buildings

MDPI

Article

Exploring Critical Factors Influencing the Resilience of the Prefabricated Construction Supply Chain

Tianyang Liu [1], Li Ma [2,*] and Hongwei Fu [3]

[1] Department of Construction Management, Dalian University of Technology, Dalian 116024, China; liutianyang@mail.dlut.edu.cn
[2] International School, Hainan Tropical Ocean University, Sanya 572022, China
[3] School of Urban Construction, Changzhou University, Changzhou 213164, China; hongweifu@cczu.edu.cn
* Correspondence: cm_mali@dlut.edu.cn

Abstract: In this volatile, uncertain, complex, and ambiguous (VUCA) era, resilient and sustainable construction methods, such as prefabricated construction, are essential for addressing the planet's sustainability challenges. However, disruptions in the prefabricated construction supply chain (PCSC) frequently arise, seriously impeding the performance of prefabricated building projects. Therefore, this study aims to identify the factors influencing the prefabricated construction supply chain (RPCSC) and analyze their intrinsic interconnections. Initially, an exhaustive literature review was conducted to identify the primary factors affecting the RPCSC. Subsequently, the Delphi technique was applied to validate and refine the list of factors, resulting in the identification of 11 key concepts. Finally, the impact of these concepts on the RPCSC, along with their interactions, was assessed using the fuzzy cognitive map (FCM) approach. The results indicate that these factors can be ranked by their degree of effect on the RPCSC: information exchange/sharing, research and development, the performance of prefabricated components, decision alignment, the construction of prefabricated buildings, relationship quality among members, professional management personnel/labor quality, supply–demand consistency, cost/profit sharing, policies and regulations, and transport risk. Furthermore, this study elucidates both the individual and synergistic effects of these factors on the RPCSC by constructing a pathway map.

Keywords: environmental pollution; prefabricated construction; supply chain; resilience; fuzzy cognitive maps (FCMs)

check for updates

Academic Editor: Pramen P. Shrestha

Received: 8 November 2024
Revised: 4 January 2025
Accepted: 16 January 2025
Published: 19 January 2025

Citation: Liu, T.; Ma, L.; Fu, H. Exploring Critical Factors Influencing the Resilience of the Prefabricated Construction Supply Chain. *Buildings* **2025**, *15*, 289. https://doi.org/10.3390/buildings15020289

1. Introduction

Over the past century, urbanization has led to significant improvements in the quality of peoples' lives and their levels of economic prosperity [1]. However, the rapid pace of urban development has resulted in serious challenges, including resource depletion, ecological degradation, and energy shortages [2,3]. As a fundamental industry that drives urbanization, the construction industry creates the physical entity of the city, but it has long been associated with high resource consumption, low productivity, and uneven quality [4]. Studies show that the construction industry accounts for 60% of global raw material use, 40% of energy consumption, and 12% of water usage [5,6]. As the negative impacts of the construction industry intensify, there is an increasing demand for resilient and sustainable construction methods. In recent decades, the construction industry has promoted modern techniques, such as prefabricated construction, which have garnered significant attention in many regions and countries [7].

Prefabricated construction comprises three primary stages: factory prefabrication, transportation, and on-site assembly. Specifically, components are manufactured in off-site factories using automated systems, and then transported to the construction site for assembly, forming a cohesive supply chain [8]. Compared to traditional methods, prefabricated construction reduces environmental impact while enhancing safety and production efficiency [9]. However, in practice, various uncertainties, such as irregular design interfaces, equipment malfunctions, material shortages, traffic delays, and inconsistent information sharing, often disrupt the prefabricated construction supply chain (PCSC) [10]. These uncertainties can lead to schedule delays and increased costs [11]. Masood et al. [10] observed that the PCSC, due to its vulnerabilities, does not consistently outperform traditional construction methods in practice. Therefore, strengthening the resilience of the prefabricated construction supply chain (RPCSC) is a crucial area for both practical improvement and academic research [12]. In industrial supply chains, the concept of "supply chain resilience" refers to the ability to withstand disruptions while maintaining functionality or to recover quickly [13].

The PCSC is characterized by diverse components, multiple transportation and storage segments, and interconnected modular flows, which make it highly vulnerable to disruptions from both internal and external factors [14]. Meanwhile, the close linkages between the nodes in the PCSC mean that any delays in production, transportation, and assembly can trigger a "snowball effect" throughout the entire supply chain [15]. Previous research has predominantly focused on evaluating the RPCSC and investigating the effects of specific factors, such as component production, transportation, and skilled labor [16,17]. However, these studies overlook the fact that RPCSC performance is the result of interrelated influences from multiple factors, so that the study of single factors or a few factors often fails to fully reflect their mechanisms of action. Therefore, it is particularly necessary to comprehensively identify these factors and integrate them into a framework to observe their interactions and combined effects on the RPCSC's performance. Furthermore, the methods applied in previous studies often lacked systematic approaches, and they often failed to provide managers with adequate decision support when facing complex, dynamic, and uncertain environments [18,19]. The gap in academic research leaves practitioners without a clear understanding of the main factors affecting the RPCSC and how these factors affect it both directly and indirectly.

To address the lack of systematic analysis in research on factors influencing the RPCSC, a comprehensive review based on an integrative approach is needed. Moreover, for tacit and subjective knowledge regarding the mechanism of influences exerted by factors affecting the RPCSC, the cognitive maps method serves as aneffective tool. This method relies on the cognitive perceptions of expert teams to establish the structural and operational logic of systems under different conditions and improve the resolution of the system representation's through further mapping. Notably, due to the subjective and ambiguous nature of expert cognition and assessments, traditional multi-criteria decision-making applications often yield imprecise, uncertain, and qualitative outcomes. In response to this challenge, Zadeh (1965) [20] introduced the theory of fuzzy sets, a mathematical approach for addressing fuzziness by converting experts' linguistic preferences or uncertainties into numerical values or ranges using membership functions. To capitalize on the strengths of both approaches, the fuzzy cognitive maps (FCMs) method was proposed. It is widely applied in researching various real-world scenarios, including stock investment analysis, regulatory system control, child labor studies, and community mobilization for disease prevention and control [21]. Thus, this study integrates a systematic literature review with the FCMs method to systematically identify key factors influencing the RPCSC and elucidate the pathways of their effects.

This study provides members of the prefabricated construction supply chain with a clearer understanding the underlying causes of disruption, enabling them to identify problematic areas and future directions for improvement. Additionally, this research prioritizes areas for future studies, aiming to address disruptions in the PCSC. The structure of the paper is as follows: Section 2 presents a comprehensive literature review of the RPCSC. The identification and integration of factors, and the illustration of the FCMs method and proposed procedures, is addressed in Section 3, followed by the presentation of empirical findings in Section 4. Section 5 discusses the implications of the research results for management and theory. The concluding remarks and suggestions for future research are presented in the final section.

2. Literature Review

2.1. Prefabricated Construction Supply Chain

The prefabricated construction supply chain (PCSC) refers to the interconnected flow of funds, information, materials, and knowledge among general contractors, subcontractors, suppliers, and developers during the processes of designing, constructing, transporting, assembling, and delivering prefabricated buildings [22]. Compared to traditional construction projects, the PCSC is notably more complex. First, the PCSC is expanded due to the involvement of multiple production environments, namely, the factory and the construction site [23]. Second, prefabricated construction requires more extensive design work and earlier planning compared to cast-in-place construction, as prefabrication lead times must be accounted for [24]. Third, the time needed for error correction is generally longer [25]. As a result, while the PCSC can offer higher production efficiency, it is also subject to various uncertainties, such as machine breakdowns, shortages of production materials, and traffic delays [26]. Practical experience indicates that these uncertainties and risk events frequently disrupt the PCSC, leading to significant project delays and cost overruns [27].

Current studies on PCSC management primarily focus on three key areas. First, many studies are devoted to figuring out the elements that hinder or drive the development of the PCSC [28,29]. However, there are notable inconsistencies and even conflicts in these studies. For example, Stroebele et al. [30] argue that the most important factors affecting the PCSC are infrastructure preparations on site, such as foundation work and the availability of water and power supplies. Conversely, Wuni and Shen [31] emphasize that robust design specifications are the most critical ones. Second, the operation of the PCSC is inherently complex and lacks standardization, resulting in a variety of unpredictable supply chain risks [32]. Accurately identifying and evaluating these risks can help stakeholders to better prevent and manage them [33,34]. Additionally, the integration of the PCSC has garnered considerable attention. In practice, while the members of the PCSC strive to optimize their own interests, the overall interests of the PCSC are often overlooked [35]. Therefore, it is essential to establish effective cross-organizational cooperation mechanisms to coordinate strategies among PCSC members, thereby achieving the goal of integrating the PCSC. Furthermore, it is important to note that technological advancements play an increasingly significant role in improving the operational efficiency of the PCSC. Recent studies have explored the application of advanced technologies in production, transportation, assembly, and information exchange within the PCSC [36,37].

2.2. Resilience of the Prefabricated Construction Supply Chain

The term "resilience" has its roots in materials science, ecology, and psychology [15,38]. In materials science, it refers to the ability of a substance to revert to its original shape after deformation. In ecological terms, resilience describes how quickly and effectively an ecosystem can regain its structure and function after a disturbance [15]. Given its relevance to supply chain disruptions, resilience is increasingly integrated into supply chain management. A fundamental view of supply chain resilience is that not all risks can be fully mitigated, and therefore the focus needs to be on the supply chain network's capacity to recover to its original or optimal state following disruptions [39]. The speed at which the supply chain returns to a normal state, encompassing various aspects such as production, service, and supply ratios, serves as a reflection of its level of resilience [40].

Regarding supply chain resilience dimensions, initial perspectives identify two main components: resistance and recovery. Conz and Magnani [41] emphasize that a system's resistance to disruptions can be understood through two mechanisms: absorptive and adaptive mechanisms. As such, supply chain resilience can be categorized into absorptive, adaptive, and restorative capacities—a viewpoint has gained broad consensus among scholars [42,43]. The evaluation of supply chain resilience constitutes the second primary concern. Various qualitative and quantitative methods, including the time absolute error method, dynamic Bayesian networks, and expert consultation, have been employed to assess resilience levels and their impact on overall performance [44,45]. These studies lay the groundwork for the third research theme of enhancing resilience performance. For example, recent studies have confirmed that embedding redundancy can bolster absorptive capacity, while dynamic logistics and information sharing can enhance restorative capacity. Furthermore, procurement flexibility can improve adaptive capacity [46,47].

Compared to other manufacturing supply chains, the prefabricated construction supply chain (PCSC) faces unique challenges, such as low product standardization and significant transportation hurdles [48,49]. These challenges heighten the vulnerability of prefabricated construction, often leading to severe delays and cost overruns. To manage the risks associated with the PCSC effectively, several risk management models have been devised [32,34,50]. However, these models often face practical limitations due to their cumbersome application in real-world scenarios [51]. In addition, with the advancement of information technology, researchers have explored the application of new technologies such as RFID, blockchain, and IoT to improve the rate of information exchange [19,37,52].

Overall, despite the valuable insights offered by existing studies, several significant gaps remain. First, the current literature primarily focuses on isolated aspects of the RPCSC, failing to integrate the factors influencing the RPCSC into a comprehensive framework. Second, while some studies have identified factors influencing RPCSC resilience, there is a lack of consensus regarding their relative importance and interrelationships. Finally, few studies adopt systematic methodologies to examine how these factors interact to influence the RPCSC. These gaps have hindered both academics and practitioners in efforts to effectively improve the RPCSC. Therefore, this study aims to systematically identify the factors influencing the RPCSC and analyze their intrinsic interrelationships, ultimately providing a theoretical blueprint for strengthening the RPCSC.

3. Method

The structured method adopted in this study was divided into two phases. In the first phase, the RPCSC-related literature was searched and analyzed to identify the factors that have been noted by academics as affecting the RPCSC. Subsequently, the Delphi method was applied to complement, classify, and summarize these factors to establish the core concepts affecting the RPCSC. The second stage is the development of fuzzy cognitive maps (FCMs). To reveal the connections among these core concepts and their pathways and establish their levels of influence on the RPCSC, FCMs were applied. First, a questionnaire was designed to assess the relationships between the concepts, and then the results were transformed into an adjacency matrix and iterative calculations were performed to determine the steady state of the system. Finally, the results were analyzed to disclose the underlying mechanism of the RPCSC system. The specific research steps are shown in Figure 1.

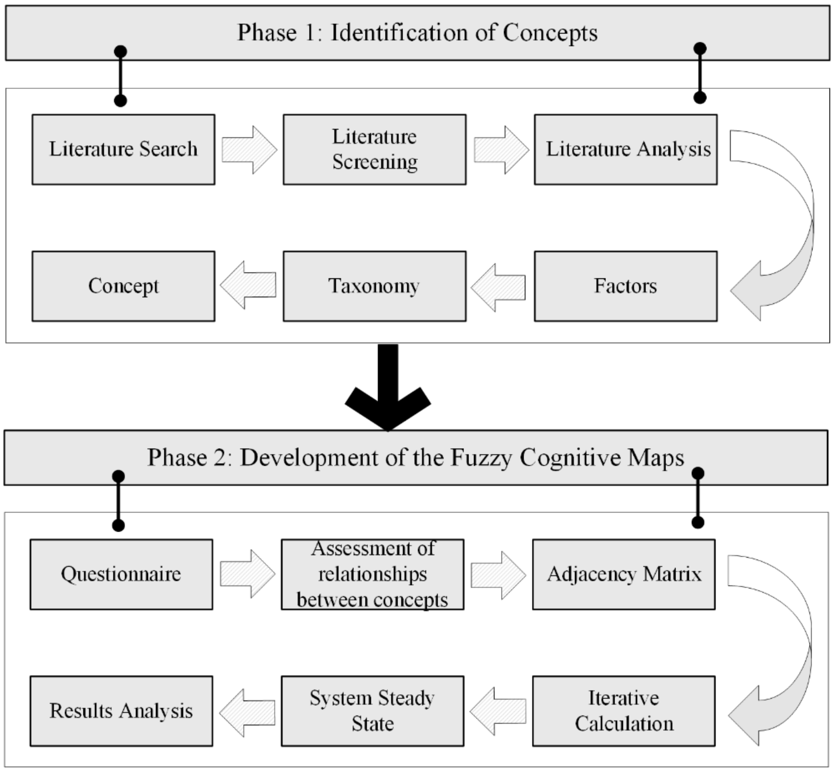

Figure 1. Research approach.

3.1. Concept Identification

3.1.1. Factor Screening

To identify the factors influencing the resilience of the prefabricated construction supply chain (RPCSC), this study began with a thorough literature review. Web of Science and Scopus were selected to search for publications. Keywords related to prefabricated construction included "prefabricated building", "prefabricated construction", "industrialized building", "industrialized construction", "modular building", and "modular construction"; the keyword relating to supply chains was "supply chain". The purpose of this study was to search for and analyze any potential risk factors (such as political risks), practices (such as innovation), and other aspects (such as partnerships) that affect the RPCSC. Therefore, keywords related to resilience included "resilience", "risk", "disruption", "sustainability", "uncertainty", and "vulnerabilities". For example, the research team searched the Web of Science database with the following formula: TI = (prefabricated OR industrialized OR industrialized OR modular) AND TI = (supply chain) AND TI = (resilience OR risk OR disruption OR sustainability OR uncertainty OR vulnerabilities). For all items searched, a review of titles and abstracts was conducted to determine whether they met the objectives of this study, and subsequently, items that were duplicated in both databases were removed. Finally, a total of 47 relevant items were obtained and downloaded in full-text formats from the corresponding databases.

Subsequently, a two-stage literature screening process was utilized to ensure the accuracy of the study's findings. In the first stage, two team members independently evaluated each of the 47 papers for relevance to the research theme. The results were then cross-referenced, and any contentious papers were discussed. As a result, 30 papers that aligned with the study's objectives were selected. In the second stage, the two team members independently reviewed the factors identified in these 30 papers and compared their findings. In cases where a consensus could not be reached, a third team member acted as an adjudicator. All the factors influencing the RPCSC mentioned in this literature are listed in Supplementary Materials.

3.1.2. Taxonomy

Due to the partial or complete overlap of identified factors, it was necessary to consolidate these factors into distinct, independent concepts. To achieve this, we employed the Delphi method—a structured communication process well suited for situations with conflicting or incomplete information. The Delphi technique is recognized for its ability to accurately build consensus and make informed decisions under such circumstances [50]. The research team first selected twenty authors who had published two or more peer-reviewed papers on the PCSC and contacted them via the email address provided in their publications. These authors were invited to participate in the study, and the email included an explanation of the study's purpose and process. Nine experts responded, with six expressing their willingness to participate. To further balance potential differences between theoretical research and practical industry insights, the research team also contacted twelve managers from leading prefabricated component manufacturers (e.g., Gold Mantis Building Decoration Enterprise Group, Broad Homes Industrial Group) and contractors in prefabricated construction (e.g., China State Construction Engineering Corporation, Shanghai Construction Group). Seven managers agreed to participate in the study. While there is no consensus in the literature on the ideal size of expert panels, Yong et al. [53] recommend that 7 to 15 experts are generally appropriate. Based on this criterion, the number of experts involved in the study was deemed sufficient.

This study was conducted from March to May 2024. First, the team eliminated duplicated factors in the literature and formed an initial list influencing the RPCSC. This list was emailed to 13 experts, who were asked to integrate and categorize the factors. The guiding principle was to group factors with similar connotations and represent each group with a distinct concept, ensuring that each set of factors remained independent of the others. After the first round, the research team compiled the experts' feedback and sent the results back to them for review, asking if they wished to revise their initial responses. The second round followed the same process as the first. By the end of the third round, all experts had reached a consensus on the factors influencing the RPCSC, resulting in the identification of 11 key concepts, as shown in Table 1.

Table 1. Research approach.

Code	Concept	Description	Main Factors Involved
C1	The performance of prefabricated components and equipment	All issues related to component design and production.	The performance of prefabricated components, the unproven durability of prefabricated goods, geometric and dimensional intolerance, and the performance of transport and lifting equipment.
C2	Construction of prefabricated building	Factors related to the construction of prefabricated buildings.	Construction technology used for prefabricated components, machine breakdown, safety issues, and the installation errors of precast elements.

Table 1. *Cont.*

Code	Concept	Description	Main Factors Involved
C3	Policies and regulations	The completeness and changes of laws and regulations related to the prefabricated building supply chain.	Local government policy preferences, implementation of new laws/regulation, changes in the political economy, and the unreasonable site layout of prefabricated components.
C4	Information exchange/sharing	The type, quantity, form and medium of information exchange between supply chain members.	Communication breakdown/issues, information loss, inadequate IT systems, and information misuse.
C5	Transport risk	All risks that may occur during prefabricated components and raw material transportation.	Transport disruptions, including port stoppages, site logistics, damage to prefabricated elements during transportation.
C6	Research and development (R&D)	The process and elements of supply chain members developing new technologies and new products.	Technology failure, the cost of technology investment share, cooperative innovation, the absence of standard modular components, a monopoly of techniques by a few firms, and a lack of R&D input.
C7	Decision alignment	The degree of consistency of management decisions of supply chain members.	Conflict resolution, buffer space hedging, strategy alignment, solution consistency, and inappropriate business strategies.
C8	Professional management personnel/labor quality	The quantity and quality of managerial personnel, labor of the members of the prefabricated construction supply chain.	A lack of highly skilled workers, insufficient construction capacity, a lack of management best practices, inaccurate cost estimation, and operation efficiency.
C9	Relationship quality of members' relationships	The level of friendship and trust among members of the prefabricated building supply chain.	Relationship coordination, poor cooperation across multiple interfaces, trust between members, and stakeholders' lack of awareness.
C10	Supply–demand consistency	The degree of matching between products and demand in the prefabricated building supply chain.	Variations and/or rework, quality loss, supply–demand mismatch/shortages, supply–demand mismatches, or shortages.
C11	Cost/profit sharing	Reasonable and fair degree of cost and benefit distribution among members of assembly building supply chain.	Cost of technology investment share, and transaction costs.

3.2. *Fuzzy Cognitive Maps (FCMs)*

Prefabricated construction supply chain operations involve multiple participants and complex interactions, making them susceptible to interference from a variety of internal and external factors. Mathematical and statistical methods are insufficient to fully represent these complex causal chains and feedback paths. To achieve this study's objectives, the fuzzy cognitive maps (FCMs) method is adopted. FCMs are modeling tools based on graph theory and fuzzy set theory, and they were first proposed by Kosko (1986) [54]. It helps researchers to analyze the interaction and feedback mechanisms of factors in complex systems by constructing conceptual nodes and their causal networks. This study applies this approach to integrate expert cognition into causal association modeling, which can visually describe the interaction mechanisms of factors within the system and their influence paths on the RPCSC.

The topological structure of FCM modeling is a triple pattern G = (*C*, *E*, *W*), where C = {C_1, C_2,. . ., C_n} represents the set of *n* concept nodes in FCMs; E = {<C_i, C_j> | C_i, C_j∈C} is the causal-association-directed arc between all nodes in FCMs (directed arc <C_i, C_j> means that node C_i has a causal relationship or influence on C_j); and W = {w_{ij}} is the weight of the directed arc <C_i, C_j>. w_{ij} represents the degree of influence of node C_i on C_j, and the value range is [−1, 1], where the following rules apply:

If $w_{ij} > 0$, it means that w_i has a positive effect on w_j;

If $w_{ij} < 0$, it means that w_i has a negative influence on w_j;

If $w_{ij} = 0$, it means that w_i has no effect on w_j, and there is no arc connection between w_i and w_j.

FCMs with *n* concept nodes can be uniquely determined by an interaction matrix W = $(w_{ij})_{n\times n}$. For example, Figure 2 is a fuzzy cognitive map, and its corresponding interaction matrix W can be expressed as shown in Equation (1):

$$W = \begin{bmatrix} 0 & w_{12} & 0 & 0 & 0 & w_{16} \\ w_{21} & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{32} & 0 & w_{34} & w_{35} & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{46} \\ 0 & 0 & 0 & w_{54} & 0 & 0 \\ 0 & 0 & w_{63} & 0 & w_{65} & 0 \end{bmatrix} \quad (1)$$

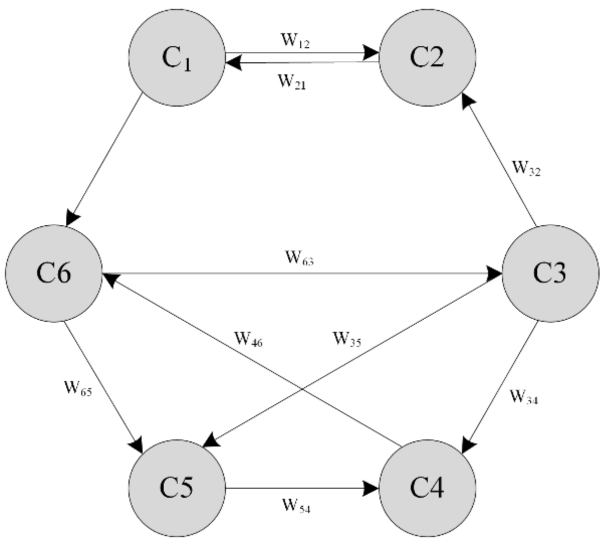

Figure 2. A simple FCM.

The reasoning mechanism behind FCMs is the evolution process of an event based on its topological structure, in which each concept node *Ci* represents a certain sub-event in the event, often driven by other sub-events, such as C_j. The degree of the drive is determined by the causal (correlation) strength between *Ci* and C_j. This strength is the weight w_{ij} of the directed arc < C_i, C_j > in FCMs. The reasoning process of FCMs is realized by the recursive effect of the forward node on the backward node state, and the specific steps behind this are as follows:

(a) It is necessary to determine an initialized state vector A_n (0);
(b) It is necessary to obtain the interaction matrix with the help of expert knowledge and experience;

(c) Multiple iterative calculations of the initial state vector are carried out through Equations (2) and (3). When the final result satisfies A_n (t) = A_n (t + 1), the iteration is stopped. At this time, FCM reaches A stable state, and the whole iteration process ends.

$$A_i^{(t+1)} = f(A_i^{(t)} + \sum_{j=1, j\neq i}^{n} w_{ji} A_j^{(t)}) \tag{2}$$

where $A_i^{(t+1)}$ the value of concept C_i at the step $t + 1$, $A_i^{(t)}$ is the value of the each interaction of the interconnected concept C_j at step t, w_{ji} is the weighted arc from C_j to C_i, and f is a threshold function used to make sure the node concept value remains in the interval [0, 1]. It can be the Sigmoid threshold function:

$$f = \frac{1}{1 + e^{-\lambda x}} \tag{3}$$

where $\lambda > 0$ determines the steepness of the continuous function f. The Sigmoid function is usually used when the concept interval is [0, 1].

4. Results

4.1. Case Information

Over the past decade, the Chinese government has actively promoted prefabricated construction through a series of policies, aiming for prefabricated buildings to account for 40% of new urban construction by 2030. However, prefabricated construction projects still represent a relatively small portion of China’s construction industry. In practice, the prefabricated construction supply chain (PCSC) lacks standardization and is frequently disrupted, severely limiting productivity. Consequently, this study examines how various internal and external factors impact China’s PCSC, with the goal of helping PCSC members to collaborate more effectively to enhance the resilience of the prefabricated construction supply chain (RPCSC).

This survey was conducted using a Chinese version of the questionnaire. It was developed by the research team and revised by three professors specializing in prefabricated construction, along with three senior executives with over 15 years of experience in the production and construction of prefabricated buildings. Data were collected from the Chinese prefabricated construction industry using a convenience sampling method via electronic questionnaires. Given that China has a large number of prefabricated building component manufacturers and construction companies, dispersed across various cities and provinces, the use of convenience sampling and email communication helped to improve the response rate.

To ensure that a representative sample was obtained, the survey targeted CEOs and managers from the top 30 component manufacturers and 30 prefabricated construction companies, based on 2022 corporate revenue rankings. These participants were invited to assess the interactions between various factors and their influence on the RPCSC. Respondents were asked to rate the strength of causality between concepts using the options “no”, “very low”, “low”, “medium”, “high”, and “very high”. The direction of influence between concepts was indicated by a positive (+) or negative (−) sign. By the questionnaire submission deadline, 43 completed responses had been received, resulting in a response rate of 71.67%.

4.2. Case Analysis

Given the inherent vagueness in expert language and the variation in expert opinions, linguistic values must be converted into numerical weights using the triangular fuzzy number method to facilitate data processing. The conversion format for each linguistic value is illustrated in Figure 3. Once the linguistic values are converted, the fuzzification step is performed to transform the triangular fuzzy numbers into precise values. There are several methods for defuzzification, with the center-of-gravity method being the most commonly used. The specific calculation rules for this method are presented in Equation (4).

$$U^* = \frac{\sum_{i=1}^{n} (A_i \times L_i)}{\sum_{i=1}^{n} A_i} \tag{4}$$

where n is the number of experts, A_i represents the area covered under each fuzzy set, and L_i represents the midpoint of the fuzzy set on the X-axis.

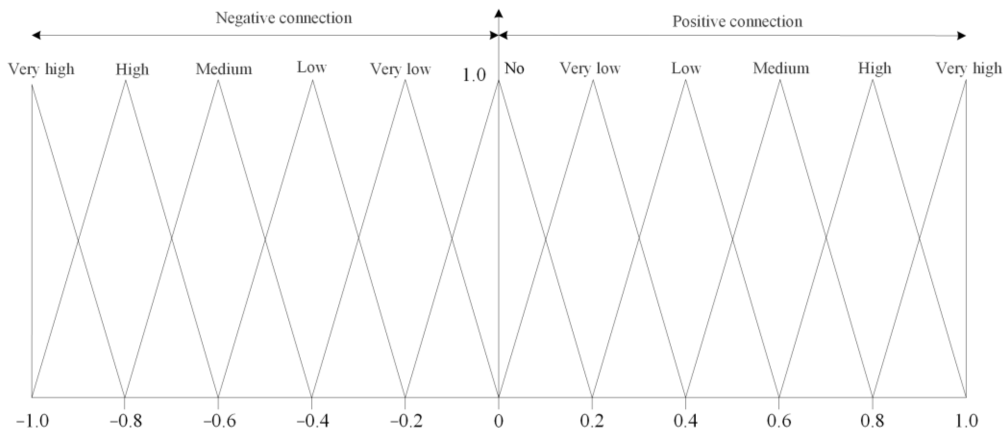

Figure 3. The membership function used to deffuzify linguistic values.

Equations (1) and (4) were applied to aggregate experts' opinions to obtain the quantitative value W_{ij} of the relationship between all conceptual nodes and establish their impact on the RPCSC, and the results are shown in Table 2. Due to the simplicity of the FCM calculations, the w_{ij} values in the interval [−0.1, 0.1] are set to zero. The cognitive map is sketched (Figure 4) according to the final interaction matrix. As shown in Figure 4, all 11 core concepts have significant influence on PRCSC, meanwhile, Figure 4 demonstrates the influence paths between the factors. Notably, professional management personnel/labor quality (C8) and policies and regulations (C3) only affect other factors, without being influenced by other factors, which indicates that they are the two most fundamental factors emerging from the PCSC system itself and the external environment, respectively.

Table 2. The final interaction matrix.

Code	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	RPCSC
C1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.395	0.000	0.298
C2	0.363	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.172
C3	0.274	0.200	0.000	0.000	−0.134	0.176	0.377	0.000	0.302	0.000	0.000	0.758
C4	0.186	0.144	0.000	0.000	−0.456	0.771	0.835	0.000	0.815	0.775	0.447	0.660
C5	−0.288	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	−0.186	0.000	−0.493
C6	0.819	0.642	0.000	0.000	−0.214	0.000	0.000	0.000	0.000	0.530	0.000	0.353
C7	0.311	0.000	0.000	0.000	−0.358	0.000	0.000	0.000	0.633	0.856	0.535	0.716
C8	0.823	0.842	0.000	0.521	−0.344	0.771	0.200	0.000	0.381	0.260	0.358	0.493
C9	0.000	0.000	0.000	0.847	−0.521	0.433	0.846	0.000	0.000	0.651	0.637	0.805
C10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.693
C11	0.000	0.000	0.000	0.000	0.000	0.335	0.000	0.000	0.479	0.000	0.000	0.488
RPCSC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

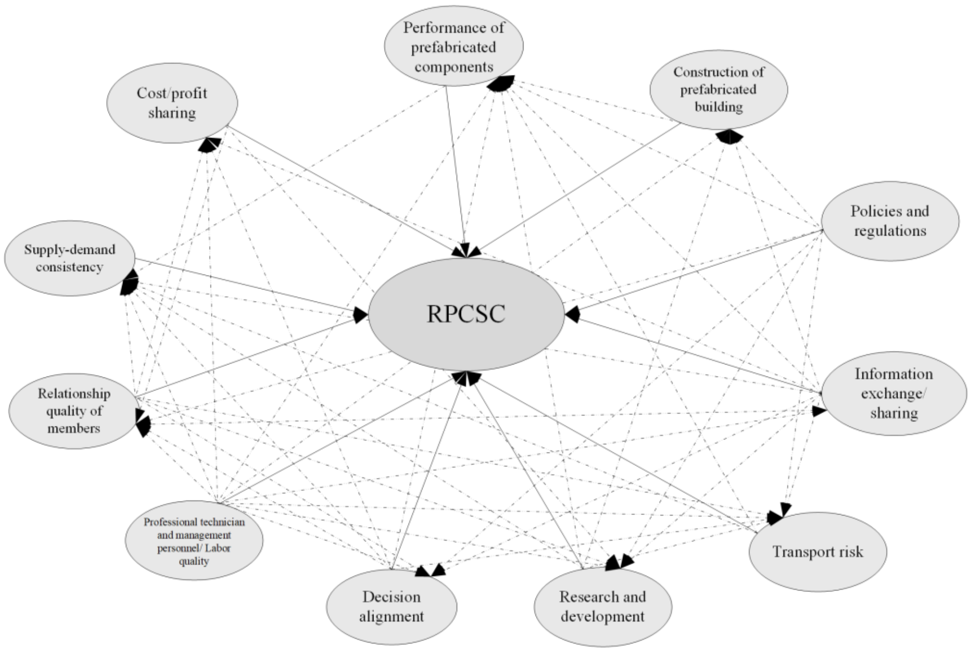

Figure 4. A cognitive map of factors influencing the RPCSC.

To reveal the relative effect level of all factors on the RPCSC, the iterative calculation is conducted according to Equations (2) and (3). In consideration of the simplicity of calculation and the speed of convergence of each concept, it is necessary to set $\lambda = 1$ in Equation (3) [55]. Before the iterative computation starts, the initial states of all nodes need to be set. Since the calculation results of the FCM method are not affected by the initial state vector, the research team set the initial state vector A(0) = (0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2). After 7 rounds of iterative computation, the criterion $A_n(t) = A_n(t+1)$ is satisfied, the system reaches a stable state, and the computation ends. Table 3 shows the state values of all nodes at the end of each round of iterative computation, and correspondingly, the trend of the state values of each concept is presented in Figure 5.

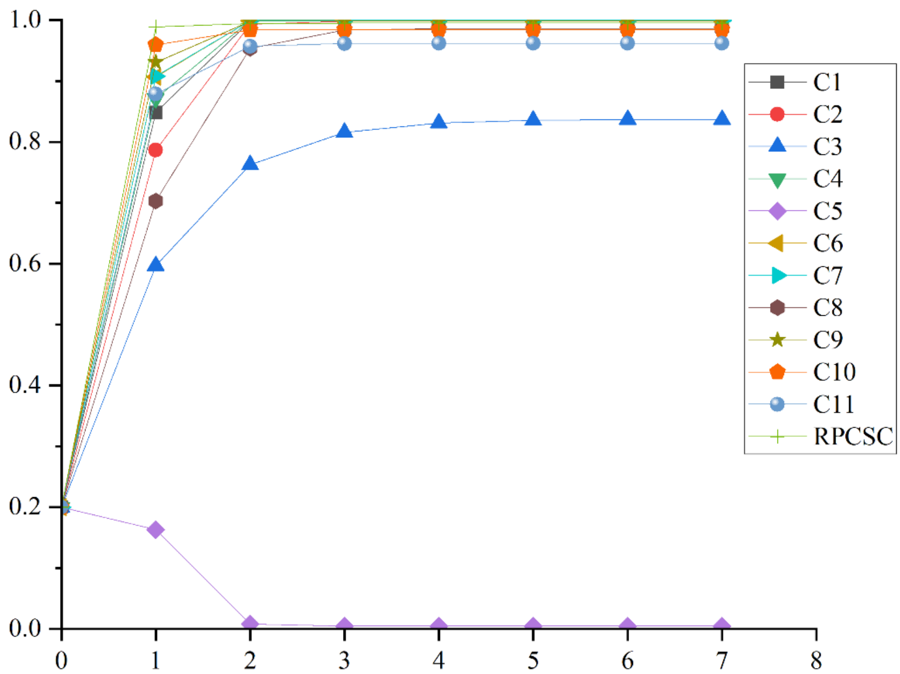

Figure 5. Change trend of concepts.

Table 3. The state value of concepts.

Iterative Rounds	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	RPCSC
0	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
1	0.8482	0.7865	0.5964	0.8711	0.163	0.9067	0.9079	0.7029	0.9307	0.9595	0.8787	0.989
2	0.9987	0.9931	0.7622	0.9997	0.0079	0.9991	0.9992	0.9537	0.9976	0.9839	0.957	0.9945
3	0.9997	0.9981	0.8159	0.9999	0.0048	0.9997	0.9996	0.9838	0.9983	0.9844	0.9614	0.9948
4	0.9997	0.9983	0.8311	0.9999	0.0046	0.9998	0.9996	0.9857	0.9983	0.9844	0.9617	0.9949
5	0.9997	0.9983	0.8352	0.9999	0.0046	0.9998	0.9996	0.9858	0.9983	0.9844	0.9617	0.9949
6	0.9997	0.9983	0.8363	0.9999	0.0046	0.9998	0.9996	0.9859	0.9983	0.9844	0.9617	0.9949
7	0.9997	0.9983	0.8366	0.9999	0.0046	0.9998	0.9996	0.9859	0.9983	0.9844	0.9617	0.9949

From Table 3 and Figure 5, it can be seen that the overall level of the RPCSC in China is expected to continue to improve and reach a high steady-state level, which indicates the huge development potential of prefabricated construction in China. For the factors affecting the RPCSC, the order of importance is as follows: C4 (information exchange/sharing), C6 (research and development), C1 (performance of prefabricated components), C7 (decision alignment), C2 (Construction of prefabricated buildings), C9 (quality of members' relationships), C8 (professional management personnel/labor quality), C10 (supply–demand consistency), C11 (cost/profit sharing), C3 (policies and regulations), and C5 (transport risk). Overall, the continuous improvement in the status and situation of these factors ultimately improves the RPCSC in China. It is worth noting that the calculation results show a gradual decrease in the state value of C5, which demonstrates that the transportation risk of prefabricated components gradually decreases along with the improvement in other factors.

5. Discussion

The goal of this study is to enhance the resilience of prefabricated construction supply chain (RPCSC) in China. The proposed systematic factor identification and fuzzy cognitive maps method categorizes the factors influencing the prefabricated construction supply chain (PCSC) and reveals the complex interactions among them. These insights help PCSC member companies and practitioners to understand the impact of their roles on the RPCSC and guide their efforts to improve it.

The findings indicate that information exchange and sharing (C4) are the most critical factors affecting the RPCSC. Previous research has highlighted the persistent challenges faced in information exchange within the PCSC. Ekanayake et al. [48] found that while prefabricated construction can significantly enhance efficiency, the lack of real-time information sharing often leads to fragmentation and disruptions. For example, inadequate real-time communication regarding assembly planning, production scheduling, and logistics often results in project delays and increased costs. Consequently, scholars have emphasized the potential of information interaction platforms based on ICT technology or blockchain technology to enhance the efficiency of information exchange among members and bolster the RPCSC [56,57].

Additionally, as indicated in Figure 4, the relationship quality (C9) influences information exchange among supply chain participants, suggesting that strong relationships are the basis of willingness to share and exchange information. Effective communication and coordination are essential in the PCSC for various stakeholders such as component manufacturers, designers, transporters, prime contractors, subcontractors, and owners. A prime example of this is the need for seamless communication among designers, component manufacturers, and construction contractors to ensure that design changes are aligned with component production capacity and assembly technology [58]. This process heavily relies on fostering a strong relationship among these members of the supply chain. However, Hofman et al. [10] found that in practice, the relationship between the members of the PCSC is disconnected and distrusted, leading to frequent disruptions in the PCSC. Therefore, an important effort for all supply chain members is to seek to establish strong formal and informal relationships with upstream and downstream partners to build trust, which will enhance their willingness to exchange and share information.

Research and development (R&D) (C6) is the second most influential factor affecting the RPCSC, following information exchange and sharing. Compared to traditional construction supply chains, the PCSC enables the standardized production of components and standardized assembly at construction sites, offering clear advantages in terms of product quality and production efficiency. However, the PCSC currently faces significant challenges in production, transportation, and assembly, leading to frequent disruptions. One major limitation is the restricted range of prefabricated components available, which does not fully satisfy the diverse and personalized demands of customers [25]. Additionally, due to incomplete technological advancements, the performance of prefabricated components (C1), including safety and durability, often faces skepticism [59]. A key factor contributing to these challenges is the insufficient level of R&D investment by PCSC member companies. Wu et al. [60] noted that prefabricated construction occupies a relatively small market share compared to traditional methods, which may lead to diseconomies of scale arising from high R&D expenditures. Nonetheless, the prefabricated construction market presents promising growth potential. Thus, supply chain members should increase their R&D investment through various means, such as financing and joint R&D efforts, to gain an early competitive advantage [61]. The government could also consider subsidizing R&D costs for prefabricated component firms to further incentivize innovation.

Decision consistency (C7) is the third factor impacting the RPCSC. This finding aligns with previous studies showing that one of the key reasons for the slow development of prefabricated construction in China is the lack of strategic alignment among key stakeholders [59]. In China, local governments, owners, contractors, and component manufacturers exert significant influence on the PCSC [24]. These stakeholders often pursue different objectives based on their own interests. For example, owners and contractors may favor customized building products using non-standardized prefabricated components, while component manufacturers prefer to increase production efficiency through greater standardization [62]. Disconnected decision-making processes between stakeholders may lead to inefficiencies, such as production delays or rework during assembly. Therefore, supply chain members may consider establishing strategic alliances to coordinate the needs of all parties to reduce potential decision-making conflicts in component design, production, and construction.

Finally, the construction of prefabricated buildings (C2) also plays a significant role in the RPCSC. While prefabricated construction simplifies the construction process compared to traditional methods, the technical complexity and quality requirements of the procedures are higher [63]. Moreover, as prefabricated construction is still in its early stages of promotion in China, contractors lack professional assembly workers and managers [64]. Numerous studies have indicated that quality defects in prefabricated construction are primarily caused by assembly errors, and that these errors are predominantly attributed to the low skill level of assembly workers and managers [16]. In practice, such defects in the assembly process often result in quality issues, cost overruns, schedule delays, and even disruptions to the entire supply chain. Therefore, prefabricated component manufacturers and contractors must prioritize the training of managers and workers to ensure they possess the necessary knowledge and skills for prefabricated construction, thereby improving the quality of both component production and assembly.

6. Conclusions

Compared to traditional construction methods, prefabricated construction offers several advantages, such as reduced environmental pollution, lower resource consumption, and increased productivity. However, the PCSC in China is frequently interrupted by various factors, resulting in decreased efficiency. In this context, improving the RPCSC has become a significant challenge. This study identified 11 categories of factor affecting the RPCSC through a comprehensive literature review and the Delphi method. Subsequently, the fuzzy cognitive map method was employed to evaluate the relationships between these concepts and their degrees of impact on the RPCSC. These findings provide guidance for strategic planning among prefabricated construction supply chain members in China, as well as for government efforts to enhance the level of the RPCSC. Furthermore, in practice, prefabricated construction supply chain members and governments remain unclear about how and to what extent they, as key stakeholders, affect the RPCSC. This study addresses this gap by revealing the mechanisms through which the factors identified influence the RPCSC, enabling stakeholders to recognize their shortcomings and future areas for improvement. For example, the findings suggest that the top priority for all prefabricated construction supply chain members in China should be to enhance information sharing across the entire supply chain. For component manufacturers, investing in R&D is a crucial measure with which to strengthen the RPCSC. Meanwhile, for construction contractors, improving the skills and knowledge of assembly workers and managers is an urgent task.

The findings of this study have substantial theoretical and practical implications. Currently, theoretical research on the RPCSC is limited. It is not clear which factors affect the RPCSC. Using a literature review and the Delphi method, this study identifies the factors affecting the RPCSC, on the basis of which this study explains the linkages between these factors using the fuzzy cognitive map method. The relevant findings provide directions for future research on RPCS improvement mechanisms. Moreover, in practice, the vulnerability of the PCSC severely delays the construction schedule and leads to increased costs. Practitioners in the PCSC need to examine and evaluate the deficiencies in PCSC to enhance the PCSC through more effective measures. This study offers a framework that can assist them in effectively identifying the factors that influence the RPCSC and the relationships among these factors. For example, this study finds that the relationship quality of members is the most crucial factor influencing the RPCSC. Consequently, contractors, suppliers, and designers of prefabricated construction must carefully evaluate and improve their relationships with upstream and downstream supply chain members, emphasizing communication and interaction. Overall, the findings presented in this paper are helpful for industry professionals seeking to enhance the RPCSC and improve the performance of prefabricated construction.

Although this study achieved notable theoretical and empirical advancements, it is important to recognize certain limitations. First, this study identified factors influencing the RPCSC through a comprehensive literature review; however, there may still be gaps in the completeness of factor identification. Future research should attempt to find more factors influencing the RPCSC by utilizing alternative methods, such as extensive interviews and multiple case studies. Additionally, this study applied the fuzzy cognitive maps method to analyze the interactions and effects of factors affecting the RPCSC; however, it had limitations regarding sample size and respondent diversity, notably the absence of participants from government departments. Therefore, future studies should expand the sample size and respondent sources, and consider incorporating more quantitative measurements to obtain more accurate and reliable results. Finally, the generalization of the results may be another limitation of this study. The respondents based their answers on the current state of the prefabricated construction supply chain in China; thus, the applicability of these findings to stakeholders in other countries and regions remains to be assessed. Future research could broaden the study to include more countries or industry contexts to validate the results and identify localized strategies for improving the resilience of prefabricated construction supply chains.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings15020289/s1. References [16,18,19,26,27,33,34,43,50,56,57,60,65–82] are cited in the supplementary materials.

Author Contributions: T.L. Writing—original draft, visualization, validation, methodology; L.M. writing—review and editing, validation, resources, data curation; H.F. validation, resources, data curation. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported in part by the Liaoning Province Social Science Planning Research key Project, China under Grant No. L23AGL010, in part by the Hainan Province Social Science Planning Research funding Project, China under Grant No. HNSK(YB)24-14.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Qian, L.-P.; Xu, L.-Y.; Huang, B.-T.; Li, Y.; Lan, J.; Gong, F.; Guan, H. Functionalization of waste-derived artificial aggregates: A state-of-the-art review. *Resour. Conserv. Recycl.* **2025**, *212*, 107999. [CrossRef]
2. Lee, C.; Won, J.W.; Jang, W.; Jung, W.; Han, S.H.; Kwak, Y.H. Social conflict management framework for project viability: Case studies from Korean megaprojects. *Int. J. Proj. Manag.* **2017**, *35*, 1683–1696. [CrossRef]
3. Dong, Y.; Lan, J.; Zang, M.; Lu, H.; Zhang, D.; Huang, B.-T. Eco-friendly preparation of self-bonding materials from natural aeolian sand and secondary aluminum dross for sustainable desert construction. *J. Clean. Prod.* **2024**, *144*, 144214. [CrossRef]
4. Ma, S.; Li, Z.; Li, L.; Yuan, M. Coupling coordination degree spatiotemporal characteristics and driving factors between new urbanization and construction industry: Evidence from China. *Eng. Constr. Archit. Manag.* **2023**, *30*, 5280–5301. [CrossRef]
5. Bribián, I.Z.; Capilla, A.V.; Usón, A.A. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Build. Environ.* **2011**, *46*, 1133–1140. [CrossRef]
6. Chen, Y.; Liu, B.; Shen, Y.; Wang, X. The energy efficiency of China's regional construction industry based on the three-stage DEA model and the DEA-DA model. *KSCE J. Civ. Eng.* **2016**, *20*, 34–47. [CrossRef]
7. Zhang, Z.; Tan, Y.; Shi, L.; Hou, L.; Zhang, G. Current state of using prefabricated construction in Australia. *Buildings* **2022**, *12*, 1355. [CrossRef]
8. Mostafa, S.; Chileshe, N.; Zuo, J. A synergistic supply chain enhancing offsite manufacturing uptake in Australian house building. In Proceedings of the 30th Annual ARCOM Conference, Portsmouth, UK, 1–3 September 2014; Raiden, A.B., Aboagye-Nimo, E., Eds.; Association of Researchers in Construction Management: London, UK, 2014; pp. 1143–1152.
9. Aghasizadeh, S.; Tabadkani, A.; Hajirasouli, A.; Banihashemi, S. Environmental and economic performance of prefabricated construction: A review. *Environ. Impact Assess. Rev.* **2022**, *97*, 106897. [CrossRef]
10. Hofman, E.; Voordijk, H.; Halman, J. Matching supply networks to a modular product architecture in the house-building industry. *Build. Res. Inf.* **2009**, *37*, 31–42. [CrossRef]
11. Pan, Y.; Liu, J.; Cheng, C. Research on Urban Resilience from the Perspective of Land Intensive Use: Indicator Measurement, Impact and Policy Implications. *Buildings* **2024**, *14*, 2564. [CrossRef]
12. Cheng, S.; Zhou, X.; Zhang, Y.; Duan, M.; Gao, J. Study on resilience factors and enhancement strategies in prefabricated building supply chains. *Buildings* **2024**, *14*, 195. [CrossRef]
13. Ponomarov, S.Y.; Holcomb, M.C. Understanding the concept of supply chain resilience. *Int. J. Logist. Manag.* **2009**, *20*, 124–143. [CrossRef]
14. Masood, R.; Lim, J.B.; González, V.A.; Roy, K.; Khan, K.I.A. A systematic review on supply chain management in prefabricated house-building research. *Buildings* **2022**, *12*, 40. [CrossRef]
15. Ahmed, A.E.; Ucbasaran, D.; Cacciotti, G.; Williams, T.A. Integrating psychological resilience, stress, and coping in entrepreneurship: A critical review and research agenda. *Entrep. Theory Pract.* **2022**, *46*, 497–538. [CrossRef]

16. Ekanayake, E.; Shen, G.; Kumaraswamy, M.; Owusu, E.K. A fuzzy synthetic evaluation of vulnerabilities affecting supply chain resilience of industrialized construction in Hong Kong. *Eng. Constr. Archit. Manag.* **2022**, *29*, 2358–2381. [CrossRef]
17. Shen, K.; Li, X.; Cao, X.; Zhang, Z. Prefabricated construction process optimization based on rework risk. *J. Constr. Eng. Manag.* **2022**, *148*, 04022031. [CrossRef]
18. Luo, L.; Jin, X.; Shen, G.Q.; Wang, Y.; Liang, X.; Li, X.; Li, C.Z. Supply chain management for prefabricated building projects in Hong Kong. *J. Manag. Eng.* **2020**, *36*, 05020001. [CrossRef]
19. Zhang, H.; Yu, L. Resilience-cost tradeoff supply chain planning for the prefabricated construction project. *J. Civ. Eng. Manag.* **2021**, *27*, 45–59. [CrossRef]
20. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
21. Obot, O.; John, A.; Udo, I.; Attai, K.; Johnson, E.; Udoh, S.; Nwokoro, C.; Akwaowo, C.; Dan, E.; Umoh, U.; et al. Modelling differential diagnosis of febrile diseases with fuzzy cognitive map. *Trop. Med. Infect. Dis.* **2023**, *8*, 352. [CrossRef]
22. Du, Q.; Pang, Q.; Bao, T.; Guo, X.; Deng, Y. Critical factors influencing carbon emissions of prefabricated building supply chains in China. *J. Clean. Prod.* **2021**, *280*, 124398. [CrossRef]
23. Du, Q.; Hao, T.; Huang, Y.; Yan, Y. Prefabrication decisions of the construction supply chain under government subsidies. *Environ. Sci. Pollut. Res.* **2022**, *29*, 59127–59144. [CrossRef]
24. Han, Y.; Yan, X.; Piroozfar, P. An overall review of research on prefabricated construction supply chain management. *Eng. Constr. Archit. Manag.* **2023**, *30*, 5160–5195. [CrossRef]
25. Hussein, M.; Eltoukhy, A.E.; Karam, A.; Shaban, I.A.; Zayed, T. Modelling in off-site construction supply chain management: A review and future directions for sustainable modular integrated construction. *J. Clean. Prod.* **2021**, *310*, 127503. [CrossRef]
26. Jiang, L.; Li, Z.; Li, L.; Gao, Y. Constraints on the promotion of prefabricated construction in China. *Sustainability* **2018**, *10*, 2516. [CrossRef]
27. Masood, R.; Lim, J.B.; González, V.A. Performance of the supply chains for New Zealand prefabricated house-building. *Sustain. Cities Soc.* **2021**, *64*, 102537. [CrossRef]
28. Chang, Y.; Li, X.; Masanet, E.; Zhang, L.; Huang, Z.; Ries, R. Unlocking the green opportunity for prefabricated buildings and construction in China. *Resour. Conserv. Recycl.* **2018**, *139*, 259–261. [CrossRef]
29. Hong, J.; Shen, G.Q.; Li, Z.; Zhang, B.; Zhang, W. Barriers to promoting prefabricated construction in China: A cost–benefit analysis. *J. Clean. Prod.* **2018**, *172*, 649–660. [CrossRef]
30. Stroebele, B.S.; Kiessling, A.J.; Zhang, J. Impact analysis of complexity drivers in the supply chain of prefabricated houses. *J. Manag. Strategy* **2017**, *8*, 1–9. [CrossRef]
31. Wuni, I.Y.; Shen, G.Q. Stakeholder management in prefabricated prefinished volumetric construction projects: Benchmarking the key result areas. *Built Environ. Proj. Asset Manag.* **2020**, *10*, 407–421. [CrossRef]
32. Wang, L.; Cheng, Y.; Zhang, Y. Exploring the risk propagation mechanisms of supply chain for prefabricated building projects. *J. Build. Eng.* **2023**, *74*, 106771. [CrossRef]
33. Wuni, I.Y.; Shen, G.Q.; Mahmud, A.T. Critical risk factors in the application of modular integrated construction: A systematic review. *Int. J. Constr. Manag.* **2019**, *22*, 133–147. [CrossRef]
34. Hsu, P.-Y.; Aurisicchio, M.; Angeloudis, P. Risk-averse supply chain for modular construction projects. *Autom. Constr.* **2019**, *106*, 102898. [CrossRef]
35. Zhong, R.Y.; Peng, Y.; Xue, F.; Fang, J.; Zou, W.; Luo, H.; Ng, S.T.; Lu, W.; Shen, G.Q.; Huang, G.Q. Prefabricated construction enabled by the Internet-of-Things. *Autom. Constr.* **2017**, *76*, 59–70. [CrossRef]
36. Jafari, M.; Khoshand, A.; Sadeghi, N.; Mirzanagh, P.A. A comparative LCA of external wall assemblies in context of Iranian market: Considering embodied and operational energy through BIM application. *Environ. Sci. Pollut. Res.* **2024**, *31*, 7364–7379. [CrossRef] [PubMed]
37. Rangasamy, V.; Yang, J.-B. The convergence of BIM, AI and IoT: Reshaping the future of prefabricated construction. *J. Build. Eng.* **2024**, *84*, 108606. [CrossRef]
38. Van Meerbeek, K.; Jucker, T.; Svenning, J.C. Unifying the concepts of stability and resilience in ecology. *J. Ecol.* **2021**, *109*, 3114–3132. [CrossRef]
39. Shishodia, A.; Sharma, R.; Rajesh, R.; Munim, Z.H. Supply chain resilience: A review, conceptual framework and future research. *Int. J. Logist. Manag.* **2023**, *34*, 879–908. [CrossRef]
40. Wieland, A.; Durach, C.F. Two perspectives on supply chain resilience. *J. Bus. Logist.* **2021**, *42*, 315–322. [CrossRef]
41. Conz, E.; Magnani, G. A dynamic perspective on the resilience of firms: A systematic literature review and a framework for future research. *Eur. Manag. J.* **2020**, *38*, 400–412. [CrossRef]
42. Liu, J.J.; Reed, M.; Girard, T.A. Advancing resilience: An integrative, multi-system model of resilience. *Personal. Individ. Differ.* **2017**, *111*, 111–118. [CrossRef]
43. Zhang, M.; Liu, Y.; Ji, B. Influencing factors of resilience of PBSC based on empirical analysis. *Buildings* **2021**, *11*, 467. [CrossRef]

44. Spiegler, V.L.; Naim, M.M.; Wikner, J. A control engineering approach to the assessment of supply chain resilience. *Int. J. Prod. Res.* **2012**, *50*, 6162–6187. [CrossRef]
45. Abimbola, M.; Khan, F. Resilience modeling of engineering systems using dynamic object-oriented Bayesian network approach. *Comput. Ind. Eng.* **2019**, *130*, 108–118. [CrossRef]
46. Arshad, H.; Zayed, T. Critical influencing factors of supply chain management for modular integrated construction. *Autom. Constr.* **2022**, *144*, 104612. [CrossRef]
47. Pettit, T.J.; Croxton, K.L.; Fiksel, J. The evolution of resilience in supply chain management: A retrospective on ensuring supply chain resilience. *J. Bus. Logist.* **2019**, *40*, 56–65. [CrossRef]
48. Ekanayake, E.M.A.C.; Shen, G.Q.P.; Kumaraswamy, M.M. A fuzzy synthetic evaluation of capabilities for improving supply chain resilience of industrialised construction: A Hong Kong case study. *Prod. Plan. Control* **2023**, *34*, 623–640. [CrossRef]
49. Zhai, Y.; Zhong, R.Y.; Li, Z.; Huang, G. Production lead-time hedging and coordination in prefabricated construction supply chain management. *Int. J. Prod. Res.* **2017**, *55*, 3984–4002. [CrossRef]
50. Zhu, T.; Liu, G. A novel hybrid methodology to study the risk management of prefabricated building supply chains: An outlook for sustainability. *Sustainability* **2022**, *15*, 361. [CrossRef]
51. Wang, Y. Research on risk management of prefabricated construction supply chain based on immune principle. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *371*, 052058.
52. Olawumi, T.O.; Chan, D.W.; Ojo, S.; Yam, M.C. Automating the modular construction process: A review of digital technologies and future directions with blockchain technology. *J. Build. Eng.* **2022**, *46*, 103720. [CrossRef]
53. Yong, Y.W.; Keng, K.A.; Leng, T.L. A Delphi forecast for the Singapore tourism industry: Future scenario and marketing implications. *Int. Mark. Rev.* **1989**, *6*, 3.
54. Kosko, B. Fuzzy cognitive maps. *Int. J. Man-Mach. Stud.* **1986**, *24*, 65–75. [CrossRef]
55. Baker, C.M.; Holden, M.H.; Plein, M.; McCarthy, M.A.; Possingham, H.P. Informing network management using fuzzy cognitive maps. *Biol. Conserv.* **2018**, *224*, 122–128. [CrossRef]
56. Demiralp, G.; Guven, G.; Ergen, E. Analyzing the benefits of RFID technology for cost sharing in construction supply chains: A case study on prefabricated precast components. *Autom. Constr.* **2012**, *24*, 120–129. [CrossRef]
57. Wang, Z.; Wang, T.; Hu, H.; Gong, J.; Ren, X.; Xiao, Q. Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. *Autom. Constr.* **2020**, *111*, 103063. [CrossRef]
58. Zhao, S.; Wang, J.; Ye, M.; Huang, Q.; Si, X. An evaluation of supply chain performance of China's prefabricated building from the perspective of sustainability. *Sustainability* **2022**, *14*, 1299. [CrossRef]
59. Wuni, I.Y.; Shen, G.Q. Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *J. Clean. Prod.* **2020**, *249*, 119347. [CrossRef]
60. Wu, H.; Qian, Q.K.; Straub, A.; Visscher, H. Exploring transaction costs in the prefabricated housing supply chain in China. *J. Clean. Prod.* **2019**, *226*, 550–563. [CrossRef]
61. Sabahi, S.; Parast, M.M. Firm innovation and supply chain resilience: A dynamic capability perspective. *Int. J. Logist. Res. Appl.* **2020**, *23*, 254–269. [CrossRef]
62. Wu, H.; Qian, Q.K.; Straub, A.; Visscher, H. Stakeholder perceptions of transaction costs in prefabricated housing projects in China. *J. Constr. Eng. Manag.* **2021**, *147*, 04020145. [CrossRef]
63. Xie, L.; Wu, S.; Chen, Y.; Chang, R.; Chen, X. A case-based reasoning approach for solving schedule delay problems in prefabricated construction projects. *Autom. Constr.* **2023**, *154*, 105028. [CrossRef]
64. Wen, Y. Research on the intelligent construction of prefabricated building and personnel training based on BIM5D. *J. Intell. Fuzzy Syst.* **2021**, *40*, 8033–8041. [CrossRef]
65. Chen, Q.; Hall, D.M.; Adey, B.T.; Haas, C.T. Identifying enablers for coordination across construction supply chain processes: A systematic literature review. *Eng. Constr. Archit. Manag.* **2020**, *28*, 1083–1113. [CrossRef]
66. Du, J.; Sugumaran, V. Ontology-based information integration and decision making in prefabricated construction component supply chain. In Proceedings of the Twenty-third Americas Conference on Information System, Boston, MA, USA, 10–12 August 2017; pp. 1–10.
67. Du, J.; Sugumaran, V.; Gao, B. RFID and multi-agent based architecture for information sharing in prefabricated component supply chain. *IEEE Access* **2017**, *5*, 4132–4139. [CrossRef]
68. Ekanayake, E.; Shen, G.; Kumaraswamy, M.M. Critical capabilities of improving supply chain resilience in industrialized construction in Hong Kong. *Eng. Constr. Archit. Manag.* **2020**, *28*, 3236–3260. [CrossRef]
69. Ekanayake, E.; Shen, G.Q.; Kumaraswamy, M.M. Identifying supply chain capabilities of construction firms in industrialized construction. *Prod. Plan. Control* **2021**, *32*, 303–321. [CrossRef]
70. Ekanayake, E.; Shen, G.Q.; Kumaraswamy, M.M.; Owusu, E.K. Identifying supply chain vulnerabilities in industrialized construction: An overview. *Int. J. Constr. Manag.* **2020**, *22*, 1464–1477. [CrossRef]

71. Hsu, P.-Y.; Aurisicchio, M.; Angeloudis, P. Establishing outsourcing and supply chain plans for prefabricated construction projects under uncertain productivity. In *Lecture Notes in Computer Science; Proceedings of International Conference on Computational Logistics*; Springer: Cham, Switzerland, 2017; pp. 529–543. [CrossRef]
72. Liu, K.; Su, Y.; Zhang, S. Evaluating supplier management maturity in prefabricated construction project-survey analysis in China. *Sustainability* **2018**, *10*, 3046. [CrossRef]
73. Liu, K.; Zhang, S. Assessment of sustainable development capacity of prefabricated residential building supply chain. In Proceedings of the International Conference on Construction and Real Estate Management, Charleston, SC, USA, 9–10 August 2018. [CrossRef]
74. Liu, Y.; Dong, J.; Shen, L. A conceptual development framework for prefabricated construction supply chain management: An integrated overview. *Sustainability* **2020**, *12*, 1878. [CrossRef]
75. Luo, L.; Shen, G.Q.; Xu, G.; Liu, Y.; Wang, Y. Stakeholder-associated supply chain risks and their interactions in a prefabricated building project in Hong Kong. *J. Manag. Eng.* **2019**, *35*, 05018015. [CrossRef]
76. Mao, C.; Shen, L.; Luo, L.; Li, Z. Identification of risk factors influencing the implementation of industrialized building system in China. In *Proceedings of the 19th International Symposium on Advancement of Construction Management and Real Estate*; Shen, L., Ye, K., Mao, C., Eds.; Springer: Berlin, Germany, 2015; pp. 219–230. [CrossRef]
77. Wang, D.; Luo, J.; Wang, Y. Multifactor uncertainty analysis of prefabricated building supply chain: Qualitative comparative analysis. *Eng. Constr. Archit. Manag.* **2022**, *31*, 1994–2010. [CrossRef]
78. Wang, X.; Sun, S. Research on collaborative mode of prefabricated construction supply chain based on supply-hub. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2019; Volume 242, p. 062005. [CrossRef]
79. Wang, Y.Y.; Ren, H.; Ji, F.R. Cooperative innovation evolutionary game analysis of industrialized building supply chain. *Appl. Mech. Mater.* **2018**, *878*, 213–218. [CrossRef]
80. Yang, H.; Ren, W. Research on risk management of green supply chain of prefabricated buildings based on QCA. In *E3S Web of Conferences*; EDP Sciences: Paris, France, 2021; p. 03041.
81. Zhang, H.; Yu, L. Dynamic transportation planning for prefabricated component supply chain. *Eng. Constr. Archit. Manag.* **2020**, *27*, 2553–2576. [CrossRef]
82. Zhai, Y.; Zhong, R.Y.; Huang, G.Q. Buffer space hedging and coordination in prefabricated construction supply chain management. *Inter. J. Prod. Econ.* **2018**, *200*, 192–206. [CrossRef]