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Article

Influencing Factors of Resilience of PBSC Based on Empirical Analysis

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Abstract: With the widespread application of supply chain management ideas in the construction field, supply chain resilience as a tool for risk management has also begun to attract scholars' attention. The prefabricated building supply chain (PBSC) is greatly affected by internal and external risks in China. This paper constructs a conceptual model of the factors affecting the resilience of the prefabricated building supply chain from the perspective of resilience management. Based on 202 valid questionnaires, it makes an empirical study on the above conceptual model by using the method of the structural equation model (SEM). The results show that the production and assembly construction of components have a significant impact on the resilience of supply chain of prefabricated buildings (PB), while the process of transportation and storage of components has no significant impact on it. In addition, the study also verified that information factors and partnership factors have a strong regulatory effect on these three processes. In theory, it provides a new perspective for the supply chain management of prefabricated buildings. In practice, it provides a decision-making basis and scientific guidance for the enterprises in the supply chain of prefabricated buildings in China.

Keywords: prefabricated building supply chain; influencing factors of prefabricated building supply chain resilience; empirical analysis effects

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1. Introduction

Under the background of implementing the "urban renewal" process and striving to achieve the "carbon emission" and "carbon peak" goals in China, prefabricated buildings (PB), as a new type of residential building transformation, are highly compatible with the current civilized construction requirements of energy conservation and environmental protection. It adopts factory manufacturing of components and on-site splicing production methods, which has a better advantage in simplifying the process of construction, improving production efficiency and reducing labor costs and environmental pollution than cast-in-place. Besides, PB is a major reform in the field of building energy efficiency, which will have a sustained and broad development space in the future. In terms of economy and policy, PB has received strong support in China, but the overall development of it is still in the initial stage. Hong pointed out that the implementation of supply chain management is a necessary condition for the transformation of the construction industry's market environment (from competition to coordination and cooperation) [1] and competition between enterprises will also become competition between the supply chain [2]. The introduction of supply chain management can help companies in the supply chain of engineering projects to form strategic partnerships, integrate high-quality resources, reduce overall costs and improve project quality and benefits, which has been confirmed in western developed countries. Western countries represented by the United Kingdom and the United States have achieved remarkable results in aspects of the construction period, quality, cost and corporate relations [3]. Therefore, the introduction of supply chain management ideas into the field of construction has attracted more and more attention from scholars.

At present, the world is showing more and more characteristics of VUCA (volatility, uncertainty, complexity, ambiguity) [4]. In such an environment, the supply chain is also facing this environment state. The biggest problem of PB is that the prefabricated components (PCs) are produced in different places and then transported to the site to complete the assembly construction [4]. The PBSC is a relationship chain involving the coordinated management of multi-level enterprise units in the vertical direction and a task chain based on multi-resources, such as materials, equipment and information technology, which integrate and closely contact each other [5]. In the whole process, different stages and enterprises are closely associated. Both internal management and external situations may cause uncertainties in the supply chain. From the inside of the supply chain, the loose management status of each enterprise severely limits the further development of PB. Besides, most of the enterprises cooperate temporarily and lack cohesion [6]. There are problems, such as the low level of cooperation between suppliers and enterprises, the urgent need to improve the level of information, the poor sharing of data resources and the lack of timely communication. As a result, enterprises lack innovation enthusiasm and competitiveness. From the outside of the supply chain, with the development of society, a single architectural form can no longer satisfy the residents' pursuit of high quality and individuality. PB in developed countries has prematurely introduced supply chain management ideas and has rich experience, which poses a great competitive threat to China's PB market [7].

Due to disadvantages in technology, talents and products, the PBSC in China is vulnerable to internal and external uncertainties and has poor stability. It is often in a passive state when responding to the risk of force majeure events. In case of emergencies, the supply chain is likely to be interrupted [5], although when companies in the PBSC make reasonable decisions to meet production needs, the supply chain has "resilience" [2]. The resilience of the PBSC reflects the ability of business entities related to PB to survive, adapt and develop in the face of risk changes. A resilient PBSC can promote node companies to use their own technological advantages and resource advantages more efficiently. At the same time, it can reduce the probability of risk occurrence and improve the ability to resist risks [8]. It also can prompt node companies to form good partnerships and facilitate long-term cooperation. This improves the stability of the PBSC, so as to promote the stable and sustainable development of PB.

In summary, PB are ushering in development opportunities in China. The supply chain management to improve the overall color of PB is also becoming more and more important. Facing the current VUCA environment background, combining supply chain resilience (SCR) ideas with the development of PB is beneficial to improve the ability of the PBSC to resist risks and is of great significance for achieving its large-scale and stable development.

2. Literature Review

2.1. PBSC

Based on existing research, there is no accurate definition of the PBSC. The traditional building directly transports materials to the site through equipment processing and then construction, while PB needs to combine the materials with the equipment supplied to the component factory for processing and then prefabricated components (PCs) are transported to the site for installation by the third-party logistics company. Some scholars have made certain explanations based on the production characteristics of PB [9]. For example, Wang (2016) believes that the PBSC can be described as "through the control of information flow, capital flow and logistics in the housing development process, from investment decision-making, design, construction to the end users use the units involved in the whole life cycle, they will be connected into a whole functional network chain structure" [10]. Xue (2016) proposed that the PBSC should include all business processes at all stages of planning, design, production, transportation, assembly and operation and maintenance [11]. Chen (2020) believes that the PBSC is composed of key business processes and organizations [12].

Ji pointed out that the main supply chain nodes of PB are design-off-site, manufacturing-logistics and transportation-on-site installation [13]. Xu pointed out that PBSC is a network composed of multiple organizations and relationships, including information flow, capital flow and service flow [14]. Xiao integrated the traditional construction manufacturing supply chain structure and proposed that all the node enterprises with direct or indirect cooperative relations are covered by the whole life cycle of the construction project [15]. According to existing research, this article defines PBSC as a relationship chain involving multi-level construction vertically and collaborative management of multiple project participants horizontally.

PB need to undergo off-site production, cross-regional transportation and assembly construction. So, it is not easily changed if the production quantity and scale of components are generally determined according to the order [16]. Due to the different production and construction methods of PB, it has attracted the attention of many scholars. They have mainly focused on the summary or evaluation of risk factors, cost control research and PBSC integration. These articles all put forward the influencing factors of the PBSC from different perspectives. For example, Li, Y. et al. established five processes from planning, design, procurement, manufacturing, assembly and delivery and four dimensions of nature, politics, economy and the market model based on rough set theory to screen the identified influencing factors [17]. Wang used empirical methods to study the influence of information factors and partnerships on the PBSC [10]. Xue proposed that the establishment of an information platform can help companies in the supply chain to improve communication efficiency at all stages of planning, design, production, transportation, assembly, operation and maintenance. It also pointed out that a good corporate partnership is conducive to maintaining the stable operation of the supply chain [15]. Chen constructed a conceptual model of the influence of partnership and logistics capabilities on the supply chain of PB and analyzed the correlation between factors [12]. Ji pointed out that the main supply chain nodes of PB are design–off-site manufacturing–logistics transportation–on-site installation. The factors affecting the supply chain of PB are analyzed from different angle, such as the design innovation ability of components factories, manufacturer management, the reliability of the logistics company in transportation, the quality of on-site construction personnel, etc. [13]. The above research on the influencing factors of the PBSC provides a certain theoretical basis for this article.

2.2. Supply Chain Resilience (SCR)

SCR is defined as the ability to ensure the supply chain is uninterrupted or quickly return to its original state or even better in the face of sudden shocks. With the development of SCR management, domestic and foreign scholars have also conducted preliminary explorations of the factors affecting it. Sun [18] divided the influencing factors of SCR into five dimensions: information flow, logistics, capital flow and the coordination degree, integration and matching degree among enterprises. A triangular model of SCR was constructed and the influencing factors of it were summarized from the two aspects of capability and loophole [19]. Capability is defined as the methods, technologies and skills required by an enterprise to perform core functions in the supply chain environment. Vulnerabilities are understood as possible interference from outside the context of the supply chain that may prevent the company from carrying out its day-to-day work. At the same time, it pointed out the important impact of accurate information flow and close corporate partnership on the SCR. Claudia pointed out that the leadership's organizational ability, the efficiency of information transmission, the customer relationship, the collaboration ability between enterprises and the emergency management ability have a significant impact on it through empirical research [20]. Shi used the SLNA dynamic literature review method to analyze the information sharing pair that can improve the resilience of the supply chain [8]. Wieland, A. collected 14 factors that affect PB's supply chain disruption through a survey of 7 companies around the world and pointed out that the elasticity of the supply chain is related to the improvement of supply chain performance [21]. Agi, M.A.N. pointed out that the possibility of supply chain disruption has greatly increased in the context of the increasingly complex contemporary supply chain environment [22]. Besides, it is concluded that information resource sharing can increase the visibility of the supply chain and improve it through surveys of relevant data of 264 British companies. Brandon-Jones et al. established the SEM models, which pointed out that digital technology tools and the proficiency of digital technology application can improve the resilience of the supply chain [16].

2.3. Literature Summary

Based on the literature review [20–28], it can be found that the research on the factors affecting the resilience of the supply chain and the PBSC is basically mature, which can provide a certain theoretical basis for the research of this article. However, considering the difference between the general supply chain and the PBSC, the above research on the influencing factors of PBSCR are not completely consistent. With the opportunity of China's vigorous promotion of the development of PB, the research on PBSC has attracted the attention of some scholars. However, the conceptual definition of the PBSC and its resilience is still not unified. Besides, most studies on the resilience of the supply chain are based on the resilience of the traditional manufacturing supply chain. The research on the resilience of the PBSC has not yet formed a preliminary understanding. In short, identifying the factors that affect the resilience of the PBSC and analyzing their relevance is very meaningful work.

3. Research and Design

3.1. Research Hypotheses and Model

Research on supply chain resilience at home and abroad has matured and the influencing factors of it are more comprehensive than those covering the characteristics of the supply chain itself and the external environment. However, considering the difference between the generalized supply chain and the PBSC, the influencing factors of the above research are not completely consistent with and the PBSC resilience. PBSC is a relationship chain involving the collaborative management of vertical multi-level enterprise units. It is a task chain based on multi-resources, such as materials, equipment and information technology, which tends to multi-objective integrated management. The influencing factors of it involve multiple organizations, processes and dimensions. Luthra, S (2015) divided the impact of SCR into internal and external categories [29]. The internal includes risks related to the production capacity and operations and the external includes nature, political systems and markets. It is difficult to assess due to external shocks, such as sabotage, terrorist attacks and coups. Therefore, combined with the construction characteristics and development status of PB, this article aims to consider the influencing factors that affect the entire process, focusing on the three main PBSC processes (PC production-transportation and storage-influencing factors-assembly and construction, namely PC production-transportation and storage-influencing factors-assembly construction) from the perspective of resilience. Based on research literature at home and abroad, the relationship between path hypotheses is proposed and the conceptual model is established as follows:

The Impacts of PF on PBSCR

The biggest difference between PB and traditional buildings is that the production of PC must be carried out in a prefabricated component factory and then be transported to the site for assembly. Therefore, the production stage of PC has an important impact on the operation of the entire supply chain [9]. The formulation of the transportation plan of the logistics company needs to be formulated according to the design and production plan of the PC. The modulus and quality of structural parts affect the smooth progress of on-site installation and construction. Chang established the ISM model and pointed out that the application of high technology in enterprises is beneficial to ensuring quality standards and reducing risks. So, it is of great significance to improving the resilience of the supply chain [26]. Lin, Y. believes that the ability to handle design changes and design innovations efficiently and accurately is very important in the production process of prefabricated parts, which is conducive to improving the flexibility and agility of the supply chain [30]. Therefore:

Hypothesis 1a (H1a). *The production factors of structural parts have a positive influence on the resilience of the PBSC.*

Hypothesis 1b (H1b). *The PC production factors affect the resilience of the PBSC by influencing transportation and storage factors.*

Hypothesis 1c (H1c). *The PC production factors affect the resilience of the PBSC by influencing assembly construction factors.*

The Impacts of TSF on PBSCR

The research on logistics capabilities and inventory on supply chain performance or supply chain integration provides a theoretical basis for this article to study the relationship between transportation and storage of components on the PBSCR. Improving the integration capabilities of the supply chain is conducive to building a resilient supply chain. Morash proposed that the logistics speed of goods and reliability of a logistics company are important factors for logistics capabilities. As a semi-finished product, PC are transported across regions from the component factory to the construction site. The quality and transportation timeliness of the components have a direct impact on the construction and installation plan. Luthra, S.D. et al. mentioned that additional inventory provides the advantage of meeting daily fluctuations in demand and the availability of alternative suppliers greatly reduces the risk of supply chain disruption [29]. Wang proposed that reasonable design of inventory allocation and transportation routes can increase supply chain redundancy and provide a guarantee for the smooth progress of the construction plan [10]. Chen constructed a conceptual model of PBSC and analyzed the impact of partnerships and logistics capabilities on SCR [3]. Therefore:

Hypothesis 2a (H2a). *Transportation and storage factors have a positive impact on the resilience of the PBSC.*

Hypothesis 2b (H2b). *Transportation and storage factors affect the resilience of the PBSC by influencing assembly construction factors.*

The Impacts of ACF on PBSCR

The organization plan and method of PB's construction are still being explored in China. Wang pointed out that a reasonable construction organization plan is conducive to improving construction efficiency and reducing the probability of sudden risks. The construction method of PB greatly reduces the labor force for on-site construction, so the construction schedule and quality of PB are largely affected by the quality and technical capabilities of the construction personnel [13]. Scavarda, L.F et al. believe that the ability of leaders to manage loopholes and adapt to changes is very important. They also pointed out that employees should receive emergency training and courses to improve their ability to deal with risks [9]. Therefore:

Hypothesis 3 (H3). *Assembly construction factors have a positive influence on the resilience of the PBSC.*

The Impacts of IF on PBSCR

According to RBV logic, in order to create capabilities, resources may need to be combined and utilized [4]. Information can be positioned as a type of resource. Ji (2018) believes that improving the integration capability of the supply chain is conducive to the realization of a resilient supply chain [13]. The basic elements of supply chain integration include information sharing and technology sharing. The transmission of information improves the transparency of upstream and downstream suppliers, which is conducive to improving the response efficiency of supply chain enterprises [23]. Xue found that information plays an important role during the design and construction phase. He also pointed out that the establishment of an information platform can improve the communication efficiency of supply chain companies, which can improving the visibility and agility of the supply chain [11]. The three important stages of PCs from production and transportation to on-site construction include the circulation of a large amount of information, such as production plans, transportation plans and on-site construction plans. The timely and smooth sharing of information among enterprises is the basic requirement for coordination and cooperation of various units in the PBSC [9], which is the basis for maintaining an uninterrupted supply chain. Therefore:

Hypothesis 4a (H4a). *Information factors positively regulate the positive impact of production factors on the resilience of the PBSC.*

Hypothesis 4b (H4b). *Information factors positively regulate the positive impact of transportation and storage factors on the resilience of the PBSC.*

Hypothesis 4c (H4c). *Information factors positively regulate the positive impact of assembly construction factors on the resilience of the PBSC.*

The Impacts of RF on PBSCR

Supply chain enterprise partnership is a complex variable, but the theoretical research on it is relatively mature. Many empirical studies involve this variable. The measurement dimensions of partnerships are relatively consistent and most of them include trust, communication, commitment, interdependence, adaptation and cooperation. The PBSC involves the cooperation of multiple companies at different stages and the partnership factors exist in the entire supply chain, such as the cooperation of the PC factory with the parts logistics company. K.H. et al. proposed that the ability of different functional personnel of professional enterprises to work together and the enthusiasm regarding interaction and cooperation with suppliers affect business risks [27]. Shi proposed that the dependence, trust and commitment of partnerships between enterprises are of great significance to improving the performance of the supply chain [8]. Chen verified through empirical research that partnership has a significant impact on supply chain integration. Therefore:

Hypothesis 5a (H5a). *Partnership factors positively regulate the positive impact of production factors on the resilience of the PBSC.*

Hypothesis 5b (H5b). *Partnership factors positively regulate the positive impact of transportation and storage factors on the resilience of the PBSC.*

Hypothesis 5c (H5c). *Partnership factors positively regulate the positive impact of assembly construction factors on the resilience of the PBSC.*

The conceptual model is shown in Figure 1.

After summarizing the influencing factors from the perspective of resilience, the research team conducted semi-structured interviews with experts who work in the Beijing Municipal Commission of Housing, Urban-Rural Development and the Self-discipline Committee to confirm the validity and reliability of the influencing factors. According to the background of the PB industry in China, the experts determined 18 observation variables under five dimensions (prefabricated component (PC) production factors, PC transportation storage factors, PC assembly construction factors, information factors and partner factors) in Table 1.

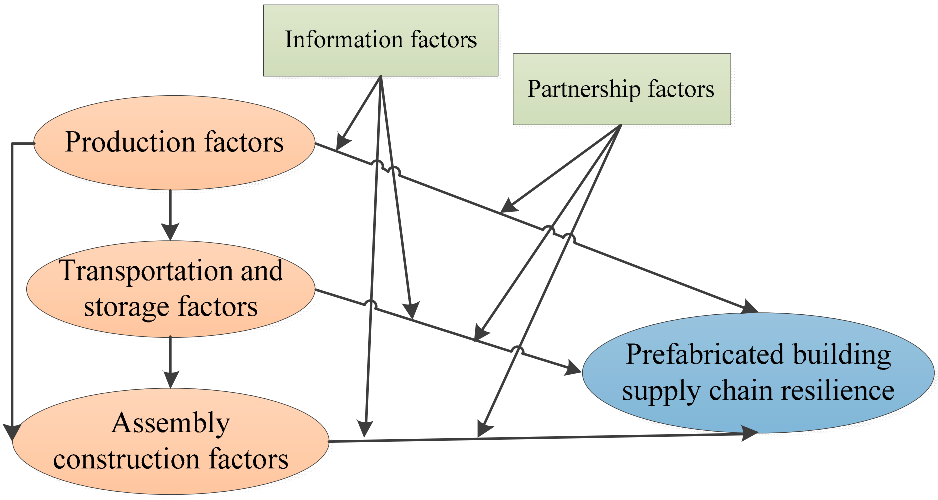

Figure 1. Conceptual model of factors affecting the resilience of PBSC.

Table 1. Factors influencing the resilience of PBSC.

Impact Category	Factors	References
PF	Number of component factories	[22,26,29,31]
	Management of component manufacturers	[2,25,27,28]
	Component production technology capabilities	[2,14,17–19]
	Redundancy of components	[18–21,25]
TSF	Transportation capacity	[2,16,32]
	Transportation redundancy	[21,29,33–35]
	Storage capacity	[24,27,34]
ACF	Assembly construction capacity	[7,12,23]
	Construction Technology Assembly	[9,21,35]
	Risk emergency management capability at assembly construction site	[26,34]
IF	Information sharing	[2,6,14]
	Information oversight	[22–24]
	Application of Information Technology	[8–10,23]
RF	Trust	[14,15,24]
	Adaptation	[9,22,24]
	Collaboration	[14,18,36]
	Commitment	[5,15,32]

PC production factors (PF): Number of component factories. Refers to the influence of the number of component factories that upstream and downstream enterprises can choose from on the PBSC, which can improve the redundancy of the supply chain.

Management of component manufacturers. Supplier management maturity, supply plan, standardization, specialization and standardization of component factories, etc., which have an impact on the quality and quantity of components and the cooperation relationship between manufacturers [16].

Component production technology capabilities. Including the degree of integration of production and the technological innovation ability of manufacturers, which can affect the types and quality of PC to meet market demand that improve the adaptability of the supply chain [17].

Redundancy of components. Product inventory, emergency inventory levels, overcapacity in production and the ability to replace defective components in a timely manner can improve the redundancy of the supply chain.

Transportation and storage factors (TSF): Transportation capacity. The rationality and flexibility of inventory allocation, transportation vehicles and route planning cannot be separated from a reliable logistics company.

Transportation redundancy. The ability to transport products with excessive demand can affect the flexibility and adaptability of the supply chain.

Storage capacity. It reflects the storage capacity of finished or semi-finished components to be constructed and installed after transportation or transportation is completed.

Assembly construction factors (ACF): Assembly construction capacity. Mainly includes the construction method design, site layout management, personnel flow and work efficiency, vertical transportation capacity of construction equipment, construction specialization etc., which can improve the ability to face risks [12].

Construction technology assembly. It refers to the PB construction organization design, technical plan formulation and process flow arrangement, etc. As a new type of building construction method, the construction technology process of on-site installation is still in the exploratory stage, which plays an important factor role influencing the resilience of the supply chain.

Risk emergency management capability at the assembly construction site. On-site assembly construction reduces the demand for labor but strengthens its requirements for the quality of employees. The upper-level leaders' risk identification ability, emergency response ability and responsibility risk awareness of on-site workers affect the agility of the supply chain [7]. Training employees in professional skills, experience management and innovation awareness can help improve the overall anti-risk ability.

Information factors (IF): Information sharing. The establishment of an information platform is conducive to data sharing and facilitates communication between enterprises and employees, which can improve the visibility and agility of the supply chain and detect sudden risks in time.

Information oversight. It can refer to the monitoring of component production processes, transportation processes and construction conditions through modern monitoring technology and the risks that may be caused by the external environment of the entire supply chain process, such as weather forecasts, etc. [13], which is conducive to improving the response efficiency of supply chain enterprises.

Application of information technology. With the development of Internet big data, information technology has also begun to play an increasingly important role in the development of prefabricated buildings. For example, BIM technology improves the visibility of the supply chain and block chain technology provides a reference for the practice of prefabricated building information management.

Partnership factors (RF): Trust. Loyal and reliable supply chain companies and mutual trust can be of assistance to each other in the event of a problem or emergency. Trust is the basis of friendly cooperation between enterprises [3].

Adaptation. The ability to adjust its own production system to meet the needs of enterprises or market customers in the supply chain.

Collaboration. The cooperation between enterprises of the same nature of the supply chain and the cooperation between the upstream and downstream enterprises of the supply chain are mainly in the stages of design, production, transportation and construction.

Commitment. A good collaborative relationship helps maintain the stability of the supply chain. Companies in the supply chain intend to maintain a good long-term cooperative relationship and make some efforts and commitments to this end. Commitment is a measure of corporate credibility. Re-promise enables companies to face emergencies together, which helps reduce risks.

PB Supply Chain Resilience (PBSCR):

There are many indicators to measure the resilience of the supply chain, such as flexibility, agility, innovation, redundancy, robustness, etc. For example, Li identified 24 elastic strategies and divided them into four main categories, namely flexibility, redundancy, collaboration and agility [30]. Flexibility is the supplier's ability to manage disconnection and respond to changes in demand. This ability is enhanced through highly redundant, adaptable and standardized processes [21]. Tang 2006 proposed the use of three indicators including flexibility, redundancy and innovation to measure the resilience of the supply chain [31]. Combined with the characteristics of the PBSC and its influencing factors on resilience, after expert discussion, the following three indicators were used as the standard to measure the resilience of PBSC.

Flexibility. The ability of enterprise management to disconnect and respond to changes in demand.

Agility. Identifying the risk or the speed of reaction when encountering an impact.

Innovation. Innovative capabilities in various aspects of information technology application, product diversity and logistics storage construction technical solutions.

3.2. Research Methods

The research methods on influencing factors are relatively mature. For example, some scholars have applied the theory of supply chain management to the development of PB and used SNA to explore the influencing factors of supply chain transportation costs [32]. For example, Govindan, k, et al. (2016) used FCM to describe the causal relationship among the following nine engineering flexibility factors, namely teamwork, awareness, preparation, learning culture, reporting, flexibility, redundancy, management and commitment [33]. PBSC resilience factors affecting the analysis have thus far only been summarized in the literature only from a qualitative point of view. Zhu and Chen summarized the factors affecting the SCR based on the perspective of the supply chain itself [2,3]. For example, Zhu summarized the factors affecting the resilience of the supply chain from related units and the supply chain itself and established an ISM model to qualitatively analyze the correlation between the factors [2]. This article comprehensively adopts the literature review method and the social survey method. The influencing factors are qualitatively identified through a keyword search and then summarized and sorted together with research to establish a conceptual model. Model path analysis based on SEM and multiple regression can quantitatively reveal the relationship between influencing factors through a hypothetical model.

4. Data and Result Analysis

4.1. Data Collection

The questionnaire was distributed to the participants of the prefabricated construction project online with the questionnaire star platform and then the information of the surveyed persons was collected as shown in the table below. The items in the questionnaire refer to mature scales and some innovative factors were added based on the characteristics of the PBSC. The questionnaire measured the variables in the form of a Likert five-level scale, including strongly disagree, disagree, neutral, agree and strongly agree, which were represented by 1–5 points in turn. The notes to the questionnaire explained the purpose and significance of the survey and marked professional vocabulary to help respondents to fill out the questionnaire better. The questionnaire used a unified instruction language to explain the purpose, meaning and filling requirements of the survey, so as to obtain the informed consent of the research subjects. All entries were set as required questions to ensure completeness. Besides, the questionnaire used the lottery function to increase the enthusiasm of the research objects. Besides, questionnaires with too short answers, regular answers and illogical questions were eliminated. A total of 240 questionnaires were distributed in this survey. After excluding invalid questionnaires, there were 202 valid questionnaires and the effective recovery rate was 84.17%. The information of the interviewed person is shown in Table 2.

Table 2. Basic information of the interviewee.

Type		Quantity	Percentage
Working unit	Owner unit	26	12.90%
	Design unit	22	10.90%
	Construction unit	38	18.80%
	Supervision unit	16	7.90%
	Prefabricated component factory	44	21.80%
	government	16	7.90%
	University or research staff	40	19.80%
education level	Junior college	13	6.40%
	Undergraduate	100	49.50%
	Postgraduate	83	41.10%
	PhD and above	6	3.00%
Working years	≤3years	85	42.10%
	3–5 years (5 years included)	65	32.20%
	5–8 years	40	19.80%
	≥8 years	12	5.90%

According to the statistics in the above table, the number of employees in each work unit was relatively evenly distributed. The research group did not communicate with the specialized component logistics company. Through the cooperation relationship between the PC factory and logistics company, the personnel filling in the questionnaire of the logistics unit are included in the PC factory. The education level of the investigators is concentrated in the undergraduate and graduate personnel, with academic qualifications high quality, strong understanding of the questionnaire and high credibility in the results. From the perspective of working years, it has an important relationship with the nature of work. The reasonable distribution of different interval years means that the positions of the PBSC personnel participating in the research are evenly distributed, which can avoid extreme values of the data.

(1) Reliability and validity analysis.

The study conducted reliability and validity analysis using SPSS26.0. The data analysis results are shown in Table 3.

Table 3. Reliability and validity table.

Variable	Number of Items	Cronbach's Alpha Coefficient	KMO	Bartlett's Test of Sphericity
PF	4	0.733	0.724	0.000
TSF	3	0.777	0.758	0.000
ACF	4	0.830	0.794	0.000
IF	3	0.791	0.693	0.000
RF	4	0.822	0.810	0.000
PBSCR	3	0.810	0.706	0.000

It can be seen from the results that the overall questionnaire data is 0.952 and the KMO value is greater than 0.6. Table 4 shows that the KMO value of each dimension is also greater than 0.6 and it passed the Bartley sphere test with a significance level of 0.05, which can be used for factor analysis.

Table 4. Results of the rotated component matrix.

Component Matrix					
Component	**1**	**2**	**3**	**4**	**5**
PF_1	0.607				
PF_2	0.662				
PF_3	0.713				
PF_4	0.542				
TSF_1		0.68			
TSF_2		0.615			
TSF_3		0.585			
ACF_1			0.71		
ACF_2			0.689		
ACF_3			0.754		
ACF_4			0.738		
TF_1				0.758	
TF__2				0.745	
TF__3				0.673	
RF_1					0.734
RF_2					0.732
RF_3					0.729
RF_4					0.693
Cumulative variance interpretation %			65.215% > 50%		

(2) Factor analysis.

Factor analysis is used to characterize the basic structure of data by analyzing the internal mapping relationships among variables. In this study, principal component analysis (PCA) was used to obtain the results using SPSS 26.0. The basic function of factor analysis is to analyze the mapping relationships within the data matrix. Factor analysis can group variables according to the mapping degree, extract the key indices of different groups and calculate the cumulative contribution rate of variance. These key indices can directly reflect the basic structure of things.

Table 5 shows that the exploratory factor loaded with the 15 indicators obtained through the maximum variance rotation analysis showed values greater than 0.5, which meets the model requirements. Five factors can be extracted to explain the structure of the variables. After skew is rotated, the latent variable explains 65.215% of the initial information, which fully reflects the influencing factors of PBSC resilience.

Table 5. Results of model fit test.

CMIN/DF	RMSEA	GFI	IFI	CFI	TLI
1.749	0.061	0.92	0.958	0.958	0.947

(3) Model fit test.

Table 6 shows that GFI, IFI, CFI and TLI are all greater than 0.9, indicating that the model fits well.

Table 6. Intrinsic quality verification factor analysis.

Path Hypothesis				Estimate	S.E.	C.R.	P	Test Result
H1b	PF	→	TSF	0.798	0.104	7.667	***	Significant impact
H2b	TSF	→	ACF	1.183	0.15	7.909	***	Significant impact
H1a	PF	→	PBSCR	1.665	3.32	4.502	0.016	Significant impact
H2a	TSF	→	PBSCR	−1.521	4.207	−0.362	0.718	No Significant impact
H3a	ACF	→	PBSCR	0.425	0.204	2.086	0.037	Significant impact

*** means significant impact.

(4) Hypothetical model.

This article uses AMOS 26.0 to process the data and the result is shown in Figure 2:

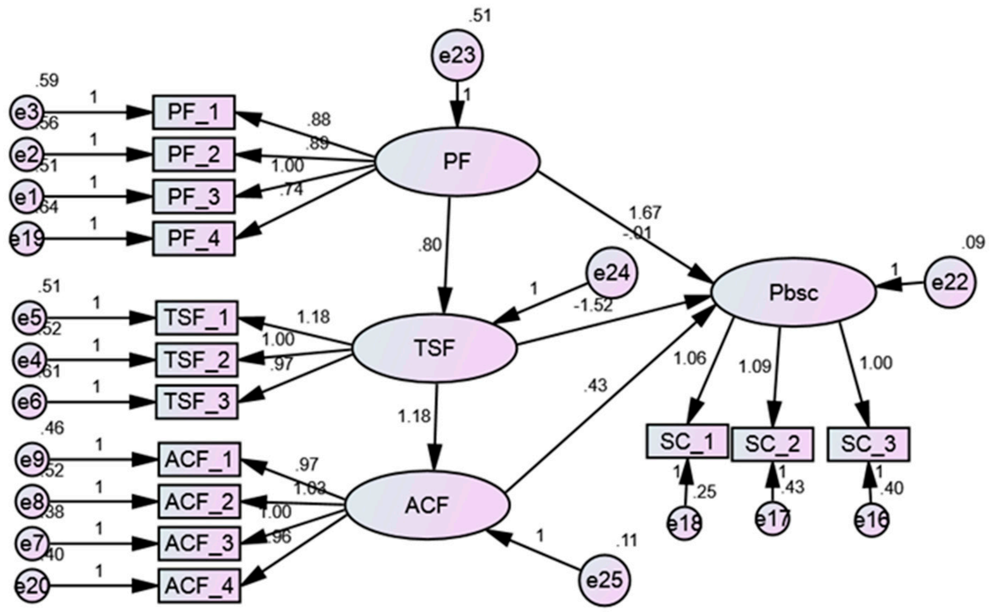

Figure 2. Initial model of PBSC resilience.

4.2. Result Analysis

(1) Hypothetical analysis based on SEM

According to Figure 2, both production factors and assembly construction factors have a significant impact on the PBSCR. Among them, PF has the greatest impact, where the path coefficient of production factors is 1.16 and the path coefficient of ACF is 0.425. The effect of TSF on the resilience of the PBSC is not significant.

(2) Mediating effect based on multiple regression

Based on the above analysis results of Table 7, the assumptions of H1b, H1c and H2b are valid. Besides, the mediation effect of ACF is greater than that of TSF.

Table 7. Results of the intermediary effect analysis.

Category		Effect	Boot SE	Boot LLCI	Boot ULCI	Effect Ratio	
Mediation Effect	TOTAL	0.5399	0.0845	37.72%	0.7097	72.84%	
	Ind1	0.1781	0.0556	7.81%	0.2946	24.03%	
	Ind2	0.2669	0.0685	14.37%	0.4109	36.01%	
	Ind3	0.0949	0.0337	3.25%	0.1641	12.80%	
Contrast mediation effect	(C1)	−0.0888	−0.0129	−0.0656	−0.1163		
	(C2)	0.0832	0.0219	0.0456	0.1305		
	(C3)	0.172	0.0348	0.1112	0.2468		
Ind1	PF	→	TSF	→	PBSCR		
Ind2	PF	→	ACF	→	PBSCR		
Ind3	PF	→	TSF	→	ACF	→	PBSCR

(3) Analysis of the adjustment effect based on multiple regression

According to the data analysis table of Table 8, it can be seen that IF and RF have a significant impact on the three processes of PC production, transportation and assembly construction.

Table 8. Results of the moderating effect analysis.

Adjusted Variable	Independent Variable	R2-Chng	F	p	B	T Value	Standard Error
Information regulation	PF	0.0048	3.0759	0.0410	0.36	1.754	0.021
	ACF	0.0089	5.7528	0.0174	0.5	0.118	−0.3990
	TSF	0.0099	6.3954	0.0122	0.52	0.12	−0.5290
Partnership moderating	PF	0.0113	7.7154	0.006	0.49	2.553	0.019
	ACF	0.0096	6.5193	0.0114	0.46	0.115	−0.4760
	TSF	0.009	6.1286	0.0141	0.52	0.12	−0.5290

5. Discussion and Suggestions

5.1. Discussion

Starting from the whole process and local nodes of the PBSC, this paper explored the influencing factors of its resilience and discussed the following in combination with other documents.

(1) PF:

As an important stage in the front stage of PBSC, the production of PC has the characteristics of a slow production cycle and complex process [9]. Once the PCs are designed and produced, their parameters and styles cannot be changed. The number of prefabricated parts manufacturers and the number of prefabricated parts produced increases the redundancy of the supply chain. The more companies and components, the more opportunities for upstream and downstream companies to choose. This is consistent with the conclusion that the number of commodities mentioned can increase the redundancy of the supply chain and thus improve the resilience of the supply chain [37]. The quantity of products will directly affect the supply plan to suppliers in the PBSC and as logistics companies are often regarded as suppliers, PCs are regarded as finished or semi-finished products [35]. The quantity of them will directly affect the selection of logistics companies and the planning of transportation routes in the later period [36]. As a special commodity, prefabricated parts have an important influence on the accuracy of later construction and installation. During the production process, an efficient management plan of the component factory and the innovative technical ability of the technicians provide a guarantee for the production quality parameters of the PC, which improves the stability of the supply chain [16]. It was also mentioned that the quality of products spreads in the whole process of the supply chain. However, reliable logistics companies and reasonable transportation plans can reduce the damage rate of prefabricated components, improve the transportation efficiency and enhance the agility and visibility of the supply chain [25].

(2) TSF

This paper concludes that transportation and storage factors have no significant impact on the resilience of the prefabricated building supply chain, which is inconsistent with the opinion that Kim, Y proposed [7]. Combining the characteristics of PB, the reasons are summarized as follows: At present, PB has not achieved a large-scale development and the number of orders will not suddenly increase or be canceled. The PCs are so large in size that they are difficult to load and unload. Therefore, logistics companies that play the fixed role of PBSC suppliers and their transportation plans impact on the resilience of PBSC. In view of the fact that this factor is inconsistent with other studies, it provides a new perspective for existing research. The number of questionnaires can be increased to expand the scope of research objects for further verification. Regarding storage, the current construction site is relatively small and the PCs are basically placed in the open air. In addition to major sudden impact accidents, such as earthquakes and heavy rains, the rust, oxidation and small wear of the components are within the acceptable range, which cannot affect their construction and installation [23]. Due to the volume and material limitations of PC, once the quality is damaged during transportation or storage, it will directly affect the accuracy of later assembly construction operations. Therefore, the mediating effect between production and assembly construction is significant, which is consistent with the research conclusion of [19].

(3) ACF

Assembly construction factors have a significant impact on the resilience of PBSC. As a new type of construction and installation, the comprehensive quality of technical personnel is of great significance to the improvement of construction efficiency. This is consistent with Zhu's conclusion that the technical operation level of construction personnel effectively affects the resilience of the PBSC [10]. Improving the innovation of construction organization plans can effectively alleviate the impact of uncertain events, which helps improve the flexibility of the supply chain. In addition, this article also provides proof and data support for the higher-level leadership's awareness of risk responsibility and management training for employees, which is beneficial to improving the ability to adapt to risks.

(4) TF

Information factors can affect the whole process of PBSC through three aspects: information sharing, information technology application and information exchange. Azadegan, A. proposed that it can be analyzed from the perspective of improving the visibility and agility of the supply chain and be divided into two aspects: the application of information methods and the maturity of the use of information technology [19]. Yang also emphasized the important application of BIM and 4-D technology in the PBSC [38], which is conducive to the identification and classification of components in the two-dimensional code information technology section used in the PB process mentioned in this article. Anjali Shishodia proposed that the transmission of information improves the transparency of suppliers at the upstream and downstream levels [8]. This contrasts with the establishment of the information platform and big data database proposed in this article, which can be used for exchanges and communication between enterprises, which is beneficial to the resilience of the supply chain.

(5) RF

Research on the impact of partner factors on supply chain resilience is quite mature. Existing research mainly divides it into four dimensions: trust, commitment, adaptation and collaboration. This article also carried out further verification. Govindan, K. et al. pointed out that trust can promote cooperation between enterprises [33]. This article also concludes that trust is the basis for a good cooperative relationship between enterprises, which is conducive to improving the ability to resist risks. This paper verifies that in the face of emergencies, adaptability can significantly improve the stability of the supply chain, maintain the sustainable development of the supply chain and improve the resilience of the supply chain. This is consistent with the research conclusion put forward by Kathryn E. Stecke that cultivating the enterprise's ability to adapt to risks is important for maintaining an uninterrupted supply chain [39].

5.2. Suggestions

As an important part of precast PB, prefabricated structure built with the production, transport and storage and on-site installation and construction with the traditional construction industry has a very different place. According to the research data, it can be seen that the resilience of the PBSC has the greatest impact on the assembly and construction process of the components [40], followed by the transportation, storage and production of the components. In addition to the three stages of PBSC, which have an important impact on the resilience of the supply chain, the partner factors and information factors throughout the entire supply chain itself also have a great impact on the resilience of the PBSC. Based on the research results and the analysis of this article, suggestions for improving the resilience of the PBSC are as follows:

(1) Increase the number of prefabricated component factories, divide qualifications and standardize management. Pay full attention to the demonstration effect of state-owned

enterprises with higher qualifications and strengthen the production and management of manufacturers' components, improve the quality of employees and the training of professional talents, encourage technological innovation and strengthen communication between departments.

(2) It is recommended to develop a multi-carrier transportation method in the transportation of raw materials to the PC factory, such as railway transportation. Moreover, the development of special-purpose components and transportation vehicles to meet the needs of large volume and heavy weight of PC [41]. At the same time, rationally plan transportation routes to prevent emergencies and strengthen the warehouse management of prefabricated building components. Strengthen the storage management of PC in the prefabricated component factory and construction site, such as reasonable planning of the storage area to increase the redundancy of components.

(3) At present, the on-site management system is not yet mature [42]. More communication paths should be explored to facilitate mutual understanding between construction personnel and management personnel to improve work efficiency. At the same time, strengthen the training of higher-level leaders and skilled workers' sense of risk and responsibility, and improve the ability to prevent risks.

(4) Strengthen the application of information in the supply chain process, whether it is within an enterprise or a node enterprise, the application of information technology and information management have greatly improved work efficiency and become an important means of operation management. For example, the use of information marks for components and parts to enhance their loading and transportation efficiency, the establishment of an information and data sharing platform, the integration of unstructured information and the development of information supervision such as video and QR code drone technology are conducive to the prevention and rapid detection of emergencies and improve the resilience of the supply chain [29].

(5) Encourage the formation of benign and friendly partnerships and treat the supply chain as a whole. Each node is a part of the whole. If one node has a problem, the entire supply chain may be interrupted or even destroyed. Strengthen the communication between enterprises, such as regular organization of team building, mutual visits and other activities [43]. Enhancing the trust between enterprises and improving the ability of mutual assistance and collaboration which is conducive to improving the resilience of the supply chain.

6. Conclusions

This article has important research significance both in theory and practice. Theoretically, it provides a new research perspective. Taking the resilience of the prefabricated construction enterprise supply chain as the research object which enriches the related theoretical system of the resilience of the PBSC. It also further expands the content and depth of supply chain management thought in the field of PB. Besides, this article expands the application fields of related theories and methods. It validates the application of empirical methods in analyzing resilience management research. In practice, it is conducive to creating a resilient PBSC and improving the continuity and balance of PB in the construction process. In addition, in the process of constructing and analyzing the model of the factors affecting the resilience of the PBSC, the research team conducted surveys and interviews with some experts and personnel who have participated in and studied PB projects. An accurate grasp of the key points of the project promotes the smooth completion of the project and promotes the application of supply chain resilience management in actual construction.

At present, the research on the elasticity theory of PBSC is still in its infancy and there are not many documents that can be directly referred to. The research in this article is still being explored. Due to certain conditions, the research team was limited to investigating the Beijing-Tianjin-Hebei region. Although the questionnaire survey collected the opinions of relevant professionals across regions, the results of the research may restore the influence of geographical restrictions. In addition, the sample size is also a limitation of this article. Therefore, further research will be conducted based on this conclusion later.

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