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Critical Factors Influencing Interface Management of Prefabricated Building Projects: Evidence from China

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Abstract: Recently, interface management has been regarded as the key to the success of prefabricated building projects (PBPs) due to its capabilities to manage numerous interfaces caused by PBPs' inherent geographical and organizational fragmentation. However, the factors influencing the interface management of PBPs are largely unknown and poorly studied. To compensate for this gap, this study aimed to investigate the critical factors influencing interface management in PBPs with quantitative and qualitative methods. Twenty-seven critical factors influencing the interface management of PBPs were identified through a literature review, questionnaire survey, and face-to-face interviews with professionals in the construction industry. A questionnaire survey was sent out to developers, designers, manufacturers, contractors, and consultants in China, and 66 completed questionnaires were received. Results showed the top five critical factors influencing the interface management of PBPs were (1) accuracy of design, (2) timeliness of information communication, (3) timeliness of component production and supply, (4) standardization of design, and (5) definition of work content and scope. The 27 influencing factors of PBPs were further categorized into seven groups via exploratory factor analysis, namely: (1) information communication, (2) trust and cooperation, (3) technical and management capability, (4) organizational integration, (5) standardization, (6) technical environment, and (7) contractual management. Improving these issues will contribute to the successful implementation of PBPs. Finally, combined with relevant literature and expert interviews, the impact of these seven clusters on the interface management of PBPs was discussed. The findings may contribute to deepening the understanding of interface management, reducing unnecessary conflicts and difficulties, and promoting the sustainable development of prefabricated building (PB).

Keywords: interface management; prefabricated building; sustainable development; critical factors; factor analysis

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Citation: Zhang, S.; Li, Z.; Ma, S.; Li, L.; Yuan, M. Critical Factors Influencing Interface Management of Prefabricated Building Projects: Evidence from China. *Sustainability* **2022**, *14*, 5418. https://doi.org/10.3390/su14095418

Academic Editors: Primiano Di Nauta, Francesca Iandolo and Gianluigi Mangia

Received: 27 March 2022
Accepted: 28 April 2022
Published: 30 April 2022

1. Introduction

Recently, prefabricated building (PB) has aroused more interest due to its advantages of improving quality control, reducing technical labor force, shortening construction time, reducing material waste, etc. [1–3]. In view of these advantages, PB has been considered to be a modern sustainable construction method that can replace the scattered, low-level and inefficient handicraft mode [4]. China, characterized by rapid urbanization [5], is vigorously using PB to achieve sustainable construction [6]. Currently, the Chinese government has mandated that 15% (by building floor area) of the nation's annual new buildings will be PB by 2020, and this will increase to 30% by 2025 [7]. With the introduction of promoting policies in various regions [6], an extremely large PB market is being born in China. However, for China, a developing country, the promotion of PB may be challenging. It is reported that the advantages of PB are difficult to achieve due to lack of knowledge and experience [8], non-standardized design [9], inefficient collaboration [9], poor communication [10], and fragmented construction process [11]. Some studies indicated that the current construction processes are geographically and organizationally fragmented because some of the tasks (e.g., manufacturing and preassembly of some building components, modules, and elements) have moved to the factory [1,12–15]. Specifically, the functional modules of the building are decomposed into components for production and assembled on site, which adds a large number of physical interfaces that need seamless connection, actually increasing the complex interface issues. In addition, due to the participation of more stakeholders (e.g., offsite manufacturers, transporters, and local authorities), PB faces more organizational interface issues [16]. According to Gibb, G.F. and Pavitt, T.C. the fragmented construction process and greater number of involved stakeholders lead to complex interface issues, and effective management of these issues is the key to PB success [17,18].

Morris, P.W.G proposed the concept of interface management while studying the issues caused by the fragmentation between construction activities [19]. Subsequent studies also proved the potential of interface management in construction project management. For example, interface management was adopted for improving the build process, thereby reducing rework and the total duration by identifying and tracking interfaces [20]. For temporary construction projects, the improvement of interface transparency is conducive to the definition of responsibilities and authority [21]. Increased permeability of organizational interfaces enables participants to scan the environment, obtain work and resources, and respond appropriately and quickly to change [22]. Through the case analysis of 45 large construction projects, it is also reported that interface management practices can effectively alleviate the negative impact of project complexity [23]. Accordingly, given the advantages of interface management in the construction industry, the number of studies of interface management in the PB field are gradually increasing. However, interfaces in PB are usually more complex, and it is more critical that they be managed, because they are highly fragmented in terms of geography and organization [24]. In the book "*Off Site Fabrication-Prefabrication, Preassembly and Modularisation*", Gibb, G.F. demonstrated the need to bring interface management into PBPs to deal with the complex interface issues [18]. Pavitt, T.C. et al. also discussed the need for interface management within PBPs, and categorized the interface management of PBPs into physical, contractual, and organizational groups [17,25]. Overall, previous studies defined the concept of interface management, analyzed the importance of interface management to construction projects, put forward some methods and strategies for interface management, and discussed the potential of the interface management applications in PBPs. These studies provide a theoretical basis for the interface management of PBPs. However, the early studies on interface management of PBPs remained at the conceptual level, mainly discussing the necessity and feasibility of interface management in the construction process of prefabricated construction projects. It was not until recent years that scholars begin to pay attention to the specific interface issues in PBPs. For example, relevant studies have found that early involvement of the contractor in the design phase and communication with all parties is critical to interface management [26]. Standardization of physical interfaces can reduce the interdependence between component installation activities performed by different subcontractors [27]. Appropriate interface management can optimize the module design of components and provide the most concise assembly scheme [28]. As a result of the progress of information technology, building information modeling (BIM) is also being employed to improve the interface management of design–production interfaces, which can not only improve the traditional architectural interface, information sharing, and efficiency in the process of project tracking, but can also optimize interface information sharing in the process of design, manufacture, and installation, promoting better coordination among all participants [29].

The above work provides the research basis and theoretical inspiration for this study. However, most interface management-related studies are based on traditional cast-in-situ projects or undifferentiated types of construction projects. Few PBP interface management-related studies focus on methods and strategies for interface improvement, and lack an in-depth examination of the influencing factors. Most of the influencing factors of interface management mentioned in existing studies are obtained by qualitative reasoning of the relevant authors, and lack the support of quantitative analysis methods. Moreover, the research on interface management is relatively scattered, and there is no unified classification standard for the influencing factors. To compensate for these limitations, the present study aimed to explore the critical factors influencing the interface management of PBPs by combining qualitative and quantitative methods. The results provide a systematic list of influencing factors for PBP interface management, which is not available in previous studies.

2. Literature Review

2.1. Interface Management of Construction Projects

Interface management refers to the management of information, coordination, and responsibility across physical, contractual, and organizational boundaries, and is considered an effective method for achieving harmonious collaboration between project organizations in the construction industry [23]. Wren, D.A. first introduced the concept of the interface in the field of organizational management and defined the interface as the relatively autonomous point of contact between interacting organizations. The study illustrated that effective connectivity of interaction points between organizational subsystems is critical to the success of the entire system [30]. Subsequently, Berenson and Berenson, C. defined the interface as the boundary between two systems from a systems theory perspective [31]. Souder, W.E. and Chakrabarti, A.K. proposed the concept of interface management. They deeply analyzed the serious impact of the interface between traditional R&D and marketing departments (R&D–marketing interface) on the commercialization of R&D technology [32]. In recent years, interface management, as a management theory that can eliminate coordination barriers, has gradually received extensive attention from scholars in the field of innovation management and project management. Scholars in the construction industry also believe that interface management can increase the consistency of goals between participants, reduce conflicts, and increase the efficiency of cooperation.

Morris, P.W.G was early to recognize the importance of interface management in the construction industry [19]. France (1993) considered that the effectiveness of interface management is the key to project success. He stressed the need for interface management in design, procurement, and construction to coordinate the work of the participants [33]. Gibb, G.F. classified interfaces into physical, organizational, and contractual interfaces in PBPs [17,25]. Love, P.E.D. identified the interface relations between owners–suppliers, and contractors–subcontractors, in the supply chain of construction projects [34]. Based on this, Mitchell, A. proposed a conceptual model of interface management to deeply understand the interface connotation between the design and construction process [35]. In addition, Fellows, R. and Liu, A.M.M. attempted to overcome the complexity and fragmentation of construction projects by interface management [22].

2.2. PBPs Interface Management Influencing Factors

PB refers to the process of manufacturing and preassembly of specific quantities of building components, modules, and elements, prior to their shipment and installation on construction sites [1]. At present, few studies have been conducted on the influencing factors of interface management in PBPs. For example, Gibb, G.F. explored the influencing factors of organizational interface management in PBPs from the perspective of people and process. The results showed that early intervention of contractors and open communication among stakeholders was critical to solving organizational interface problems [26]. To address the challenges faced by offshore oil and gas projects in terms of schedule and cost, Nooteboom, U. proposed an interface management approach. He attributed most failed projects to a common cause: insufficient attention to the interface between design, discipline, executive team, regional culture, and contract scope [36]. It is worth noting that offshore oil and gas projects adopt prefabricated or modular construction methods, which is similar to the construction and organization logic of PBPs. Other PBP-related studies have found that the government can effectively interact with enterprises through interface activities to achieve the purpose of regulation. For example, some incentive behaviors of the government can increase the psychological and functional benefits of real estate development enterprises and better promote the promotion of PB technology [6]. According to Ye, M., some physical interface problems result in risks regarding the costs of PB, such as large position deviations in embedded parts and reserved holes, and hoisting position deviations in prefabricated components [37]. Zhao, S. believes that it is necessary to focus on information sharing, cooperation degree, response time, and other factors between organizational interfaces in PBPs [38]. The application of advanced technologies is also considered to be a key factor in improving the interface management of PBPs. For example, the application of Blockchain and Internet of Things (IOT) in PBPs are proven to increase the transparency and alignment of the supply chain's coordination and configuration, regardless of functional and organizational interfaces [39]. In addition, Vassiliades, C. developed a plug-and-play physical interface to integrate the hybrid photovoltaic/thermal solar system into housing units, solving the cost and energy-saving problems in PBPs [40]. A higher prefabrication rate also causes logistics pressure on the production–construction interface [41]. Although these papers do not study PBPs directly from the perspective of interface management, their results involve the issues of physical interface and organizational interface to a large extent, which is of great reference value to this study.

PBPs are different from the traditional cast-in-situ construction projects in that there are more complex and more critical interfaces to manage [24]. However, some studies have important reference value for the analysis of influencing factors of interface management in PBPs. For example, Bdul-Mohsen and Al-Hammad summarized the causes of interface problems in construction projects arising from standard specifications, labor allocation, regulation, and contract management [42,43]. Awakul, P. and Ogunlana, S.O. found that interface conflicts were caused by stakeholders' different attitudes towards projects [44]. Huang, R. used quantitative methods to determine the six main dimensions of project interface problems of rail transit system projects, among which project participation experience and coordination ability are the main dimensions of interface problems [45]. Chen, Q. discussed the comprehensive causes of interface problems in construction projects from the perspectives of participants, methods, resources, archives, project management, and environment [46]. Weshah, N. identified six critical factors in interface management for building projects in Alberta: management, information, contracting models, standards and codes, technology, and site issues [47]. Hazem, M., Sha'ar, K.Z. and Yeganeh, A.A. focused on the study of design–construction interface management. Poor communication between participants, lack of professional experience in design and construction management, poor contract design, and project management experience were generally identified by the researchers as critical factors affecting interface management [48–50]. Shokri, S. identified the drivers of interface management and the impact of interface management on construction projects from a systems perspective [51]. Shen, W. used structural equation modeling (SEM) and social network analysis (SNA) to quantitatively analyze the impact of trust, communication, formal governance, partnership, social norms, and other behaviors on interface management in construction projects [52–54].

3. Methodology

This study adopted a literature review, in-depth interviews, and a questionnaire survey as its methods of data collection, and also conducted factor analysis using IBM SPSS 22.0. Further, a qualitative analysis based on the literature review and interviews was conducted to discuss the impact of these factors on interface management. The research roadmap is shown in Figure 1.

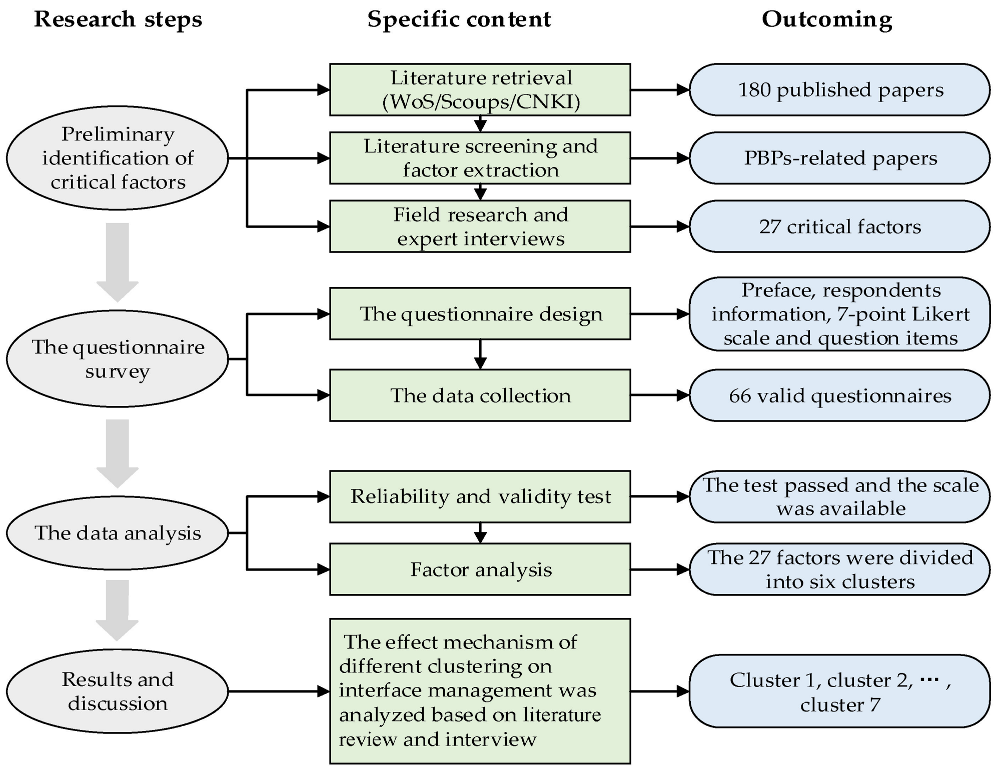

Figure 1. Research framework for the study.

3.1. Preliminary Identification of Interface Management Influencing Factors

The preliminary method for identifying the influencing factors of PBP interface management was designed following the principles of scientific integrity, systematicity, relevance, and feasibility. First, we retrieved 180 papers related to interface management from domestic and international mainstream journal databases (Web of Science, Scopus, CNKI, etc.), including 97 papers related to the construction field and 18 papers related to PBPs. Then, the literature was further screened according to the source, topic, and the fit of the research object with PBPs, from which the critical factors affecting the interface management in PBPs were extracted. Finally, to verify the rationality and comprehensiveness of the influencing factors, we conducted site investigation of PBPs (Country Garden Phoenix Gongguan in Shenzhen, Guangdong, China, Luneng Lingxiu-Park in Jinan, Shandong, China, and Vanke Xihuafu in Shenyang, Liaoning, China) and component manufacturing plants (China Grand Enterprisesin Changsha, Hunan, China and Dalian Dongdu Building Materials Co., Ltd. in Dalian, Liaoning, China), and conducted in-depth interviews with five experts. Based on this, we filtered, added, or deleted the initial extracted critical factors to form an initial list consisting of 27 factors (see Table 1).

Table 1. List of preliminary factors.

Code	Factors	Sources
1	Technical innovation	[50,55,56]
2	Degree of perfection of standards and specifications	[57]
3	Accuracy of design	[17,25,58,59]
4	Standardization of design	[19,60,61]
5	Technical level of operators	[45]

Table 1. *Cont.*

Code	Factors	Sources
6	Complexity of the connection interface between components	[14,17,21,46,62]
7	Reasonableness of production and construction plan	[63]
8	Standardization of production and construction processes	[47,64]
9	Formal interface management process	[23,53]
10	Cultural differences between participants	[11,16,65]
11	Project management mode	[66]
12	Experience and level of participants	[57]
13	Professional differences between participants	[67,68]
14	Degree of participant involvement in design	[26,69,70]
15	Definition of work content and scope	[57,71]
16	Reasonableness of organizational structure design	[72,73]
17	Definition of responsibility-power-benefit	[17,57,71,72]
18	Consistency of organizational goals	[17,22,53,72,73]
19	Standardization of information	[22,46,74–76]
20	Degree of information sharing	[17,26,57,77]
21	Completeness and accuracy of information delivery	[72,78,79]
22	Timeliness of information communication	[57,72,73]
23	Cooperative attitude of the participants	[14,16,46,80]
24	Communication and learning of the participants	[69]
25	Understanding and trust of the participants	[52,57,81]
26	Timeliness of component production and supply	[16,72,73,82]
27	Tracking of component production and installation process	[16,82–84]

3.2. Questionnaire and Data Collection

A formal questionnaire survey was conducted to solicit opinions from the target respondents. The questionnaire was composed of three main parts: (1) Preface. This part aimed to explain the purpose of the survey, and briefly introduce the interface management-related concepts and professional vocabulary. (2) Respondent's information. This part mainly included organization, education level, and years of working in the construction industry and PB industry (see Table 2). (3) The respondents were asked to evaluate the degree to which each item impacted PBP interface management using a seven-point Likert scale, in which 7 represented "very high impact", 1 represented "little to no impact", and the middle position 4 was "fair". The questionnaire survey was conducted in mainland China from August to November 2021. A total of 200 questionnaires were distributed via face-to-face methods, WeChat, QQ, email, and a professional online questionnaire platform (www.sojump.com (accessed on 15 November 2021)), and 87 completed questionnaires were received. All questionnaires were sent to experts from development, design, manufacture, contracting, and consulting companies, and scientific research institutions engaged in PB research. However, as the answers of some respondents may be casual, disorganized, or random, the data quality may be threatened [85]. Therefore, the questionnaires were removed when the following two situations occurred: ① respondents answered each item in less than 2 s [85]; ② respondents gave a string of consistent answers equal to or greater than half the length of the total scale [86]. A total of 66 questionnaires were deemed genuine and valid after screening, and the effective response rate was 33%. Strict data screening techniques ensure good quality of data. Although small, this small sample size is characteristic of construction industry surveys. This sample size was considered adequate because the normal response rate for surveys in the field of engineering management is between 20 and 30% [87,88].

Table 2. Respondents' information.

Categories	Type Description	Number of Respondents	Percentage (%)
Organization	developer	16	25.40%
	designer	8	12.70%
	Manufacturer	9	14.29%
	contractor	15	23.81%
	consultant	5	7.94%
	scholars	13	20.63%
Education	Doctor degree	12	19.05%
	Master degree	24	38.10%
	Bachelor degree	29	46.03%
	Junior college and below	1	1.59%
Years of experience in the construction industry	>10	10	15.87%
	6~10	24	38.10%
	3~5	24	38.10%
	≤3	8	12.70%
Years of experience in the construction industry	>10	2	3.17%
	6~10	14	22.22%
	3~5	31	49.21%
	≤3	19	30.16%

3.3. Data Analysis Method

Factor analysis is a well-established method of data reduction that uses statistical methods to describe variability between a large number of observed, correlated variables that may have a low number of observed variables called factors. Factor analysis, which is a statistical method used to detect clusters of related variables, is used to group variables into a small number of underlying factors [89]. This method has been widely used in the analysis and clustering of key influencing factors in the construction industry. For example, Mao, C. used this method to analyze the obstacles of off-site construction [89]; and Li, L. used factor analysis to cluster the key success factors of PBP planning and control [4]. In these studies, using SPSS to calculate data has been proved to be accurate and convenient. Therefore, this study used IBM SPSS 22.0 to conduct factor analysis on the critical influencing factors of PBP interface management.

Before the application of this method, various tests are needed to verify the suitability of factor analysis for factor extraction. In this study, reliability and validity analysis were used to test. Reliability analysis of scale refers to the use of some methods to analyze the recovered scale data, and effectively measure the consistency and stability of the results. Reliability analysis uses Cronbach's alpha (CA) reliability coefficient as the reference standard. The greater the CA value, the greater the consistency of the set of assessment questions, the more meaningful the content of the corresponding scale, and the more reliable the resulting assessment results. CA values between 0.5 and 0.7 are considered to be reliable, those between 0.7 and 0.9 are considered to be highly reliable, and those greater than 0.9 are considered to be very reliable [90]. The Kaiser–Meyer–Olkin (KMO) index is generally used as the reference standard for the validity analysis of the scale, and the KMO index should be greater than or equal to 0.5. Bartlett's sphericity test ($p < 0.05$) was used to verify whether the factor is suitable for data analysis.

4. Result

4.1. Reliability and Validity Analysis

(1) Reliability test

In this paper, the reliability test of IBM SPSS22.0 was used to analyze the scale data. The overall CA value of the scale is 0.908, and the CA value based on the standardized item is 0.910. Both CA values are greater than 0.9, indicating a high degree of consistency within the scale (see Table 3). When the factor itself is removed, CA values of other factors in the scale range between 0.901 and 0.913, indicating that all listed factors have high confidence and should be retained (see Table 4).

Table 3. Reliability test results.

CA	CA-Based on Normalized Terms	Number
0.908	0.910	27

Table 4. Factor CA value after removing the factor itself.

Factors	Average after Deletion of Factor	Variance after Deletion of Factor	Correlation of the Corrected Factor with the Total	CA after Removing the Factor
Technical innovation	137.16	230.716	0.096	0.913
Degree of perfection of standards and specifications	137.05	224.627	0.273	0.909
Accuracy of design	136.54	223.672	0.356	0.907
Standardization of design	136.86	225.157	0.281	0.909
Complexity of the connection interface between components	136.94	225.544	0.336	0.907
Reasonableness of production and construction plan	136.89	223.100	0.449	0.906
Standardization of production and construction processes	137.05	219.014	0.528	0.904
Formal interface management process	137.32	221.672	0.483	0.905
Cultural differences between participants	138.06	218.673	0.447	0.906
Project management mode	137.21	220.779	0.409	0.906
Consistency of organizational goals	136.98	215.629	0.655	0.902
Technical level of operators	137.03	214.225	0.557	0.903
Professional differences between participants	137.41	215.311	0.571	0.903
Degree of participant involvement in design	137.02	213.597	0.651	0.902
Definition of work content and scope	136.90	224.507	0.282	0.909
Reasonableness of organizational structure design	137.52	217.673	0.548	0.904

Table 4. *Cont.*

Factors	Average after Deletion of Factor	Variance after Deletion of Factor	Correlation of the Corrected Factor with the Total	CA after Removing the Factor
Definition of responsibility-power-benefit	137.08	216.365	0.585	0.903
Experience and level of participants	137.25	216.709	0.584	0.903
Standardization of information	137.22	217.434	0.594	0.903
Degree of information sharing	136.92	215.042	0.673	0.902
Completeness and accuracy of information delivery	136.78	213.014	0.679	0.901
Timeliness of information communication	136.87	212.113	0.740	0.900
Cooperative attitude of the participants	137.08	219.332	0.485	0.905
Communication and learning of the participants	137.56	214.025	0.655	0.902
Understanding and trust of the participants	137.37	217.558	0.597	0.903
Timeliness of component production and supply	136.87	218.209	0.442	0.906
Tracking of component production and installation process	136.97	220.096	0.503	0.905

(2) Validity test

The KMO value of the measurement scale of influencing factors of PBP interface management is 0.755 (see Table 5), indicating moderate suitability. The approximate chi-square value of Bartlett's sphericity test is 994.234 (p = 0.000), which is less than the significance level 0.001. This indicates that the scale is suitable for factor analysis, because the correlation coefficient matrix and the identity matrix are significantly different, and each factor is correlated.

Table 5. KMO and Bartlett tests.

Kaiser–Meyer–Olkin		**0.755**
Bartlett	Approximate Chi-Square	994.234
	df	351
	Sig.	p = 0.000

4.2. Ranking and Clustering Results of Critical Factors

Table 6 shows that, among the initial 27 factors, the top five factors in terms of mean value are (1) accuracy of design, (2) timeliness of information communication, (3) timeliness of component production and supply, (4) standardization of design, and (5) definition of work content and scope. Therefore, these factors are deemed most the critical factors affecting interface management in PBPs.

Table 6. Factor analysis results.

Factors	Components						Mean Value (Rank)	Variance
	1	**2**	**3**	**4**	**5**	**6**		
Cooperative attitude of the participants	**0.802**	0.143	0.071	0.042	−0.016	−0.013	5.262	1.057
Degree of information sharing	**0.773**	0.061	0.192	0.258	0.207	0.156	5.462	0.962
Completeness and accuracy of information delivery	**0.742**	0.159	0.241	0.224	0.044	0.164	5.585	1.051
Understanding and trust of the participants	**0.730**	0.279	0.258	−0.004	−0.156	0.197	5.000	0.945
Timeliness of information communication	**0.585**	0.377	0.421	0.157	−0.096	0.224	5.523 (2)	1.009
Communication and learning of the participants	**0.548**	0.257	0.532	0.144	−0.023	0.027	4.815	1.036
Degree of participant involvement in design	**0.513**	0.470	0.186	0.344	−0.042	−0.027	5.354	1.115
Timeliness of component production and supply	0.180	**0.791**	0.050	−0.056	−0.114	0.192	5.523 (3)	1.178
Technical level of operators	0.259	**0.650**	0.277	0.084	0.076	−0.036	5.338	1.193
Tracking of component production and installation process	0.142	**0.594**	0.031	0.418	−0.062	0.036	5.385	0.956
Accuracy of design	−0.020	**0.588**	−0.053	0.095	0.405	0.113	5.846 (1)	0.996
Experience and level of participants	0.211	**0.547**	0.071	0.204	0.102	0.489	5.385	0.956
Reasonableness of production and construction plan	0.115	**0.479**	−0.029	0.448	0.253	−0.130	5.477	0.861
Project management mode	0.300	−0.127	**0.832**	0.064	−0.001	−0.073	5.154	1.085
Cultural differences between participants	0.045	0.129	**0.736**	0.204	−0.215	0.219	4.262	1.206
Consistency of organizational goals	0.207	0.397	**0.600**	0.142	0.213	0.149	5.154	1.011
Reasonableness of organizational structure design	0.409	0.020	**0.569**	0.324	−0.037	−0.016	4.877	1.015
Professional differences between participants	0.246	0.333	**0.566**	0.047	0.112	0.189	4.938	1.121
Standardization of information	0.102	0.167	0.215	**0.772**	0.044	0.259	5.154	0.964
Standardization of production and construction processes	0.257	0.079	0.127	**0.771**	0.165	−0.088	5.308	1.006
Formal interface management process	0.055	0.051	0.199	**0.699**	0.115	0.251	5.031	0.894
Complexity of the connection interface between components	0.150	0.170	−0.026	**0.524**	0.284	−0.284	5.415	0.893
Technical innovation	0.001	−0.020	0.035	−0.027	**0.776**	−0.155	5.200	1.126
Degree of perfection of standards and specifications	0.125	0.109	−0.229	0.201	**0.766**	0.155	5.338	1.127
Standardization of design	−0.187	−0.012	0.112	0.383	**0.721**	0.194	5.508 (4)	1.054
Definition of work content and scope	0.076	0.038	0.040	0.107	−0.068	**0.877**	5.508 (5)	1.125
Definition of responsibility–power–benefit	0.333	0.211	0.217	0.054	0.270	**0.668**	5.323	1.024
Eigenvalues	8.776	3.114	1.936	1.685	1.418	1.243		
Variance (%)	32.502	11.534	7.170	6.239	5.252	4.605		
Cumulative variance (%)	32.502	44.036	51.206	57.445	62.697	67.303		

Note: The part marked in bold and grey background color indicate that its corresponding factor has the highest factor loading on the cluster to which it belongs.

Factor analysis of scale items was realized by principal component analysis and orthogonal rotation method of maximum variance, and six clusters (common factors) with eigenvalues greater than 1 were extracted. The six common factors account for 67.303% of the total variance. Table 6 shows that seven critical factors belong to Cluster 1, six critical factors belong to Cluster 2, five critical factors belong to Cluster 3, four critical factors belong to Cluster 4, three critical factors belong to Cluster 5, and only two critical factors belong to Cluster 6. According to the connotation and characteristics of each factor, the six clusters are named: (1) information communication, trust, and cooperation, (2) technology and management ability, (3) organizational structure design, (4) standardization, (5) technical environment, and (6) contract relationship.

5. Discussion

Combining the connotation and reflection characteristics of the internal factors of each cluster, it can be found that although most of the factors' reflection characteristics in the same cluster have high consistency, the factors in Cluster (1) "information communication, trust and cooperation" have differences in their reflection characteristics. Therefore, in this study, Cluster (1) was divided into "information communication" and "trust and cooperation". Finally, the seven clusters can be renamed:

Cluster 1: Information communication;
Cluster 2: Trust and cooperation;
Cluster 3: Technical and managerial ability;
Cluster 4: Organizational integration;
Cluster 5: Standardization;
Cluster 6: Technical environment;
Cluster 7: Contract management.

5.1. Information Communication (Cluster 1)

This cluster consists of three critical factors: (1) completeness and accuracy of information, (2) timeliness of information communication, and (3) degree of information sharing. In the existing literature, information communication was one of the most common and critical influencing factors in interface management of construction projects [75,91]. Valuable data, information, knowledge, experience, and ideas exist in the various organizations of the construction project, and cross-interface linkages must be established between organizations to ensure the effectiveness of information communication [52].

PBPs involve data information of design, procurement, production, transportation, construction, and other processes. Therefore, the process of information transfer is very complex, and the integrity of information must be considered. Defects in the expression of early design information usually lead to the lack of integrity of the design information, and it is difficult for component manufacturers and constructors to use the design information [79]. Project information is transferred across time, space, and the organization [74]. Due to differences in expertise among different stakeholders, the recipients may exaggerate or distort the information when transmitting it to other participants [67]. Therefore, managers should pay more attention to the accuracy of information across interfaces. The application of BIM technology in PBPs is a good example. BIM is committed to addressing the omission and asymmetry of information across the interface through a standardized information model [78,92,93], which can ensure the integrity and accuracy of information. In addition, the timeliness of information communication is also identified as a challenge of interface management [57,72,73]. The more timely the information communication, the higher the efficiency and value of information use. Due to the spatial and temporal dispersion of PBP participants, the timeliness of information communication should be focused on to avoid the emergence of information silos. Similarly, information sharing is a key concern throughout the construction industry and is a crucial factor in the effectiveness of interface management. The main methods of handling interface information in construction projects include sharing drawings and specifications, face-to-face meetings, oral presentations, telephone conversations, and email [23]. Due to the spatial difference between factory, site, and office, the interface information communication is inefficient.

Information sharing can enhance the accuracy and timeliness of information transmission to a certain extent and ensure the seamless connection of information to the greatest extent. PBP is highly integrated in the production organization, and has higher requirements for information sharing. With the development of information technology, Radio Frequency Identification (RFID), BIM and other advanced technologies improve the degree of information sharing [94–96], and provide technical means for smooth information across the interface.

5.2. Trust and Cooperation (Cluster 2)

The "trust and cooperation" cluster consists of four critical factors that involve (1) the cooperative attitude of participants, (2) understanding and trust between organizations, (3) communication and learning between organizations, and (4) degree of participant involvement in design. With the development of prefabricated building technology, "trust and cooperation" is considered to be critical factor for effective communication between organizations, conflict resolution, and supply chain integration [70,97,98]. Housing industrialization alliances and prefabricated building alliances based on trust and cooperation have emerged in China. The participants in these alliances must maintain a high degree of trust and cooperation to maintain their stability. Existing research conclusions also confirm the importance of "trust and cooperation" in interface management of construction projects [22,52,54].

Many studies show that different cooperative attitudes are the root cause of interface conflicts in construction projects [44,50,54]. Due to the larger number of participants, higher professional barriers, and more complex conflicts of interest in PBPs, differences in cooperation attitudes may lead to more serious interface problems. The better interface relationship of PBPs can be ensured by enhancing the cooperative intention and attitude of participants. Understanding and trust have a direct positive effect on interface management, and can have an indirect positive effect on interface management by enhancing information communication between organizations [52]. Although no study directly mentioned the influence of "understanding and trust" on PBP interface management, some scholars expressed similar views. For example, Xue, H. believed that understanding and trust can improve the relationship between the participants of PBPs [81]. Communication learning is one of the decisive factors for the performance of temporary organizational interface management [99]. The communication and learning between organizations can effectively promote the diffusion of prefabricated building technology, improve the level of professional knowledge of participants, narrow professional differences, and thus reduce the probability of interface conflicts. Since prefabricated components or parts are difficult to change after installation, early communication between participants often leads to interface problems during the production, construction, and installation phases. Therefore, participants (designers, manufacturers, and constructors) should be encouraged to participate in collaborative design as early as possible in PBPs [26,70].

5.3. Technical and Managerial Ability (Cluster 3)

Six critical factors belong to this cluster: (1) accuracy of design, (2) experience and level of participants, (3) reasonableness of the production and construction plan, (4) technical level of operators, (5) timeliness of component production and supply, and (6) tracking of component production and installation process. This cluster accounts for 11.534% of the total variance explained among all of the critical factors.

The accuracy of the design reflects the technical ability of the designer. Inaccurate and non-standard design may lead to a wrong understanding of drawings or specifications by developers and contractors, which is not conducive to interface management [58] and even affects the compatibility between prefabricated components [59]. Management experience and ability are the important criteria for enterprises to choose partners, and also the critical indicators for selecting participants when bidding for prefabricated construction projects [100]. Participants with higher management experience and ability can better manage the interface because they have mastered prefabricated building techniques, and have accumulated rich experience in dealing with various interface conflicts. In addition, the impact of the operator's technical level on interface management is mainly reflected in the physical interface. For example, the more skilled the operator, the more familiar they are with the connection structure and installation process of the component. The connection between the upstream and downstream processes can be smoothly completed to ensure the seamless connection of the physical interface in the installation process. The timeliness of component production and supply, and the tracking of component production and the installation process, can reflect the management experience and capability of the component manufacturer. Lack of storage space and traffic congestion still hamper the smooth delivery of prefabricated components. The lack of Just in Time (JIT) capability is identified as a critical risk in PBPs [16]. Delivery delay can disrupt construction schedules and lead to ongoing interface conflicts between component producers and constructors. The tracking of component production and the installation process can ensure smooth connection of the production–construction interface. In recent years, RFID and other technologies have been widely used for this [16,83,84].

5.4. Organizational Integration (Cluster 4)

This cluster consists of five critical factors related to organizational integration: (1) professional differences between participants, (2) reasonableness of organizational structure design, (3) project management mode, (4) consistency of organizational goals, and (5) cultural differences between participants. These factors reflect the overall consideration requirements of interface management for different participants in organizational structure, specialty, goals, and culture, which are consistent with the basic requirements of organizational integration. Therefore, this cluster is named organizational integration, which refers to the degree of project organization integration. This cluster accounts for 7.170% of the total variance explained among all of the critical factors.

Professional differences have been identified as the main cause of interface management problems [67,68]. Eliminating professional differences can effectively break down cooperation barriers. The professional differences of participants are more complex in PBPs, and interface conflicts are more likely to occur in the process of cooperation. Similarly, consistency of goals and cultural differences are often cited as critical factors in interface management research. The commitment to common goals can reduce the complexity of interface interactions in construction projects [22]. Gibb, G.F. clearly demonstrated the importance of consistency of goals between organizations for PBP interface management [17,26]. Participants need a more culturally compatible environment because of their different cultural backgrounds. Otherwise, cultural differences may affect information communication, trust, and cooperation, and thus affect the interface relations between participants [11,65]. Because PBPs require highly integrated organizational management, managers must pay more attention to organizational structure. Similarly, scholars have carried out a large number of studies on interface management under various construction project management modes [71,101]. For example, integrated project delivery (IPD) [102] and partnering [54] emphasize the integration of organizations, consistency of goals, and long-term partnership, and they have more advantages than the traditional project management mode. Pavitt, T.C. and Gibb, G.F. also verified that adoption of the partnering mode is more able to deal with difficult interface management problems in PBPs [17].

5.5. Standardization (Cluster 5)

This cluster accounts for 6.239% of the total variance explained among all of the critical factors, and consists of four critical factors: (1) standardization of information, (2) standardization of production and construction processes, (3) complexity of connection interfaces between prefabricated components, and (4) formal interface management process. Although these factors refer to different objects, they all focus on standardization–related issues. Notably, this cluster does not include standardization of design; the specific reasons for this are outlined in Section 5.6.

Standardized information transfer and storage is the basis for stakeholders to realize project information sharing in their own information management systems [76]. The expression, storage, and exchange of standardized information are helpful to coordinate interface conflicts and track interface information. In recent years, the standardized information management system has gradually been widely applied in PBPs. Standardization of production and construction processes is a critical factor in the interface management of construction projects [47] and the necessary condition for PBP implementation. Chen, Q. believes that standardizing the technological process of various interfaces in construction projects can reduce the uncertainty of interface management [64]. Therefore, it can be concluded that improving standardization of production and construction processes is also an effective way to reduce interface conflicts and risks of PBPs. In addition, the complexity of connection interfaces between prefabricated components is also a critical factor in interface management. Zhang, Y. found that this factor makes various components or parts prone to conflict when matching [103]. The complex interfaces and dependencies between many different components or parts may lead to installation difficulties for field workers [25]. Therefore, standardization of physical interfaces can be improved by reducing complexity. Similarly, some scholars believe that formal the interface management process can effectively alleviate the adverse effects of project complexity [23] and improve the behaviors of participants [53]. It is necessary to develop a formal interface management process to deal with more complex interface management problems.

5.6. Technical Environment (Cluster 6)

This cluster accounts for 5.252% of the total variance explained among all of the critical factors, and consists of three critical factors: (1) technological innovation, (2) degree of perfection of standards and specifications, and (3) standardization of design. In contrast to other clusters, it seems that technological innovation, standard specification, and design standardization cannot be easily summarized in the same cluster. However, all three critical factors reflect problems with the technology itself and are the basis of the technology on which PBPs rely. These problems are not immediately transferable to the subjective will of the project participants. Therefore, this study believes that Cluster 6 is the external manifestation of the technical environment, which directly affects project construction and has nothing to do with the project itself.

The application of new technology (especially transformative technology) is often accompanied by technological uncertainty, and, due to the lack of knowledge and experience, users have to seek technology and knowledge support across interfaces [104]. In recent years, the research focus of prefabricated building technology innovation in China has mainly included component connection and installation integration; that is, the interaction of prefabricated components with physical interfaces is the focus of the current research. In addition, the role of PB-related technologies (such as BIM) in improving interface management has also been affirmed [29]. Based on this, this study confirms the impact of technological innovation on interface management. The importance of technical standards and specifications for the implementation of PB is the consensus of academia and industry. With the large-scale popularization of PB, technical standards and specifications have been gradually improved in recent years. These standards and specifications are the basic reference for design, production, construction, product delivery, and acceptance of construction projects. Therefore, well-developed standards and specifications can help participants clarify technical requirements, standardize work processes, and deliver qualified products. At present, the low standardization of design is a common problem faced by PB technology, rather than being only a problem of a project or design institute itself. From this perspective, we can understand why this factor is clustered into the technical environment. The rules of standardized components or parts are uniform and reproducible, thus reducing the complexity of entity interface tasks. Furthermore, the interface has strong interoperability between different professions, thus reducing the degree of dependence between building component installation activities [61]. Therefore, it is of great significance to improve the standardization of design for interface management in PBPs.

5.7. Contract Management (Cluster 7)

This cluster is responsible for 4.605% of the total variance explained among all critical factors, and contains only two critical factors: (1) definition of work content and scope, and definition of responsibility–power–benefit. The above two critical factors are the main content of contract management, so this cluster is named contract management. Notably, these two factors have nevertheless received much attention in construction project interface management studies [17,26,57,71,72], and have been mentioned in the PBP interface management literature [17,26].

PBPs involve professional and complex contractual relationships. The contract should clearly define the content and scope of work, and the boundaries of each profession should be clearly divided and rationally overlapped. This can prevent participants from avoiding responsibilities due to ambiguous interfaces and prevent related interfaces from becoming management blind spots. To a certain extent, the definition of work content and scope also affects the attribution of responsibility–power–benefit. For example, in some highly integrated management modes, project managers can coordinate the consistent goals among organizations through responsibility–power–benefit, and pursue the optimization of the overall goals of the project. In this case, the definition of responsibility–power–benefit needs to remove the constraints of work content and scope, and serve the overall goal of the project. Otherwise, project participants may not cooperate effectively in order to avoid risks. Therefore, in order to ensure the rationality of the responsibility–power–benefit interface in PBPs, it is necessary to clarify the responsibilities and obligations of all parties, and fully mobilize the enthusiasm of the participants to cooperate on the interface.

6. Conclusions and Suggestions

Compared with traditional cast-in-situ projects, PBP interface management needs to consider more complex elements. Based on a literature review, questionnaire survey, and expert interviews, this paper identified and examined the list of factors influencing interface management of PBPs. The 27 factors were further analyzed by factor analysis, thus providing a clear understanding of the interrelationship among these factors.

The results show that the most critical factor among the 27 influencing factors is the accuracy of design, followed by the timeliness of information communication, the timeliness of component production and supply, the standardization of design, and the definition of work content and scope. These results are helpful for managers to improve their interface management ability. In addition, using factor analysis, the underlying relationships among the 27 critical factors were further explored, and the factors were categorized into seven clusters: (1) information communication, (2) trust and cooperation, (3) technical and management capability, (4) organizational integration, (5) standardization, (6) technical environment, and (7) contractual management. This study enriches the development of research in the field of interface management in the construction industry and contributes to the existing body of knowledge. The results are expected to help managers to deeply understand the causes of various interface problems in PBPs and offer useful guidance for the sustainable and healthy development of PB technology.

Based on the above research conclusions, the following suggestions are proposed for the interface management of PBPs: First, stakeholders should establish long-term stable partnerships and be encouraged to use information technology (e.g., BIM, RFID). This may improve communication, trust, and organizational integration, enabling better interface interactions between stakeholders. Furthermore, the training of management and technical personnel should be strengthened to enhance the technical and management capabilities of project participants. It is also necessary to emphasize the importance of contract management and clarify the relevant contract interfaces. Stakeholders without contractual relationships should establish close ties by signing partnership agreements. In addition, the integration of design, production, and construction should be strengthened. The standardization of information, construction technology, and management procedures throughout the life cycle can ensure the integration of design, production, and construction. Finally, the government should play a greater role in the development of the PB industry to improve interface management, such as by promoting collaborative innovation, establishing information and technology standards, and optimizing the technological environment.

In addition to improving the interface management effect, these suggestions also contribute to the sustainability of PB. For example, standardized construction processes can ensure a seamless flow from stage to stage, reducing unnecessary construction activities and waste. Improving communication, trust, and cooperation between organizations can reduce transaction costs and promote economic sustainability. Governments can also promote the use of clean energy and improve environmental sustainability by issuing green construction standards. This suggests that the improvements in the technological environment may lead to more environmental benefits.

It should be noted that the majority of respondents in this study were from prefabricated concrete building projects and did not fully cover other PBPs such as wood and steel structures. This is because the current construction form of PBPs is mainly prefabricated concrete frames. In addition, although the influencing factors were clustered, the interaction between each factor was not analyzed. In the future, we will use multiple regression analysis and other methods to deeply explore the relationship path and influence mechanism among factors. Based on this, we may also build a PBP case library and interface knowledge ontology model to provide managers with a retrieval program and analysis tool for interface management.

Author Contributions: S.Z. conducted the global study and completed the paper in English; Z.L. participated in the data collection and processing and revised important knowledge content critically; S.M. controlled the overall thinking of the study, and made a comprehensive English revision; L.L. gave guidance in methodology application; M.Y. gave some good suggestions and made an excellent contribution to the details. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 72071027, the National Key Research and Development Project of the 13th Five–Year plan, grant number 2018YFC0705900 and the Shandong Provincial Natural Science Foundation of China (No. ZR202102220230).

Institutional Review Board Statement: Ethical review and approval were waived for this study, due to this study takes the construction projects as the research object, and the questionnaire survey method adopted in this study is mainly to obtain the opinions of engineers and scholars on the construction engineering issues, which does not involve any ethical issues related to humans or animals.

Informed Consent Statement: "Not applicable" for studies not involving humans.

Data Availability Statement: Some or all data generated or used during the study are available from the corresponding author by request. (List items).

Conflicts of Interest: The authors declare no conflict of interest.

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