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Research on the Improvement Path of Prefabricated Buildings' Supply Chain Resilience Based on Structural Equation Modeling: A Case Study of Shenyang and Hangzhou, China

Yizhuoyan Qi, Lihong Li * and Fanwen Kong

College of Management, Shenyang Jianzhu University, Shenyang 110168, China; qyzy777@outlook.com (Y.Q.); kfanwen@163.com (F.K.)
* Correspondence: lilihong022@126.com

Abstract: Due to increasing cost and decreasing labor, prefabricated buildings have developed rapidly. With the prolongation of prefabricated buildings' supply chain (PBSC) and an increase in risk factors, project delays and even interruptions occur occasionally. The difficulty of supply chain management is increasing. Supply chain resilience (SCR) as a risk management tool has gradually attracted the attention of scholars. This paper uses the grounded theory to identify the influencing factors of prefabricated buildings' supply chain resilience (PBSCR) based on the dynamic capacity theory. By collecting questionnaires from relevant stakeholders in Shenyang and Hangzhou, a structural equation model (SEM) was used to test the research hypothesis. The capacity effect relationship of the PBSC was constructed. The results show that resilient capability has the highest direct effect on the improvement in PBSCR, and collaborative capability has the highest total and indirect effect on the improvement in PBSCR. The critical paths to improving PBSCR were then identified. Suggestions were made based on the calculated effect relationships. This paper is expected to improve PBSCR, enrich the research on supply chains in the construction field, and help better realize the stable development of prefabricated buildings.

Keywords: prefabricated buildings; supply chain resilience; dynamic capability theory; grounded theory; structural equation model (SEM)

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1. Background

With the "carbon peak" and "carbon neutral" goals proposed in China, prefabricated buildings, one of the main paths for the development of construction industrialization, have found growth opportunities [1]. In China, the assembly rate of the construction industry in first-tier cities, such as Beijing, Shanghai, and Hangzhou, has reached more than 30%. In second-, third-, and lower-tier cities, it has reached over 20% [2]. Prefabricated building projects involve multiple segments. The production cycle of prefabricated building projects is long, the investment is large, and there are many participating entities [3]. The biggest difference from traditional building projects is that component production and on-site installation are separate in prefabricated buildings [4]. Prefabricated components are produced at different locations and transported to the site by transportation units to complete the assembly construction [5]. Problems such as information mismatch, miscommunication, and untimely supply may occur, which delay the project schedule. As a product of the deep integration of the construction and manufacturing industries, the traditional management method is unsuitable for prefabricated buildings that adopt new industrial prefabricated production [6]. Introducing supply chain management ideas into prefabricated buildings helps enterprises form strategic partnerships and integrate high-quality resources [7,8]. The quality and overall benefit of their projects will be improved.

In the 1990s, scholars proposed the concept of supply chain management for prefabricated buildings. Scholars drew on manufacturing supply chain management theory to apply it to prefabricated buildings. They explored supply chain modeling, performance management, and other aspects. Vrijhoef R. and Koskela L. demonstrated the potential of supply chain management in the construction industry based on the special characteristics of the construction industry using practical cases [9]. Doran D. and Giannakis M. further explored the practical principles and operation modes of the prefabricated buildings' supply chain (PBSC) [10]. Aloini, D., Dulmin, R., et al. summarized the risk factors in the PBSC [11]. The research related to the PBSC has been rapidly developed. Martin Christopher, an American supply chain management expert, once pointed out that the competition in the 21st century is no longer the competition among enterprises but among supply chains [12].

The PBSC management process covers all stages of planning, design, production, transportation, assembly operation, and maintenance. A supply chain involves many stakeholders. It is extremely difficult to manage. In recent years, the upstream and downstream disturbance factors of the PBSC have gradually increased. The market environment has fluctuated sharply due to events such as the global sand scramble and frequent public health incidents [13]. Shortages of construction workers, disruptions in the supply of construction materials, backlogs of orders, and delays in the delivery of prefabricated component production are also emerging as causes of supply chain disruptions in prefabricated buildings [14]. These reduce the stability of the PBSC and increase the risk of supply chain disruption. The existing supply chain model makes it difficult to meet the development requirements of prefabricated buildings [15]. Against this backdrop, building resilient supply chains has become an important way of addressing risks. The flexibility, agility, innovation, and other rich connotations of supply chain resilience (SCR) [16] are in line with the functional demands of "informatization, lean, agile, and standardization" in the development of prefabricated buildings [17]. The concept of resilience comes from the field of physics [18]. Since then, this concept has been introduced into other disciplines [19], such as building resilience [20] and seismic resilience [21]. It can be concluded that resilience is the ability of a system to manage and bounce back after a setback, covering a wide range of issues from stability to risk management and resilience after disruption [22]. Therefore, the concept of "resilience" in PBSC management is inevitable.

The research on SCR has mainly focused on the food supply chain, medical supply chain, and oil supply chain [23–25]. In the past, scholars have studied construction supply chain management. The current research focuses on cost control [26], benefit distribution [27], and information sharing [28]. In recent years, scholars have begun to pay attention to the PBSC and introduced the concept of "resilience" into the PBSC. Most scholars have focused on a certain part of the supply chain [29], rather than the perspective of the entire PBSC, such as employee behavior, production and assembly structure of components, and skilled labor [30]. Some scholars have improved SCR by analyzing the risk factors at each stage of prefabricated buildings [13,31]. Some scholars have conducted optimization analyses on component production and information sharing in the PBSC [32,33]. Therefore, it is important to study factors that affect prefabricated buildings' supply chain resilience (PBSCR) to find out the relationship between the roles of different factors. This is of great theoretical and practical significance to improve the resilience and risk management level of the PBSC. This study innovatively analyzed factors that improve the PBSCR from the perspective of dynamic capability. SEM was used to analyze the relationship between these factors. It fills the research gap of the PBSC. This study combined the grounded theory and dynamic capability theory to identify factors influencing PBSCR.

Shenyang is one of the first batches of prefabricated building demonstration cities in China, forming a prefabricated building development model that meets local characteristics. The local government attaches great importance to the prefabricated building industry. With the rapid development of prefabricated buildings in South China, Hangzhou is in a leading position in prefabricated buildings with its advantage of having sufficient technical funds. Therefore, two representative cities in China were selected as the sample data sources.

The rest of this paper is organized as follows: We summarize the literature on the PBSC and SCR in Section 2. In Section 3, we provide information on coding, identify the influencing factors, develop path hypotheses, and analyze the data using SEM. The results of the effects analysis are presented in Section 4. Section 5 discusses specific strategies for improving PBSCR. Finally, Section 6 concludes this paper.

2. Literature Review

2.1. Prefabricated Building Supply Chain

There is no clear definition of the PBSC. This paper synthesizes the difference between prefabricated and traditional buildings. The PBSC is defined based on the traditional building supply chain and the manufacturing supply chain. The traditional building supply chain refers to the core enterprise involving the control of material flow, financial flow, and information flow; it starts from the procurement of raw materials to the completion and delivery of production and sub-projects, encompassing material suppliers, engineering subcontractors, labor subcontractors, equipment leasing enterprises into an overall functional network chain structure model [34]. The difference between prefabricated and traditional buildings is that part of the work performed on the construction site is transferred to a prefabricated component factory. It involves a completely new production process [35]. Some scholars propose that the PBSC is a network consisting of multiple subjects with material flow, financial flow, and information flow, which involves investment decisions, design, procurement, production, transportation, and assembly [5,36,37].

According to the dominance of different enterprises in the chain, it can be divided into a model led by development enterprises, a model led by general contracting enterprises, and a model led by prefabricated component factories [34]. The typical statements on the definition of the construction supply chain are as follows: (1) Starting from the needs of the owners and the material flow, financial flow, and information flow between participating enterprises, which are used for a series of processes such as project bidding, project approval, and acceptance, a functional and dynamic alliance is formed between different stakeholders [38]. (2) Led by a general contractor, the functional network chain comprises all participating enterprises due to their relationships in production and construction through the control of material flow, financial flow, and information flow. The form of the PBSC is not static.

This paper determines the object of the PBSC based on the characteristics of prefabricated buildings and the purpose of resilient improvement, as shown in Figure 1. Based on previous research and the purpose of resilient improvement, the definition of the PBSC in this paper is as follows: It is composed of general contractors, suppliers, manufacturing subcontractors, assembly subcontractors, transportation units, supervisory units, and owners. Through the control of material flow, financial flow, and information flow, the supply network covers the complete production and construction process, such as design, procurement, manufacturing, transportation, and assembly. However, it does not involve decoration, sales, maintenance, or recycling used parts.

2.2. Supply Chain Resilience

The concept of resilience was first proposed in the study of physics and used to refer to "the property that an object is deformed by an external force, and after the external force disappears, the object returns to the state before the interference [39]". Subsequently, resilience has been applied to research in ecology, sociology, and psychology. After reviewing the literature, it is found that Rice (2003) and Christopher (2004) put forward the concept of SCR successively [12,40]. The research interest in SCR gradually showed a rising trend and began to break through in 2013, becoming a global popular research topic. Horne introduced it to the study of organizational management for the first time in 2013. He sees resilience as the dynamic ability of organizational systems to cope with environmental changes [41]. SCR is a core issue in the field of management. The research interest has continued to grow, and rich research results have been obtained. However, there is no clear and unified definition of SCR in current research, as shown in Table 1.

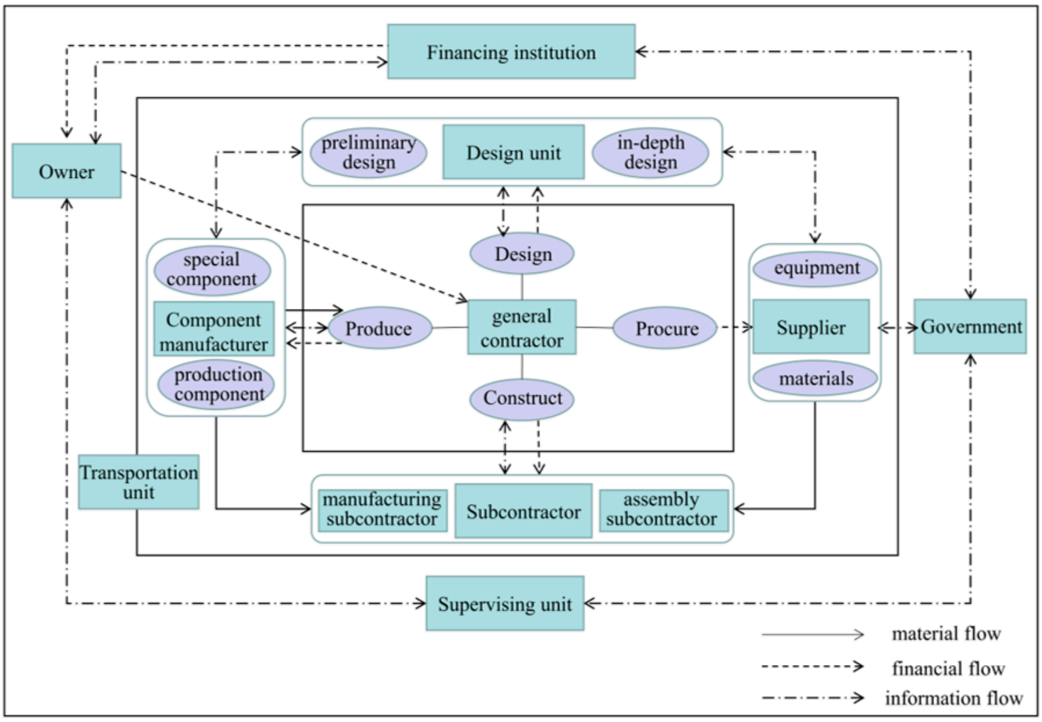

Figure 1. Structure diagram of PBSC.

Table 1. Summary of SCR definitions.

Representative Author	SCR Definition
Holling (1973)	The ability of a system to return to equilibrium or a stable state after a disturbance [42].
Carpenter et al. (2001)	The ability of a system to change, adapt, and transform in response to external or internal pressures [43].
Sheffi et al. (2005)	The rapid response of a supply chain to unexpected events to restore previous performance levels [44].
Hohenstein et al. (2015)	The ability of a supply chain network to avoid interruption accidents and recover quickly from disaster events. The evasive attributes and recovery attributes of resilience are emphasized [45].
Kamalahmadi et al. (2016)	The ability to maintain a structure that resists the spread of an interference to transcend the interference and return to a robust state [16].
Hosseini et al. (2019)	The ability of a supply chain to use its absorptive capacity to withstand the effects of perturbations, to minimize the consequences of disruptions by utilizing its adaptive capacity, and to use resilience to cost-effectively restore performance levels to normal operation when the absorptive and adaptive capacities are insufficient [46].
Manurung et al. (2023)	A supply chain demonstrates resilience when it can resist an upheaval because it is dynamic and extremely vulnerable to uncertainties. Moreover, it must not only return to its initial form but also prove to be able to achieve steady, sustainable performance [47].

The definition of SCR is revised by using the definition of Hohenstein et al. shown in Table 1 [45] from the perspective of dynamic capability as follows: SCR refers to the capability of the supply chain itself. In the face of different disruptions, it is prepared for emergencies with a capability that matches its level of disturbance, responds quickly to potential disruptions, and recovers to the original state or turns to a more ideal new state.

A review of the literature shows that Oscaro et al. identified and emphasized the important role of supply chain visibility, reserve capacity, supplier dispersion, cooperation, adaptability, flexibility, volatility, and other influencing factors on SCR from the perspective of supply chain vulnerability and supply chain capability [48]. Lu and Wang et al. established an element-based system for PBSCR-affecting factors and used the DEMATEL-ISM method combined with a Pythagorean fuzzy set to analyze the direct factors [49]. Wang and Luo et al. constructed an uncertainty analysis model of prefabricated building supply chain risk. The fuzzy set qualitative comparative analysis (fs QCA) was used to study the configuration influence of five uncertain factors, including environment, plan–control, demand–supply, manufacturing, and assembly–transportation, on the risk of the prefabricated building supply chain [31]. Zhang and others used SEM. Combined with the construction characteristics and development status of prefabricated buildings, this paper aims to identify the influencing factors of the three main processes of prefabricated buildings (production transportation and storage-influencing factors involved in assembly and construction, namely production and transportation) from the perspective of resilience. The factor analysis model and causal path analysis model of PBSCR based on the EPC model were constructed via SEM, and the correctness of the path was verified [13].

3. Materials and Methods

3.1. Research Processes

The improvement in PBSCR is a kind of supply chain capacity improvement. It refers to the ability to withstand disruptions during the normal operation of a supply chain due to small probability events, such as natural disasters, and the vulnerability of the supply chain structure itself. Simply put, it is the ability to recover quickly from disruptive events. It is an important research direction in the field of supply chain risk management. Most of the existing research studies have examined the SCR of the traditional manufacturing industry. Relatively few studies have studied PBSCR. The existing studies have mostly evaluated from the perspective of stage division. This study innovatively used the dynamic capability theory to study the improvement in PBSCR. The relationship between different factors was analyzed using SEM. The research process for this study is shown in Figure 2.

Firstly, the factors influencing PBSCR were established and divided by combining the grounded theory and the dynamic capability theory. They were divided into preventive capability, resistant capability, recovery capability, growth capability, and collaborative capability. The conceptual model of PBSCR was constructed.

Secondly, a questionnaire survey on PBSCR was carried out, and an SEM of PBSCR was set and assumed. Then, the SEM of PBSCR was verified and determined. The effect relationship of PBSCR was constructed.

Finally, the critical path leading to an improvement in PBSCR was analyzed based on the results of the previous analysis. The nodes that needed to be focused on in the improvement path of PBSCR were determined. Corresponding path optimization safeguard measures were proposed to achieve resilience improvement.

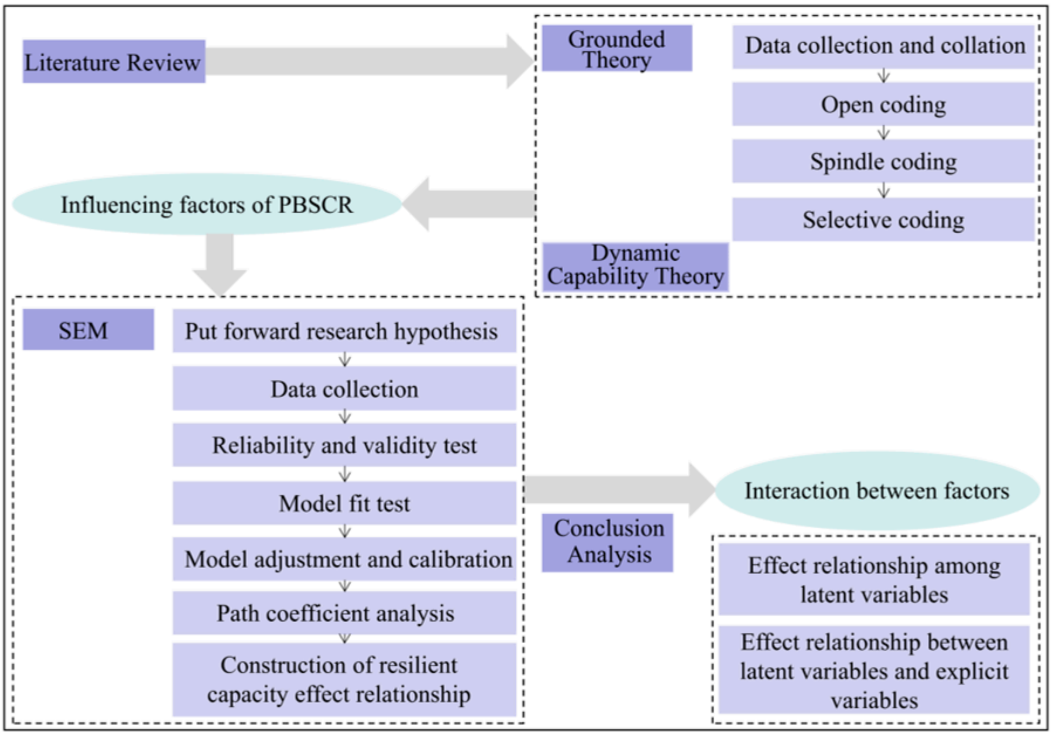

Figure 2. Research flowchart.

3.2. Access to Data

A purposive sampling method was used to select the interviewees. The criteria for selecting the interviewees were limited to individuals with education, active thinking, and rich experience. This study selected a total of 15 interviewees who are engaged in related work and understand prefabricated buildings. The basic information is shown in Table 2. The interview process was anonymous and did not involve the disclosure of personal private information [50].

Table 2. Statistics of interviewees.

Classify		Number	Proportion
Gender	Men	10	66.7%
	Women	5	33.3%
Length of work	5–10 years	1	6.67%
	11–20 years	7	46.67%
	21–30 years	5	33.33%
	More than 30 years	2	13.33%
Degree	Undergraduate	7	46.67%
	Graduate	4	26.67%
	PhD candidate	4	26.67%

The data were obtained using semi-structured interviews. In-depth one-on-one interviews were conducted with 15 interviewees. The interview time lasted for more than one hour to provide the interviewees with sufficient consideration time and expression space. The interviewers guided the interviewees to answer the questions from an individual point of view, combining their knowledge and experience. Before conducting a formal interview, the interviewers should explain to the interviewees the theme, purpose, and time of the interview, and should fully respect the wishes and ideas of the interviewees. The outline of the interview used in this study is shown in Table 3.

Table 3. Interview outline.

Interview Topics	Main Content
Basic information	Your age, education, employer, nature of work, and years of employment
Cognition of prefabricated building supply chain resilience and the current situation of supply chain construction in the city	What is your understanding of prefabricated buildings' supply chain resilience? What are your organization's main responsibilities in the supply chain? What do you think is still deficient?
Influencing factors and improvement paths of prefabricated building supply chain resilience	What factors do you think affect the prefabricated building supply chain resilience? What are the key promotion paths?

In this study, more than 30,000 words of basic interview materials were obtained by combing through the interviews. Two thirds of the basic interview data were randomly selected for coding and identification. The remaining one third of the basic interview data were tested for saturation.

3.3. Coding Identification

The identification process of the influencing factors of PBSCR was mainly based on manual coding, supplemented by using NVIVO version 11 coding. The influencing factors of PBSCR were identified through open coding, spindle coding, and selective coding of the basic interview data [51].

3.3.1. Open Coding

Open coding is to code and label basic interview materials word by word, obtain the initial concepts through continuous comparison and analysis, and reclassify and categorize them. In the selection and acquisition of the initial concepts, the original sentences of the interviewee should be selected as much as possible. The initial concepts should be directly named or extracted based on the words in these sentences to eliminate the subjective bias of the coder as much as possible.

In this study, instances in the interview corpus of the basic interview data that were too rough and vague was excluded. More than 500 original interview codes were obtained. Then, the corresponding conceptualization was obtained. This study removed the initial concepts that appeared less than twice and contradicted each other because the results of the initial conceptualization were confusing. There were different degrees of overlap and overlap between them. This process resulted in 45 initial concepts and 23 basic categories, which were the essential elements of the prefabricated building supply chain. Due to the consideration of article length and structure, the original corpus is not included in this paper.

3.3.2. Axial Coding

Axial coding is to discover and establish the logical relationship between the basic categories. Through the coding of categories and the in-depth relational analysis and linkage building around these categories, the categories are categorized at the conceptual level based on potential correlations and logical theoretical sequences. This leads to the formation of master categories. Such main categories are called the main axis. Through axial coding, this study finally obtained five main categories: preventive capability factors, resistant capability factors, recovery capability factors, growth capability factors, and collaborative capability factors, as shown in Table 4.

Table 4. Axial coding.

Main Category	Corresponds to the Basic Category	Scope Connotation
Preventive Capability (PC)	Risk awareness (PC1)	Before a risk comes, the node entity predicts the risk and formulates relevant response mechanisms and preventive measures in advance.
	Capital investment (PC2)	The supply chain has diversified sources of funds, strong or weak financing capabilities, and the use of funds in key links to ensure the continuous stability of supply chain funds.
	Information technology applications (PC3)	Establishing an information platform, realizing the transparent management of data in the whole production cycle through modern information means, monitoring the risks that may be caused by the external environment of the entire supply chain process, and timely discovery of sudden risks, which is conducive to responsibility traceability.
	Enterprise operational capabilities (PC4)	All enterprises in the supply chain accurately grasp their production capacity, fully combine internal advantages with limited resources, and carry out production management behavior.
Resistant Capability (EC)	Emergency handling capabilities (EC1)	Supply chain members can accurately identify the types of emergencies and quickly formulate emergency plans for various types of emergencies.
	Resource redundancy (EC2)	Maintaining production, transportation, and inventory capacity beyond normal levels, with spare means of production in inventory stacks, and able to delay the time it takes for supply chain disruptions.
	Resource scheduling level (EC3)	According to the schedule, the supply chain flexibly allocates various production resources to achieve a coherent production process and close ties between production activities.
	Ability to use technology (EC4)	Automation, AI, logistics 4.0 applications
	Ability to innovate (EC5)	Transform the way people think about risk response and effectively respond to risks through innovation.
Recovery Capability (RC)	Government support (RC1)	The government provides incentives, tax cuts, and loans to compensate for the economic losses caused by emergencies.
	Financial strength (RC2)	Total cash flow ratio.
	Subject coordination ability (RC3)	Timely detection of supply chain disruptions, rapid traceability of causes, and redistribution of on-chain responsibilities.
	Internal resource integration capabilities (RC4)	The internal resource structure of the construction company is reasonable, and the resource allocation rate is relatively high.
	Structural complexity (RC5)	The number of node enterprises and the degree of connection between node enterprises.
	Supply chain density (RC6)	The geographical distance between the nodes and enterprises; the greater the distance, the greater the density, and the smaller the distance, the smaller the density.

Table 4. *Cont.*

Main Category	Corresponds to the Basic Category	Scope Connotation
Growth Capability (GC)	Emergency aftercare capabilities (GC1)	Supply chain members have an emergency plan for a post-event evaluation system, and supply chain members can summarize lessons learned and update the emergency plan database promptly.
	Ability to learn (GC2)	Supply chain members effectively respond to risks by learning other organizational strategies, technologies, etc.
	Risk growth (GC3)	Each member of the supply chain reviews the causes and summarizes the experience and data preservation work after the accident.
	Technical competence (GC4)	The degree of integration of production and the technological innovation ability of manufacturers influence the type and quality of components to meet market demand, thereby improving the adaptability of the supply chain.
Collaborative Capability (CC)	Fairness in the distribution of benefits (CC1)	The responsibilities and obligations of all members in the supply chain and the fairness of benefit distribution affect the sustainable development of supply chain funds.
	The degree of strategic alliance (CC2)	All members of the supply chain have the same strategic goals and can quickly cooperate and respond to emergencies.
	The level of supervision (CC3)	Factory or construction site supervision method and implementation strength.
	Enterprise mutual trust (CC4)	It refers to a long-term and stable partnership between member enterprises, with rich cooperation experience and mutual trust, and a high degree of cross-sharing of information.

3.3.3. Selective Coding

Selective coding is to extract a core category from a main category, and systematically analyze and establish the interconnection and logical relationship between the core category, the main category, and the basic category, leading to a new theory. The determination of the core category should follow the following principles: centrality, or the category has the role and core status of a research object; cohesion, or the category can achieve a high degree of cohesion as a research object; frequent, showing the category is frequent; and connectedness, or the category can create multifaceted and deep connections with other categories [52].

This study determined the core categories of "influencing factors of PBSCR" through selective coding. The connection relationship around the core categories involves the preventive capability factors, resistant capability factors, recovery capability factors, growth capability factors, and collaborative capability factors. The five main categories directly affect PBSCR. Based on this connection relationship, this study constructed and developed the theoretical framework of PBSCR. The framework is defined as a "conceptual model of PBSCR". This is shown in Figure 3.

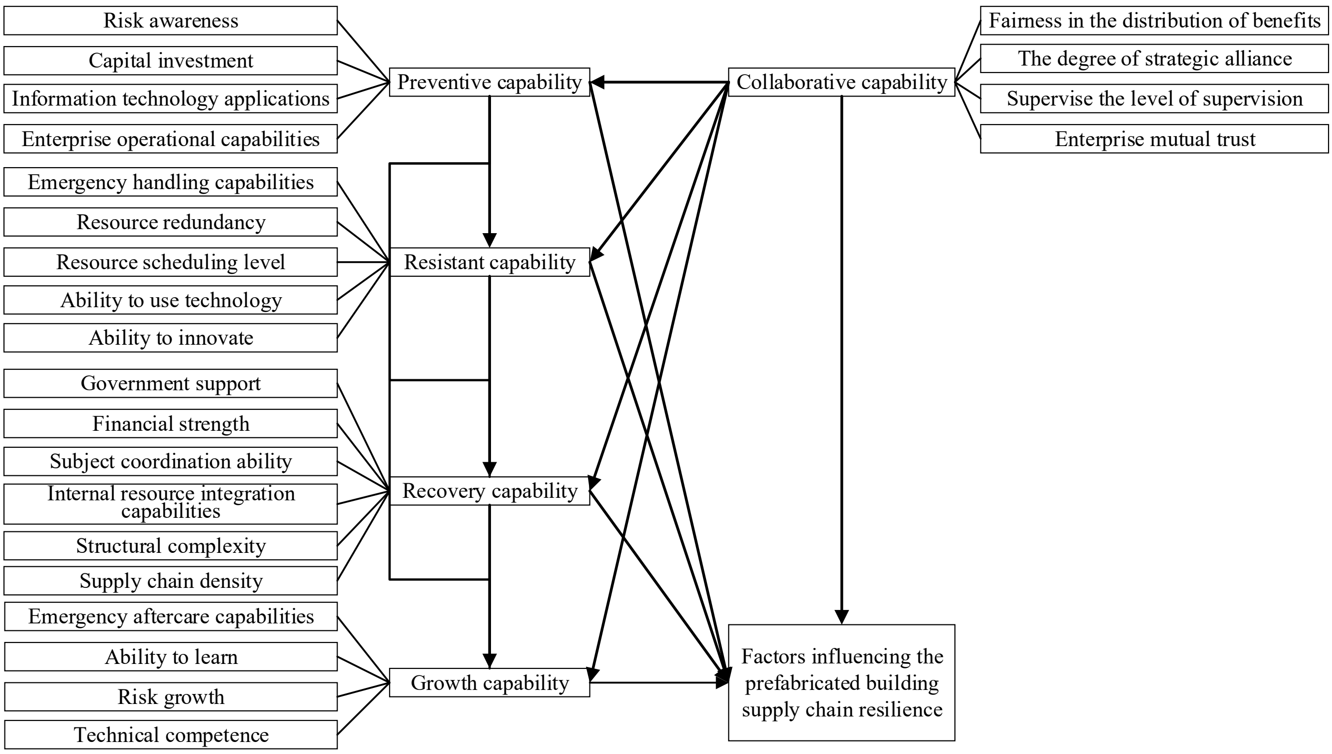

Figure 3. Conceptual model of PBSCR.

3.3.4. Saturation Test

Saturation test refers to the continuation of open coding and axial coding without obtaining additional data or information. If no new categories and relationships are found, it can be considered to have passed the saturation test. If new categories and relationships are found, the saturation test has not been passed [53].

In this study, one third of the reserved basic interview data were used for saturation testing. The results showed that except for the five main categories of influencing factors of PBSCR, no new main categories and connection relationships were found. No new basic categories and initial concepts were formed within the main categories. Therefore, it could be considered that the "PBSCR conceptual model" constructed in this study passed the saturation test.

3.4. Research Hypothesis

In this study, it is found that there may be complex interactions between the influencing factors of PBSCR. Therefore, based on our understanding of the actual situation of PBSC and the literature review, this paper proposes the following hypothesis.

3.4.1. Preventive Capability

Based on an analysis of the supply chain risk management theory and the connotation of resilience, it can be observed that a resilient supply chain has a certain preventive ability. Preventive capability is the ability to predict and identify risks before they occur. Members carry out elastic strategies in advance, deploy supply chain resources, and build supply chain capacity to improve SCR, thus effectively avoiding the negative impact of risk disturbance.

H1. *"Preventive capability" has a direct positive impact on "supply chain resilience".*

H2. *"Preventive capability" has a direct positive impact on "resistant capability".*

H3. *"Preventive capability" has a direct positive impact on "recovery capability".*

H4. *"Preventive capability" has a direct positive impact on "growth capability".*

3.4.2. Resistant Capability

Resistance refers to the ability of a supply chain to resist adjustment without any recovery activities when a risk disturbance acts on the supply chain. It can be regarded as the risk resistance of the supply chain to absorb the disturbance when a disruption is about to occur. SCR is characterized by the ability of the PBSC to adjust itself quickly by adopting alternative solutions to minimize the loss of supply chain disruptions.

H5. *"Resistant capability" has a direct positive impact on "supply chain resilience".*

H6. *"Resistant capability" has a direct positive impact on "recovery capability".*

H7. *"Resistant capability" has a direct positive impact on "growth capability".*

3.4.3. Recovery Capability

Recovery capability refers to the ability to restore the ideal performance level and ensure continuous operation through the re-integration of resources by the supply chain when the risk disturbance exceeds the resistance ability of the supply chain and causes temporary supply interruption. Therefore, recovery capability can be regarded as the supply chain's risk-elimination ability after a disruption.

H8. *"Recovery capability" has a direct positive impact on "supply chain resilience".*

H9. *"Recovery capability" has a direct positive impact on "growth capability".*

3.4.4. Growth Capability

Growth capability refers to the experience of coping after risks have ended and disturbances have occurred. It involves sorting out and summarizing the overall response process, finding the deficiencies and defects in the process, analyzing the problems and causes, summing up the experience and lessons, and reasonably modifying and improving the emergency plan and daily management measures.

H10. *"Growth capability" has a direct positive impact on "supply chain resilience".*

3.4.5. Collaborative Capability

The purpose of collaboration is to enable individuals or departments to cooperate effectively to achieve the specific goals of the enterprise. Collaborative capability regards each node enterprise in the supply chain as an independent individual. These node enterprises establish a common risk management culture and conduct in-depth cooperation based on trust and commitment. In this way, it enhances the degree of resource sharing between enterprises in the supply chain, promotes collaborative planning, effectively solves the problems caused by environmental change, and improves the resilience of the supply chain.

H11. *"Collaborative capability" has a direct positive impact on "supply chain resilience".*

H12. *"Collaborative capability" has a direct positive impact on "preventive capability".*

H13. *"Collaborative capability" has a direct positive impact on "resistant capability".*

H14. *"Collaborative capability" has a direct positive impact on "recovery capability".*

H15. *"Collaborative capability" has a direct positive impact on "growth capability".*

3.5. Data Collection

This study collected data through a questionnaire. The questionnaire was mainly distributed to prefabricated building supply chain entities in Shenyang and Hangzhou, China. The questionnaire consisted of three parts. The first part asked for the basic information of the respondents, including gender, educational background, nature of the work unit, and work experience in the prefabricated construction industry. The second part contained 26 questions that were designed based on the five dimensions of the improved path shown in Figure 3. The Likert scale used a 5-point scale to solicit the respondents' attitudes toward the measurement items. The third part asked for opinions and suggestions using a short answer form. The questionnaire was distributed to government departments, developers, contractors, design units, component production units, construction and transportation units, supervision units, scientific research institutions, universities, and other units.

3.6. Data Processing

Before forming the official scale, this study conducted consultation interviews with relevant experts and representative practitioners. The original questionnaire was summarized and revised based on relevant opinions, and the scale was further improved. To verify whether the questionnaire data collected in this study could be used for further SEM analysis, their reliability and validity were tested using spss version 26.0 to ensure that the data met the criteria for factor analysis.

As shown in Table 5, in the reliability test, the overall Cronbach's alpha coefficient of the scale was 0.907, and the Cronbach's alpha of each latent variable was greater than 0.8, indicating that the reliability of the scale as a whole and of each latent variable was high. For the validity test, this study selected Kaiser–Meyer–Olkin (KMO) values and Bartlett test as validation indicators. The KMO value of each potential variable was greater than 0.8, and the p value of the Bartlett test of each potential variable was lower than 0.000. Therefore, the sample had good reliability and validity.

Table 5. Reliability coefficient and validity coefficient.

Latent Variable	Number of Terms	Cronbach's Alpha	KMO
Preventive Capability	4	0.838	0.869
Resistant Capability	5	0.872	0.818
Recovery Capability	6	0.877	0.874
Growth Capability	4	0.845	0.822
Collaborative Capability	4	0.844	0.833
Supply Chain Resilience	3	0.808	0.800

3.7. Data Analysis

After ensuring the reliability and validity of the questionnaire data met the criteria, a confirmatory factor analysis (CFA) based on SEM was applied to the collected data in this study using Amos 28.0. The aim of conducting the CFA was to verify the path hypothesis proposed in this study. The relationship between the explicit variables and the latent variables was analyzed and tested using the Amos 28.0 software.

To evaluate model performance, this study referred to several well-established indicators [54], as shown in Table 6. In terms of fitness, this study selected the chi-square/degree of freedom ($\chi 2/\mathrm{df}$), the goodness-of-fit index(GFI), the adjusted goodness-of-fit index(AGFI), the root mean squared error of approximation (RMSEA), the normed fit index(NFI), the relative fit index (RFI), the incremental fit index (IFI), the Tucker–Lewis index (TLI), the comparative fit index (CFI), the parsimonious goodness-of-fit index (PGFI), the parsimonious normed-fit index (PNFI), and the parsimonious comparative fit index (PCFI). The relationships among different variables were interpreted based on the standardized coefficients. Through verification of the fitting degree of the PBSCR improvement structural model, it was found that the fitting degree was good. The structural model was initially accepted.

Table 6. The fit indices of SEM.

Category	Index	Standard	Estimation	Result
Absolute fit index	X^2/df	<3.00	1.461	Accept
	GFI	>0.80	0.929	Accept
	AGFI	>0.80	0.910	Accept
	RMSEA	<0.05	0.042	Accept
Value-added fitness index	NFI	>0.80	0.930	Accept
	RFI	>0.80	0.920	Accept
	IFI	>0.80	0.971	Accept
	TLI	>0.80	0.966	Accept
	CFI	>0.80	0.971	Accept
Reduced fit index	PGFI	>0.50	0.734	Accept
	PNFI	>0.50	0.806	Accept
	PCFI	>0.50	0.840	Accept

Then, Amos 28.0 was used to analyze and obtain the standardized path coefficients and *p*-values of the model, in which the path coefficients included the path coefficients of both the measurement model and the structural model, as shown in Table 7. It was found that the *p*-values of "recovery capability ← preventive capability", "growth capability ← preventive capability", and "recovery capability ← resistant capability" are much larger than the critical value. These three paths do not have a strong influence relationship. These three paths should be deleted and the hypotheses H3, H4, and H6 are rejected.

Table 7. Path coefficients.

Path	Hypothesis	Standardized Path Coefficient	*p*-Value
SCR←PC	H1	0.57	***
SCR←EC	H2	0.69	**
SCR←RC	H3	0.91	***
SCR←GC	H4	0.75	***
SCR←CC	H5	0.88	***
PC←CC	H6	0.61	**
EC←CC	H7	0.86	***
RC←CC	H8	0.72	**
GC←CC	H9	0.60	***
EC←PC	H10	0.67	***
RC←PC	H11	0.42	0.109
GC←PC	H12	0.37	0.236
RC←EC	H13	0.78	0.515
GC←EC	H14	0.43	***
GC←RC	H15	0.61	**

** represents $p < 0.01$ and *** represents $p < 0.001$.

The path coefficients of the measurement model were obtained, as shown in Table 8. The five latent variables of preventive capability, resistant capability, recovery capability, growth capability, and cooperative capability were highly representative, corresponding to their respective items. In addition, the Average Variance Extracted (AVE) value of each common factor was greater than 0.5. All the critical ratio (CR) values were greater than 0.8. This shows that the convergent validity of the structural model is ideal and acceptable.

Table 8. Measurement model's path coefficients.

Code	Standardized Path Coefficient	CR	AVE
PC1	0.78	0.868	0.567
PC2	0.78		
PC3	0.70		
PC4	0.75		
EC1	0.77	0.886	0.662
EC2	0.80		
EC3	0.70		
EC4	0.79		
EC5	0.74		
RC1	0.74	0.891	0.674
RC2	0.79		
RC3	0.73		
RC4	0.73		
RC5	0.70		
RC6	0.72		
GC1	0.70	0.882	0.6
GC2	0.76		
GC3	0.75		
GC4	0.83		
CC1	0.80	0.832	0.554
CC2	0.76		
CC3	0.76		
CC4	0.70		
SCR1	0.70	0.832	0.613
SCR2	0.66		
SCR3	0.74		

Based on the above analysis results, the model was revised. The paths "recovery capability ← preventive capability", "growth capability ← preventive capability" and "recovery capability ← resistant capability" were deleted. At the same time, a re-analysis was carried out to finally establish an SEM of PBSCR with improvement capability. The modified SEM was finally established, as shown in Figure 4.

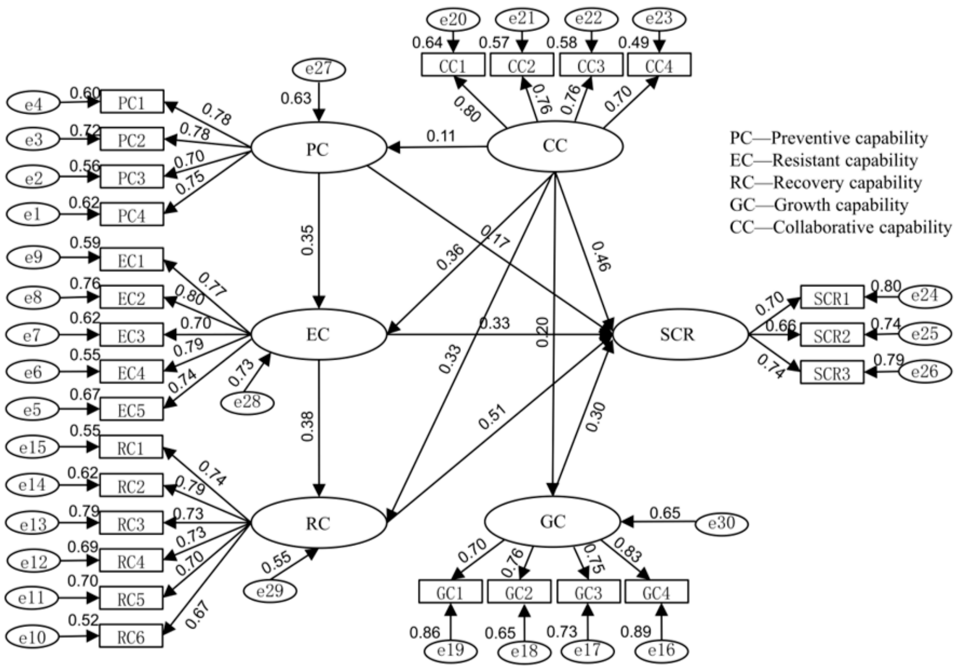

Figure 4. The modified SEM.

4. Result

SEM includes latent variables and explicit variables. Latent variables are variables that cannot be directly observed and measured. Explicit variables are variables that can be directly observed and measured. SEM includes measurement models and structural models. Measurement models, also known as validated factor analysis models, can reflect the relationship between the latent variables and explicit variables. The structural model, also known as latent variable causality model, mainly represents the relationship between the latent variables. SEM provides a model basis for the construction of the effect relationship of PBSCR, and the data basis for the study of the improvement path of PBSCR. The construction of the effect relationship of PBSCR is mainly divided into two parts. The effect relationship between the latent variables and the effect relationship between the latent variables and explicit variables are constructed.

4.1. Effect Relationship among Latent Variables

In this study, the Amos 28.0 software was used to analyze PBSCR via SEM, and 12 hypotheses were verified. The path coefficients of the structural model were obtained. Based on the path coefficients among the latent variables, the effect relationship coefficients among the latent variables were constructed, as shown in Table 9.

Table 9. Effect relationships between latent variables.

Path	Direct Effects	Indirect Effects	Rank
PC→SCR	0.17	$0.35 \times 0.33 + 0.35 \times 0.38 \times 0.51 \approx 0.183$	4
EC→SCR	0.33	$0.37 \times 0.53 = 0.1961$	3
RC→SCR	0.53	-	2
GC→SCR	0.30	-	5
CC→SCR	0.46	$0.11 \times 0.17 + 0.11 \times 0.35 \times 0.33 + 0.11 \times 0.35 \times 0.38 \times 0.51 + 0.36 \times 0.33 + 0.36 \times 0.38 \times 0.51 + 0.33 \times 0.51 + 0.2 \times 0.3 \approx 0.396$	1

By constructing the effect relationships among the latent variables, the direct effect, indirect effect, and total effect among the latent variables can be obtained. In this study, among the five latent variables of preventive capability, resistant capability, recovery capability, growth capability, and collaborative capability, the latent variables with a high direct effect, a high indirect effect, and a high total effect on resilient performance were set as the improvement path of PBSCR.

4.2. Effect Relationship between Latent Variables and Explicit Variables

It was verified that the 26 items corresponding to the five latent variables of preventive capability, resistant capability, recovery capability, growth capability, and collaborative capability were highly representative. The path coefficients of the measurement model were obtained. The effect relationships between the latent variables and explicit variables were constructed based on the path coefficients between the latent variables and explicit variables, as shown in Figure 4. By constructing the effect relationships between the latent variables and explicit variables, the effect of the explicit variables on the latent variables could be obtained. On the one hand, the explicit variables with a higher effect on the latent variables corresponding to the PBSCR improvement path were set as the key measures in the PBSCR improvement path. On the other hand, the explicit variables with a higher effect on the latent variables of SCR were set as the key factors in the improvement path of PBSCR.

5. Discussion

Starting from the dynamic capacity theory, this paper discusses the path to improve PBSCR in combination with the existing literature. Collaborative capability has the greatest impact on PBSCR, followed by recovery capability, resistant capability, and preventive capability. The impact of growth capability is the weakest. The main bodies of the supply chain cooperate to establish strategic partnerships and efficient benefit distribution mechanisms to form effective cohesion and ensure the continuous flow of capital in the supply chain, which improves PBSC. Although growth capability has the weakest impact, it cannot be ignored. After the PBSC is disrupted, all participants in the supply chain summarize the problems after the supply chain resumes its normal operation. On this basis, the participants strengthen the training and learning of emergency response methods by actively sharing knowledge achievements and information.

The improvement in key influencing factors is to fundamentally improve PBSCR. The improvement method needs to adopt multi-party means that are compatible with it to form a joint force to promote the improvement of the influencing factors and to achieve the development goal of PBSC, as shown in Figure 5. First of all, to improve preventive capability, it is necessary to improve the theoretical level of supply chain management of all participants and increase the training, publicity, and education of SCR knowledge. This involves enabling the enterprises in the supply chain to have the basic ability to assess, avoid, and control risks and issue early warnings. Second, it is important to ensure timeliness, accuracy, and quality of material supply. It is necessary to fully consider whether a supplier's supply capacity can meet the demand. Supply chain members anticipate problems that may arise during the supply phase of materials and components and prepare a response plan in advance. They establish a real-time information system to improve SCR. In terms of improving resilience, logistics solutions should be rapidly redeployed after supply chain disruptions have ended to ensure that the supply chain is operated in a way and speed to meet supply demand. At the same time, flexible adjustment in terms of technical solutions, machinery, and schedules is conducive to the diversification of supply chain risks. Finally, given the growth capability, all participants should summarize the disruption after restoring the normal operation of the supply chain. On this basis, knowledge sharing and information sharing among members should be promoted. It is also important to enhance training for people on how to respond to emergencies following supply chain disruptions.

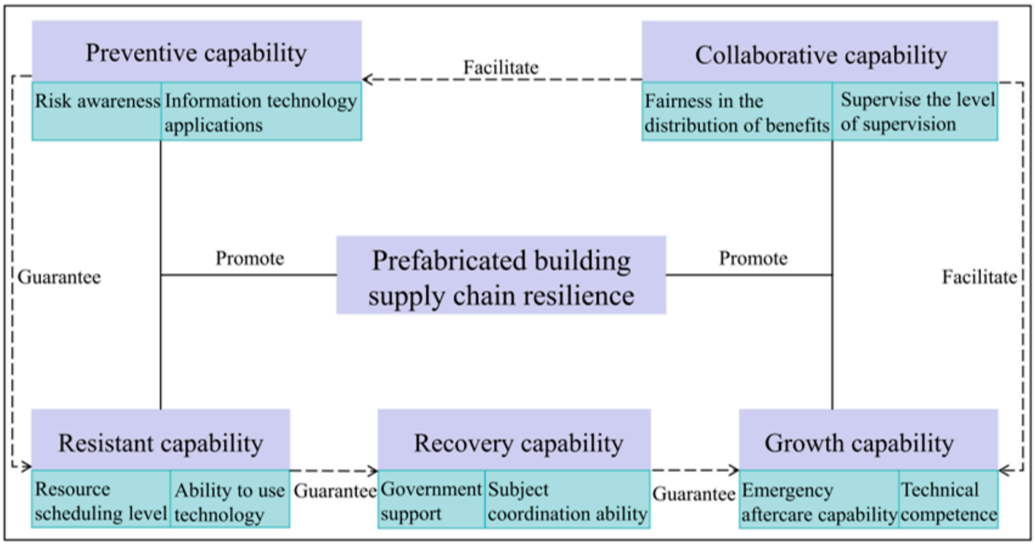

Figure 5. Critical path diagram.

The risk awareness of personnel, the application level of information technology, the way the interests of supply chain stakeholders are distributed, the level of government support, and the regulatory ability of enterprises will affect PBSCR according to the analysis of the critical path. This is similar to the 4M1E theory [55,56]. "4M1E" refers to man, machine, material, method, and environment. Zhang, W., Deng, F. and et al. expanded the meaning of the 4M1E theory. They proposed that "Man" means "human resources", "Machine" stands for "infrastructure", "Material" is the meaning of "material resources", and "Method" stands for "rules and regulations" [57]. Mao, Y. and Tuo, X. suggested that if material quality could not meet the standards, engineering quality would not meet the requirement [58]. Sun R., Zhao, S., You, J. et al. regarded material as the application of technology in the process of cleaning the egg industry chain. The method was considered to be the rules and regulations to be observed during production. The environment was considered to be the environment for the development of the industrial chain [59]. Similarly, if various technologies are not innovative, resulting in incorrect information and other problems in the PBSC, this also greatly increases the instability of the supply chain. These are the same as what the critical path covers. Based on the research results and the analysis of this study, suggestions for improving the PBSCR are shown in Figure 6.

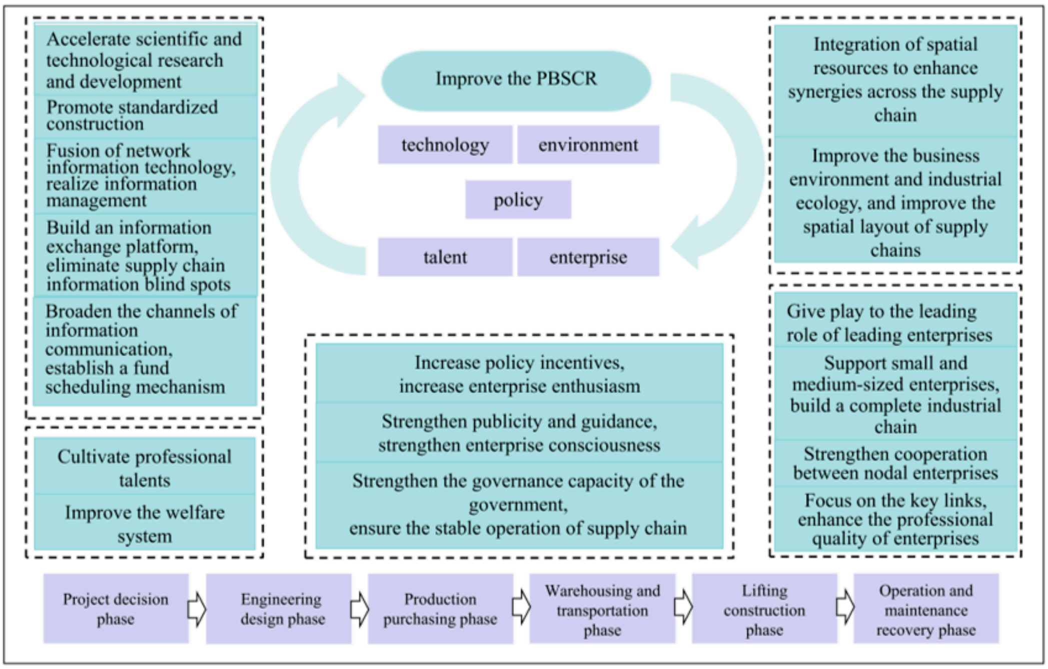

Figure 6. Safeguard plan.

5.1. Improve PBSCR from the Aspect of Talent

It is necessary to strengthen the training of professional technical management personnel and skilled industrial workers [15]. The main body of research and development (R&D) should increase technological innovation and cultivate all-around talents for the future development of the industry. These provide a basis for the high-quality development of talents and technical foundation. The units need to improve their talent training program and carry out more intelligent practice activities to prompt the active organization of technicians to learn the key contents and core technologies of prefabricated buildings. Management should fully mobilize the enthusiasm for enterprise technology research and development, as a way to improve the design innovation of prefabricated buildings and promote the production and supply of prefabricated buildings [60].

5.2. Improve PBSCR from the Aspect of Enterprise

Large prefabricated construction enterprises should actively adopt the general contract construction method to effectively control the design, construction, component production, transportation, and equipment resources [49]. The government should actively promote the construction of prefabricated building demonstration projects. It is suggested to focus on cultivating and developing leading enterprises with high industrial correlation and strong driving ability. Large enterprises should play an exemplary leading role. They drive the common development of other small enterprises and eventually form economies of scale [60]. The PBSC operation is mainly subjected to the coordination and integration of various enterprises and links. Through regular organization of team building, mutual visits, and other activities, it can enhance the trust between enterprises, establish a benign and friendly partnership, and improve collaborative capability. At the same time, enterprises should strengthen their risk prevention and control ability, improve the level of redundancy, rationalize the allocation of excess capacity, and improve their resistant capability. The material production and procurement phases should be given full consideration in the supply cycle and quality requirements of materials and components to ensure timely responses to market demand.

5.3. Improve PBSCR from the Aspect of Technology

The project development, design, construction, operation, and maintenance of prefabricated buildings are very different from the traditional construction mode. To promote the development of prefabricated buildings, it is necessary to rely on the strong support of scientific and technological research and development [29]. Therefore, the state and enterprises should take the lead in scientific and technological innovation by increasing investment in scientific and technological R&D. At the same time, we should strengthen the transformation of scientific and technological innovation achievements. Enterprises actively implement the role of scientific research results to promote the development of prefabricated buildings [60]. The industry actively introduces and promotes advanced science and technology. By consolidating prefabricated building design technology, component processing and production technology, component installation, and project management technology, the technical and quality standards of prefabricated buildings will be gradually improved. Prefabricated buildings will accelerate the deep integration with information technology, and the use of modern information technology, big data, artificial intelligence (AI), the Internet of Things, and other emerging technologies will support the construction of intelligent building projects [61]. Emerging information technology-enabled features for smart contracting, real-time monitoring, self-regulation, and provision of reliable databases have a great potential. They enable instantaneous information sharing among project participants and enhance the preventive and resilience capabilities of the supply chain. They can effectively improve the communication efficiency of all members and their timely understanding of the market situation. Enterprises can produce and purchase scientifically.

5.4. Improve PBSCR from the Aspect of Policy

The relevant departments should increase policy incentives, make full use of existing support policies, and adopt financial discounts, subsidies, and incentives to improve the enthusiasm of enterprises [62]. The government should reasonably arrange the development of land for prefabricated buildings according to the construction objectives and tasks of prefabricated buildings. The government should also give certain financial incentives to prefabricated building demonstration projects to encourage the creation of prefabricated building demonstration projects [63]. In the pilot stage, the use of prefabricated building construction projects in project approval, start permits, pre-sale permits, and other links can be employed to establish a rapid approval "green channel" [64]. For prefabricated housing, the government should strengthen the popularization of prefabricated buildings and encourage the public to make use of prefabricated buildings. Certain credit and tax incentives are given to consumers who buy prefabricated homes. It is recommended to provide policy loans with lower interest rates and longer loan terms than commercial loans for consumers who purchase residential buildings to stimulate the market for prefabricated buildings [65].

5.5. Improve PBSCR from the Aspect of the Environment

Prefabricated buildings emphasize the integrated and coordinated development of design, production, transportation, construction, and other links. Due to the low overall informatization level of the PBSC, the solidification of production and construction thinking mode, the lack of whole-process organization and management, and the asymmetry of industrial information, all links of such a supply chain are fragmented. Resource allocation is inefficient [13]. Related enterprises cannot be coupled to have synergistic effects. The PBSCR will be affected by the supply and demand interests between supply chain enterprises. To improve PBSCR, it is necessary to strengthen the coordination and unity of government macro-control and market regulation, scientifically predict the fluctuation of market economic cycles, and investigate and grasp the trend of consumer demand. Following the law of market supply and demand, enterprises achieve reasonable distribution of interests among them and ensure the autonomy and control of the PBSC to the greatest extent [15]. The PBSC is extended as a whole. The number of participating enterprises is large. The supply chain is vertically integrated. The core enterprises expand upstream and downstream, transforming some market transactions into internal transactions. Cluster development enhances the synergy of all links of the supply chain through the integration of spatial resource aggregation, thereby improving PBSCR [13]. The improvement in PBSCR emphasizes the improvement in the coordinated development of the whole supply chain. It should also start by improving the standardization level of prefabricated buildings. We should gradually build a systematic standardization development system, strengthen the connection of the supply chain, and guide the PBSC to achieve industrialization transformation and upgrading [49].

6. Conclusions

To better reflect the essential characteristics of PBSCR, this study identified the influencing factors of PBSCR from the perspective of dynamic capabilities based on the literature combined with a survey study. The five dimensions include preventive capability, resistant capability, recovery capability, growth capability, and collaborative capability. A theoretical model of PBSCR was constructed, and the questionnaire method was used to collect data. The SEM was used to explore the influence of different dimensions on PBSCR and their correlation.

The theoretical implications of this paper are mainly reflected in the dynamic capacity theory for the exploration of the improvement of PBSCR. Through the realization of prevention, resistance, recovery, growth, collaboration, and other dynamic capabilities in the development of PBSC, the factors affecting PBSC are systematically explored so that the dynamic capacity theory can be more effectively applied to the field of SCR. In terms of practical significance, it provides a scientific reference for the government to formulate policies for the prefabricated building industry. Through research, stakeholders in the PBSC can find targeted measures to focus on improving according to their weaknesses and the key points of the improvement SCR. In the future, a reasonable long-term mechanism for improving resilience will be developed to provide direction and guidance for decision makers of related enterprises in the PBSC.

Currently, the theory of PBSCR is still in the preliminary stage. There is not much literature that can be directly referred to. The research team was limited to investigating the PBSC in Shenyang and Hangzhou due to constraints. This leads to the fact that the study results may be affected by geographical constraints and local rate of economic development. In the future, this research group will conduct further research based on the findings of this paper. A follow-up study should compare and analyze the situation of PBSC in different regions. Factors such as different levels of economic development are worth considering to improve PBSCR.

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