of precast reinforced concrete shear walls, particularly after the integration of vertical joints. The study varying axial compression ratios to assess their stress processes, failure mechanisms, hysteresis behaviors, load capacity, stiffness degradation, ductility, and energy absorption capabilities. The findings revealed that the shear walls primarily failed due to shear, with the vertical joints remaining largely undamaged, and the shape of these joints significantly influenced the seismic response. This research underscores the necessity for further investigation into efficient joint configurations to enhance structural dependability. Zhang's [39] delved into the seismic response characteristics of shield tunnels, examining the impact of different assembly methods and segment widths. This study highlighted notable disparities in the seismic behaviors of shield tunnels, depending on the assembly method employed. Tunnels assembled using a straight-line method showcased superior mechanical performance but underwent more structural deformation compared to those assembled with staggered joints. Additionally, the investigation into the effect of segment width on seismic performance revealed that tunnels with a segment width of 1.5 m exhibited enhanced seismic resilience over those with a 1.2 m width.

Li's [40] introduced a comprehensive strategy utilizing digital twin technology to tackle the deformation issues encountered in the assembly and manufacturing stages of steel structures, facilitating a complete loop of tracking and management of these processes. The methodology integrates deformation detection, attitude estimation and optimization, deformation correction, and attitude control. The practicality and efficiency of this approach were validated through its application in the New Shougang Bridge project, which showcased remarkable precision in assembly and control accuracy. Wang's [41] research to assess the seismic capabilities of a novel prefabricated bolted connection design, which incorporates steel components into concrete beams and columns. This innovative connection is aimed at addressing the shortcomings of existing dry connections in prefabricated joints

by boosting construction efficiency and seismic resilience. Through low-cycle reversed loading tests, the team gathered data on various performance metrics of the prefabricated concrete joints, including their failure mode, hysteresis and skeleton curves, ductility, stiffness, and deformation capacity. The findings revealed that the joints primarily failed through the flexural failure of the steel plate connections, significantly improving the seismic capacity and collapse resistance of the structure, alongside demonstrating a high capacity for energy dissipation.

Building on this groundwork, subsequent scholarly inquiries delved deeper into the seismic performance and innovative design aspects of prefabricated structures. Huang's [42] investigation, for instance, focuses on the seismic resilience and thermal insulation enhancement of rural Chinese housing through the application of a load-bearing prefabricated composite wall panel structure. Experimental results of a 1:2 scale load-bearing prefabricated composite wall panel prototype showcase remarkable seismic resistance, surpassing design values and meeting performance requisites. Further examinations by Kashan Khan and Yan [43] scrutinized the seismic behavior of a multistory modular steel building featuring novel bolted joints and revealed its seismic performance, ductility, and stable load-carrying capacity. Zhang's [44] meticulous experimental study evaluated the seismic performance of a prefabricated framed rocking wall structure and revealed a significantly increased seismic load-resisting capacity and energy dissipation compared to conventional frame structures. Collectively, these scholarly inquiries enrich the discourse on the seismic design and performance assessment of cutting-edge prefabricated structural systems.

4.1.2. The Exploration of Prefabricated Construction Processes

In the contemporary field of construction methodology, academic endeavors have been undertaken to comprehensively examine the issues pertaining to prefabricated construction. This in-depth scrutiny encompasses various facets, including structural robustness and safety risk management, which address the critical aspects that shape the trajectory of the role of prefabricated construction in modern engineering practices.

Mao's [45] pivotal comparative study reviewed greenhouse gas emissions in off-site prefabrication and compared them with traditional construction methods. By accentuating the potential reduction in environmental impact achievable through prefabrication, Mao's research sets the stage for an in-depth understanding of the ecological implications of this innovative construction approach. Simultaneously, Wang's [46] meticulous life cycle assessment narrowed its focus to environmental impacts, particularly examining diverse prefabrication rates in building construction. These foundational studies paved the way for a nuanced exploration of the environmental benefits associated with increased rates of prefabrication. Shen's [2] work shifted the focus to safety risk management by leveraging ontology technology for knowledge sharing and automatic risk identification, and the integration of technology in safety protocols reflects a forward-looking approach to ensure the resilience and reliability of prefabricated constructions. Innovations extend to the construction process itself, as demonstrated by Zhao's [47] framework introducing a digital twin-based system for the hoisting management of prefabricated components, which not only showcases innovative solutions for efficiency and precision, but also underscores the potential of technology in advancing the intelligent management of prefabricated building construction.

Zou's [48] study delved into optimizing stacking plans for prefabricated concrete floor slabs, focusing on the assembly sequence to boost on-site lifting efficiency in the construction of concrete residential buildings. Traditional options neglect the crucial aspect of assembly sequence. This oversight can extend construction preparation time and increase the risk of injuries among workers. The study introduces a storage location allocation model designed to minimize the need for secondary sorting and improve stacking stability by taking into account the sequences of production and lifting. Furthermore, the research identifies a gap in the application of precast concrete board storage technology and suggests a methodology that combines mathematical models with optimization algorithms

to automatically generate optimal stacking plans for Precast concrete boards. Through the automation of optimal stacking plan generation, the method not only lessens the workload associated with secondary sorting but also enhances stacking stability.

The culmination of these research endeavors contributes valuable knowledge to the field of prefabricated construction. Environmental assessments provide a nuanced understanding of the ecological footprint and emphasize the benefits achievable through increased prefabrication rates. Concurrent studies on structural robustness and safety risk management have enhanced the comprehension of the crucial structural integrity and safety protocols for prefabricated structures. Furthermore, the application of digital twin technology in hoisting management systems provides innovative solutions for improving the efficiency and precision of the construction process. This multifaceted exploration reflects a comprehensive and forward-looking approach for advancing prefabricated construction methodologies, underscoring the potential for sustainable and technologically enhanced building practices in contemporary engineering.

4.1.3. Introduction to Performance Research on Prefabricated Building Components

Concerted efforts have been made to improve the understanding and performance of prefabricated building components in the dynamic landscape of construction engineering. This introduction sets the stage for a detailed exploration of prefabrication, focusing on scholarly pursuits that delve into the intricacies of prefabricated concrete wall panel building systems, mortise-and-tenon joints, and other innovative methodologies. Xiao's [49] study takes center stage, offering a comprehensive investigation into a prefabricated concrete wall panel construction system featuring alveolar-type connections. The research places particular emphasis on aspects such as fast assembly and controllable quality, and its findings, encompassing the design and fabrication of joint specimens, establishment of a shear-slip constitutive model, and proposal of a simplified analytical method, contribute significantly to the growing body of knowledge in this field. Yang's [33] research has found that grouting plays a crucial role in restricting joint deformations, with the type of grouting material having minimal impact on deformation characteristics. The lengths of the tenons and mortises also influence the ultimate bending capacity of joints, with longer tenons and mortises providing better resistance against deformation. In addition, the application of axial forces enhanced the resistance of the joint to deformation. These findings are significant for designing and calculating joints in subway stations.

Huang's [50] study investigated the flexural behavior of two-way slab components filled with wire mesh cages within modular construction frameworks. Utilizing both experimental methods and finite element analysis, they assessed the structure's capacity for bearing vertical loads and resistance to bending, focusing on the distribution of cracks, deformation patterns, and load-bearing capabilities. The innovative floor design proposed in this research consists of three prefabricated panels welded together with concealed beams poured on-site, resulting in a two-way slab that notably decreases the need for concrete. The inclusion of wire mesh cages as filler material offers several benefits, including minimized buoyancy and enhancements in production, transport, and construction efficiency, alongside increased strength and stiffness. This study is of considerable practical importance for the development of engineering standards and guidelines, promoting a shift in the construction sector towards more manufacturing-oriented practices.

Moreover, scholarly inquiries have investigated various aspects of prefabricated building components, further enriching our understanding and providing potential avenues for advancement in this domain. Fang's [51] exploration of the mechanical characteristics of lightweight concrete beams within prefabricated building structures introduces the prospect of weight reduction, improved safety, and enhanced economic viability. The document not only showcases these advantages but also introduces a theoretical calculation method for beam deflection, thereby enhancing references for engineering design. Yuan et al. [52] focused on modified high-performance cement mortar tailored for prefabricated buildings, introducing improved construction technology and enhanced mechanical properties for

the joints. They established the optimal mixing ratio and highlighted the advantages of the modified mortar in terms of setting time and early strength. Liu [53] investigated wall beam-strut joints with mechanical couplers for underground prefabricated construction, incorporating both experimental and numerical analyses. Despite some differences between the numerical and experimental results, the proposed joint exhibited good ductility and a high ultimate bearing capacity, satisfying the stringent requirements of underground prefabricated construction. These collective endeavors significantly contribute to our insights into the performance and potential advancements in prefabricated building components, thereby shaping the trajectory of future innovations in construction engineering.

4.2. Bibliometric Analysis of Documents from Other Countries

Using the same methodology, we performed a keyword co-occurrence analysis of the literature on prefabricated building from developed countries, as shown in Figure 7. The definition of the circle and line in Figure 7 is consistent with those in Figure 6. After synonym consolidation and the removal of extraneous keywords, we categorized the 57 high-frequency keywords into three distinct clusters. Cluster 1 delves into the research on energy-efficient building systems, Cluster 2 explores seismic performance across various construction systems, and Cluster 3 investigates thermal performance.

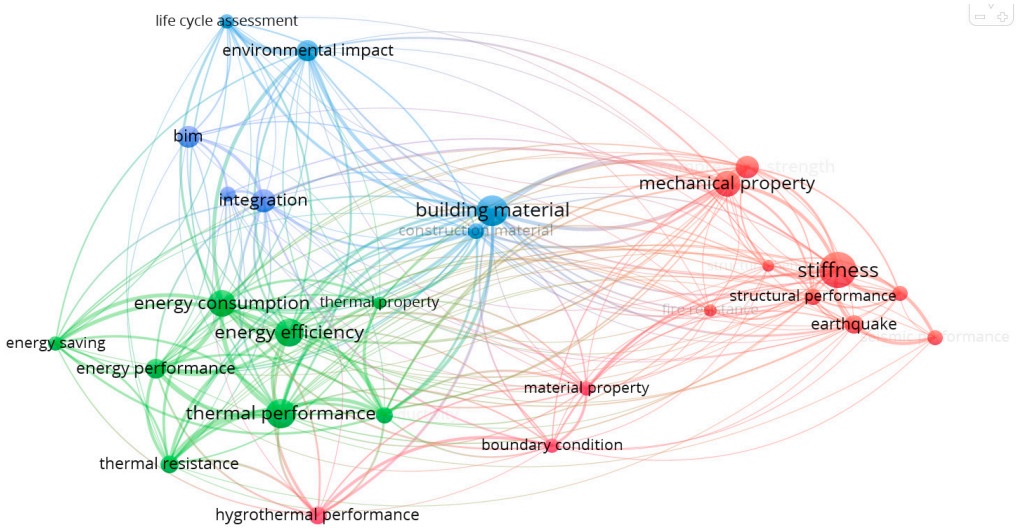

Figure 7. Network of the co-occurrences of author keywords in the literature from other countries.

4.2.1. Introduction to Performance Research on Energy-Efficient Building Systems

As societies confront the imperative of sustainable development globally, discourses on energy-efficient building systems have gained prominence. This introduction sets the stage for an exploration of scholarly inquiries that delve into the nuanced realm of energy efficiency, with a particular focus on existing buildings predating the 1970s energy crisis. Ruud et al. [54] evaluated the energy performance of a modular prefabricated façade system based on wood in contrast to conventional on-site insulation methods. As part of a broader Nordic research initiative, this study positions itself as a vital contributor to the quest for cost-efficient and sustainable solutions in the context of façade refurbishment.

Wasim [55] investigated the optimization of energy efficiency in light steel structure buildings using modular construction methods. Their research focused on enhancing thermal and environmental performance through prefabricated walls, structural analysis, and energy simulation. To accomplish this, they utilized software tools like Autodesk Revit, ETABS, and MATLAB for BIM modeling, structural analysis, and energy optimization. By addressing gaps in prefabricated building optimization and energy-efficient design, this study provides valuable insights for future sustainable architectural practices. Overall, it offers a novel approach to developing highly optimized prefabricated buildings through

advanced design and manufacturing frameworks, thereby contributing to the advancement and reform of the construction industry. Walker [56] conducted research on the compressive bearing capacity of straw brick components under concentric and eccentric loading, aiming to explore the potential of bio-based materials in reducing carbon emissions in construction. The study focused on investigating the performance of load-bearing straw brick walls with and without gypsum coatings, considering factors like wall height, gypsum usage, and load eccentricity. Through an experimental approach, the study presents 29 test results, primarily highlighting the impact of load eccentricity, gypsum usage, and wall geometry on compressive performance.

Subsequent documents have extended and enriched the discourse on energy-efficient building practices, providing valuable insights into novel structural systems, construction methodologies, and retrofitting strategies. Eckelman's [57] research delves into the environmental benefits and life cycle energy of a structural system in steel buildings designed for deconstruction. Eckelman's work emphasized the potential of design for deconstruction designs in mitigating environmental impacts through component reuse, accentuating the importance of prioritizing reuse over recycling. V. Tavares [58] explored the potential of prefabricated buildings to meet EU environmental targets and reduce costs. Employing an inventory-based approach, this study assessed the costs and impacts of conventional and prefabricated construction systems in European cities, highlighting the potential of prefabrication to align with EU targets and enhance sector productivity. Silva [59] concentrated on the development of a prefabricated retrofit module for existing building façades, aiming for near-zero energy building standards. Silva's meticulous approach involves material selection, three-dimensional modeling, cost-benefit analysis, simulation tools, and prototyping, underscoring the significance of retrofitting existing buildings to achieve energy efficiency and near-zero energy building standards.

Collectively, these documents provide valuable insights into the pursuit of energy-efficient building practices and sustainable solutions and reflect a comprehensive and multidimensional approach to addressing the challenges and opportunities in the realm of contemporary construction engineering.

4.2.2. Introduction to Seismic Performance Studies across Varied Construction Systems

Despite the increasing demand for swift and cost-effective construction, the adoption of prefabricated concrete structures has become indispensable. Offering superior-quality performance and reduced manufacturing time, these structures are an ideal choice for multifloor buildings. However, there is limited information on their behavior under seismic and dynamic loads, prompting researchers to embark on experimental and analytical studies. Seismic design conventions, relying on methods such as the equivalent static force approach, necessitate the calculation of earthquake forces using a behavior coefficient that reflects structural strength and hidden ductility. This introduction serves as a preamble to a detailed exploration of three distinctive studies, each providing insight into the seismic performance of different construction systems.

Aloisio [60] conducted research on developing an innovative seismic retrofitting system for reinforced concrete structures, employing friction dampers and cross-laminated timber panels. The primary challenge addressed by the study was identifying the optimal sliding force for the friction dampers to enhance seismic performance effectively. This effort was part of the Energy and Seismic AFfordable rEnovation research project, which introduced an asymmetric friction connection system designed to improve the seismic resilience of reinforced concrete structures. The research involved nonlinear dynamic analysis and optimization studies to devise a simplified design methodology accessible to practitioners. Focus areas included experimental evaluation of friction dampers, preferences in modeling techniques, and the calibration of hysteresis models to accurately predict seismic response. The study underscored the significance of integrating infill materials into seismic retrofit strategies and pinpointed the optimal sliding force necessary to reduce displacement drift.

Divan [61] focused on determining the response coefficient of prefabricated concrete frames coupled with prefabricated shear walls. This study considers the effects of different loading conditions and analyzes different kinds of prefabricated concrete frames featuring four- and eight-story shear walls to determine the behavior factor using a nonlinear static analysis method. The results indicate that increasing the count of bays and building stories enhances the structural behavior coefficient.

Raka's [62] literature review focused on cutting-edge partially prestressed concrete structures resistant to earthquakes, particularly in highly seismic regions. The paper discusses the use of prestressed concrete in earthquake-resistant multistory buildings, primarily in Indonesia. It introduces the most recent earthquake design methodology for prestressed concrete structures in Indonesia, based on the Indonesian Building Code for Structural Seismic and Structural Code. This study also highlighted the utilization of partially prestressed concrete in building construction and described the findings of a study on the earthquake resilience of partially prestressed concrete frameworks. The project's experimental stage involved conducting tests on six nearly full-scale beam-interior column assemblies under static cyclic loading to collect data relevant for seismic design objectives. This document emphasizes the need for ductility in seismic-resistant structures and discusses the ductile performance of partially prestressed concrete beam-column connections.

Premrov et al. [63] performed tests on wood-framed walls enhanced with carbon fiber-reinforced polymers and fortified fiber-plaster boards. This study examines how the main elements that support the load are built into prefabricated multistory wooden residential buildings. The compressive strength of fortified fiber-plaster boards for sheathing is much higher than their tensile strength, leading to cracks in tall buildings in highly seismic areas. The inclusion of the carbon fiber-reinforced polymers diagonal strip reinforcement significantly increased the load-carrying capacity, particularly when carbon strips were attached to the timber frame. However, the ductility of the walls did not improve significantly. The document also presents a preliminary numerical study of potential innovative technological solutions for reinforced wall elements in regions prone to heavy seismic activity in the future.

4.2.3. Thermal Performance Research

In the realm of thermal performance research, a noteworthy contribution comes from Roberto Garay, Beñat Arregia, and Peru Elguezabala [64] titled "Experimental Thermal Performance Assessment of a Prefabricated External Insulation System for Building Retrofitting". This study evaluates the in situ thermal performance of a prefabricated composite panel comprising polyisocyanurate and concrete designed for building retrofitting. Despite the theoretical design expectations, the experimental results revealed a reduction in the thermal resistance of the system. Factors such as thermal bridges and the thermal bypass of insulation contribute to multidimensional heat flow, highlighting the importance of in situ tests. This study underscores the significance of understanding the performance gap between predicted and measured energy use in buildings and emphasizes the need for comprehensive assessments in retrofit applications.

Saeed [65] investigated the relationship between thermal conductivity and dielectric properties of wood and wood-based materials to enable rapid and accurate on-site building energy assessments. They underscored the importance of precise thermal conductivity measurements in evaluating building energy efficiency and suggested using dielectric properties to predict thermal conductivity, thus overcoming limitations of traditional methods. The study presented experimental findings from various wood samples and explored the potential of instrument development for inferring thermal conductivity from dielectric properties. It also addressed challenges in on-site thermal conductivity measurement and discussed the significance of dielectric properties across different domains. Rahiminejad [66] conducted experimental research on the hydrodynamics and thermal performance of ventilated wall structures. The study investigated the impact of outdoor conditions, façade orientation, and wall thermal capacitance on airflow velocity within

the cavity, surface temperature distribution, indoor heat flux, and heat transfer within air gaps. It primarily analyzed the thermal resistance caused by the ventilated gap. The findings underscored the importance of monitoring outdoor microclimatic conditions and optimizing air space ventilation rates to achieve high cavity thermal resistance and efficient heat recovery from air gaps.

In a parallel study, Maroy [67] focused on the adaptability layers of prefabricated insulation modules. This study investigated the use of prefabricated lightweight envelope modules for renovating existing buildings by focusing on the impact of the adaptation layer on thermal performance. Numerical analyses of two adaptation layer configurations across the three façade types assessed the influence of compression rate and airtightness. The results indicate potential thermal improvement when the joints are airtight; however, limitations arise with non-airtight joints. To prevent air leakage, an adaptation layer should be applied to the entire façade.

Shea [68] investigated the thermal properties of straw as a natural fiber insulation material. The document provides insights into thermal conductivity tests on straw samples, resulting in an estimated overall heat transfer coefficient of approximately 0.178 $W/m^2 \cdot K$ for a prefabricated straw-bale panel. A mention is made of its application in a test building at the University of Bath and offers valuable knowledge for designers working with natural fiber insulation materials.

4.3. Comparison of Documents from China and Other Countries

From the perspective of publication volume, China contributed approximately one-third of the total research publications in the last 15 years (see Figure 2). As shown in Figure 4, based on the co-authorship network in the prefabricated building research domain, it is indicated that China's publication output significantly exceeds that of other countries. In 2022, the volume of research publications from China exceeded that of other countries (see Figure 2), focusing more attention on China in this regard. Consequently, the citation count of Chinese literature was significantly higher than that of other countries (shown in Table 2).

In addition, we used VOSviewer to analyze the timeline overlay network of author keywords shared between China and other countries. Figures 8 and 9 show the timeline-overlayed network of author keyword co-occurrences in the documents from China and other countries, respectively. The size of each circle reflects the frequency of occurrence of each keyword in the literature. The connecting line widths indicate the frequency of co-occurrence between pairs of keywords. The color of the circles corresponds to the publication time of literature related to the research. As shown in Figures 8 and 9, in 2017, extensive research on prefabricated building was conducted in other countries, whereas relevant studies in China only emerged in 2020.

In summary, research on prefabricated buildings in other countries has progressed through stages such as "energy-efficient building system performance", "seismic performance research", and "thermal performance research". Currently, research is being conducted on the coordination, simulation, and performance optimization of prefabricated structures using building information modeling. The studies by Chinese scholars predominantly revolve around "construction techniques" and "performance of prefabricated building components", while also delving into "seismic performance".

By combining the information in Figures 8 and 9, it is evident that seismic performance research is a major focus in global prefabricated building studies. However, the research in other countries appears to be more comprehensive than that in China. Scholars from these countries not only investigate the joints of prefabricated structures but also delve into the material composition of the prefabricated components themselves. By contrast, research by Chinese scholars has tended to emphasize construction techniques. Currently, research on earthquakes primarily focuses on using numerical simulation software to accurately simulate the conditions of earthquake risk assessment and predict the performance of

prefabricated structures under various seismic scenarios. Simultaneously, optimization and adjustment of assembly components are conducted prior to construction.

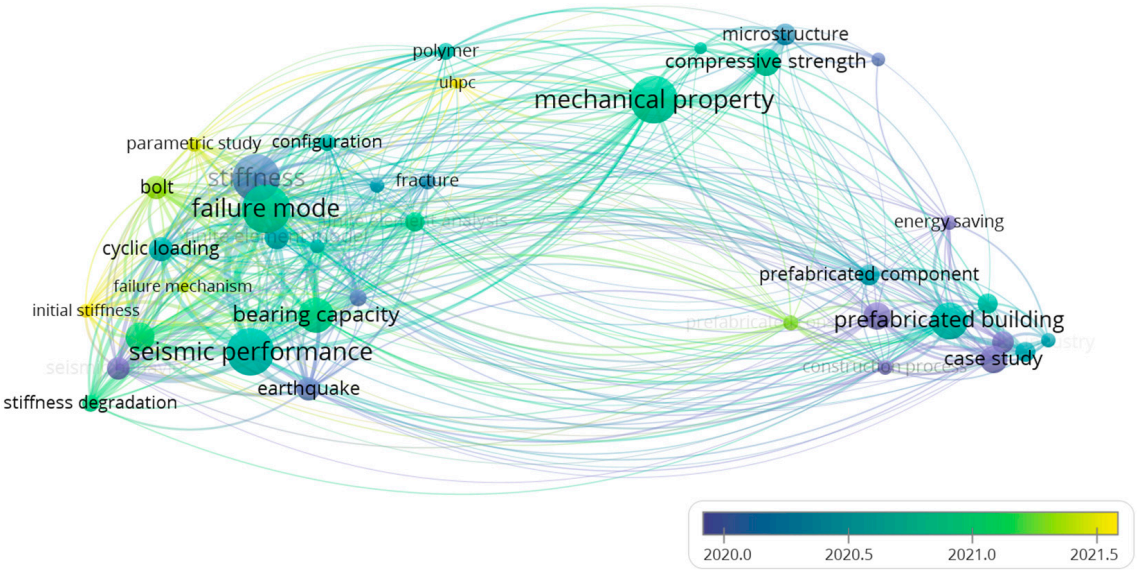

Figure 8. Timeline-overlayed network of author keyword co-occurrences in China's documents.

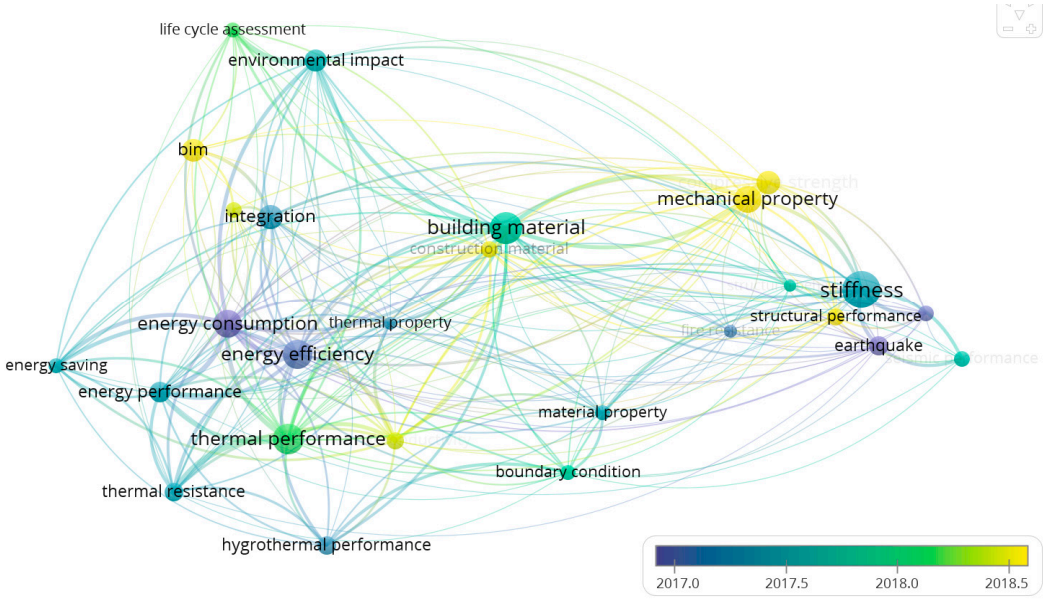

Figure 9. Timeline-overlayed network of author keyword co-occurrences in other countries' documents.

5. Conclusions

This study conducted a bibliometric review of studies on prefabricated building from 2007 to 2023. The analysis included the assessment of publication quantity, co-citation, co-authorship, and co-occurrence relationships in literature from China and other countries. The results of this study highlight a significant increase in the number of publications in the field of prefabricated building, underscoring its emerging importance as a key area for future research. This makes up for the gaps in previous studies, allowing researchers to better review previous studies. Furthermore, our analysis identified several primary research hotspots within the prefabricated building field, indicating specific areas that are garnering substantial academic interest and focus. Hence, future research could benefit from this study to acquire a deeper and more thorough comprehension of this topic.

- This study analyzed the co-citation network of publication sources, co-authorship network, co-citation network of authors, and network of co-occurrences of author keywords in the field of prefabricated construction research. Through these analyses, the development of prefabricated construction in China was compared with that in other countries. The comparison results indicate that seismic performance research is a major focus of global prefabricated construction research. In addition to this, scholars from other countries focus on the connections of prefabricated structures and the material composition of prefabricated components, while Chinese scholars tend to emphasize the improvement of construction techniques.
- The main focuses of research on prefabricated building include the following topics: seismic risk assessment and innovative design strategies for prefabricated building structures; structural strength and safety risk management encompassing understanding of the critical structural integrity and safety protocols of prefabricated structures; performance of prefabricated building components with the goal of enhancing the understanding of these components; energy-efficient building and sustainable development practices; and the importance of performance gaps between predicted and measured energy consumption in buildings, which requires comprehensive assessment.
- Considering the current state of prefabricated building development and the associated bibliometric analysis, it is evident that future international researchers can provide innovative insights in these areas: enhancing the environmental assessment of prefabricated buildings and reducing environmental impacts during construction; prefabricated component research to strengthen our understanding of the fundamental theoretical calculations for components; new materials to improve component strength; and examination of the current information on the behavior of prefabricated buildings under seismic and dynamic loads, which is insufficient and requires repeated experiments. It emphasized how recent developments in this field strengthen comprehensive research and provide important perspectives on development trends and innovative areas.

However, this study has certain limitations. First, there is a possibility of omissions or oversights in the literature retrieval and selection processes, which could lead to the exclusion of significant journals, authors, or papers. Additionally, emerging areas might not have been thoroughly considered owing to the limited relevant literature available. Furthermore, the recommendations proposed in this paper are somewhat reliant on the authors' opinions.

Author Contributions: Conceptualization, X.W., J.H. and T.L.; methodology, J.H., H.C. and T.L.; investigation, X.W. and J.H.; resources, X.W., H.C., X.B. and N.L.; writing—original draft preparation, X.W. and J.H.; writing—review and editing, J.H. and Y.H.; visualization, N.L., H.C. and X.B.; supervision, J.H. and T.L.; funding acquisition, J.H. and X.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research work is supported by the Key Research and Development Program of Gansu Province, China (Grant No. 22YF7FH224) and the Doctoral Research Fund of Shandong Jianzhu University (Grant No. X19080Z).

Acknowledgments: All of these financial supports are gratefully acknowledged. The authors also wish to thank Shandong Jianzhu University for providing access to the software and other facilities.

Conflicts of Interest: Authors Hongliang Cui, Yanlong He and Na Liu were employed by the company Jinan Energy Engineering Group Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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