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Constraints on the Promotion of Prefabricated Construction in China

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Abstract: Prefabricated construction has been proven effective, environmentally-friendly, and labor-friendly. It is widely considered a sustainable approach to the construction industry. China is still in the initial process of adopting prefabricated construction practices and has conducted a few studies to date on the constraints of prefabricated construction up to the operation stage. This paper focuses on the major factors obstructing prefabricated construction development in China. Twenty-three variables affecting said development are summarized per the results of a literature review and a semi-structured interview. A questionnaire was delivered to developers, designers, contractors, engineers, component suppliers, and property managers. A total of 160 valid respondents were collected. Twenty-three variables were ranked by the mean score after an Analysis of Variance (ANOVA) indicated that no statistical differences in the data from six stakeholders. Principal Component Analysis (PCA) was employed to reduce the dimensionality of four factors: industry chain, cost, social climate and public opinion, and risk. The risk is found to be the main influencing factor even though it is rarely the focal point of research on prefabricated construction. The findings presented in this paper may assist different stakeholders in better understanding issues with prefabricated construction practices in China at present and, therefore, find workable solutions.

Keywords: constraints; factors; prefabricated construction; China; construction industry

1. Introduction

Sustainable development has become a global imperative as humanity moves through the 21st century. The construction industry, in particular, may benefit from long-term sustainable development. Prefabricated construction is a relatively recent innovation in the construction industry, which represents a shift from the traditional on-site construction to off-site. Construction components are prefabricated in the factory after they are designed, then delivered to construction sites, and simply assembled there to complete the desired structure [1]. Prefabricated construction has many advantages over traditional construction. For example, preparing components at a factory and preparing them on-site can be done simultaneously, which streamlines the construction schedule [2,3]. The majority of the construction "work" is, therefore, transferred from the site to the factory. When standardized properly, the strict production and operation of prefabrication yields higher quality structures with fewer accidents on site [4–9]. Assembly lines will accomplish most of the work, which means many parallel activities can be carried out without interruption. The operation is highly organized, which demands a smaller labor force at higher productivity [10,11]. Prefabricated construction is more environmentally-friendly than traditional construction. It produces less construction waste, noise, and dust while using less energy [12–16]. Prefabricated construction improves quality, safety, productivity, labor efficiency, construction timeframe, construction waste, noise, dust, and energy use [17–20]. These advantages can upgrade the entire industry and benefit all stakeholders in the industry chain, making prefabricated construction more green, environmentally-friendly, and sustainable [21].

The construction industry plays an indispensable role in China's national economy and prefabricated construction is the inevitable trend. China's construction industry gross product in 2016 was 4952.22 billion yuan encompassing 6.8% of the country's GDP [22]. The floor space of buildings constructed by construction enterprises has reached 12.64 billion square meters while the floor space of prefabricated buildings was only 0.11 billion square meters in China in 2016, i.e., only 0.87% of the country's total floor space [22,23]. There is remarkable potential for the prefabricated construction industry in China to expand. Many problems, unfortunately, have emerged in the implementation of prefabricated construction and many factors impede its further development. It is necessary to accurately identify and assess the barriers restraining the wider application of prefabricated construction projects. Previous researchers have investigated these problems from the perspective of stakeholders in design, prefabrication, and construction stages. None have yet considered issues with the operation and maintenance of prefabricated structures even though the service stage comprises the majority of any given building's life cycle. Our goal in conducting the present study was to fill this knowledge gap.

We investigated restraints on the development of prefabricated construction in China. This involved first reviewing the factors affecting prefabricated construction as stated in the literature and then conducting a semi-structured interview to supplement and modify the variables. We distributed questionnaires to developers, designers, contractors, engineers, component producers, and property managers. Then we collected and synthesized the data to draw relevant conclusions. The objectives of this study were:

(1) to determine variables of restraint on prefabricated construction development in China, reduce their dimensionality, and obtain key factors,
(2) to compare the differences among developers, designers, contractors, engineers, component producers, and property managers with regard to any statistical differences,
(3) to provide a valuable reference for stakeholders to assess—and ultimately resolve—problems in implementing prefabricated construction projects in China.

2. Prefabricated Construction Constraints

Although prefabricated construction has many advantages compared to traditional construction, it also works under certain constraints that are agreed upon by researchers and practitioners.

2.1. Cost

The cost problem is a critical factor influencing the development of the construction industry. Jaillion and Poon found that higher initial and transportation costs are the main economic hurdles of prefabricated versus conventional construction methods [24]. Higher initial investment and capital cost are extremely unfavorable for the long-term development of prefabricated construction [20,25–27]. Mao et al. investigated the expenditures of prefabricated and traditional construction via a multiple-case study method. They found that the total cost of prefabricated construction is significantly higher than that of conventional construction methods [28]. Hong et al. identified additional costs with highly skilled workers, design changes, initial investment, logistic processes, extra labor costs (for checking, counting, and sorting raw materials), and component storage space. This included items that directly impacted the economic performance of prefabricated construction. In a case study on eight buildings under a cost-benefit analysis framework, the cost intensity of prefabricated buildings was proven to be 26.3% to 72.1% higher than conventional buildings with a significant positive correlation to the prefabrication rate [29]. Mao et al. conducted a questionnaire survey in China to find barriers to off-site construction from the developer's perspective. They found that the high initial cost and high-cost pressure without appropriate economic scale effects were the second and fifth most important factors, respectively [30].

2.2. Supply Chain

Numerous stakeholders work together to implement a prefabricated construction project, but they usually have individual rather than common goals. This creates a tendency to work separately without cooperation or information sharing among the stakeholders. Therefore, it is urgent for China to improve the level of the supply chain integration from a managerial perspective [31]. There is a need for more detailed and effective cooperation in all stages of a prefabricated building including design, procurement, prefabrication, transportation, on-site assembly, construction, installation, declaration, and operation. Component transportation from the factory to the site is also a critical problem affecting the supply chain integration [32]. Arditi et al. and Polat investigated factors affecting the use of prefabricated concrete systems in 1995 and 2008, respectively, in the U.S. They found that contractors and designers communicate efficiently in the construction stage while designers and manufacturers do not effectively communicate [33,34]. Prefabricated components such as stairs, façades, slab, air-conditioning panels, and balconies are inherently heavy and large, which makes them challenging to transport, hoist, or assemble without functional communication across all stakeholders in the project [35,36].

2.3. Policies and Regulations

The Chinese government imposes policies and regulations on the construction industry. In the preliminary stages of prefabricated construction, policy plays an important role in Singapore and Hong Kong. The Singaporean government imposes "buildability" provisions, which indirectly control the prefabricated construction industry [37]. The Housing Authority in Hong Kong has been the only major client for prefabrication in its public housing sector since the mid-1980s [38]. The regulations and codes of the past, however, are not a good fit for modern prefabricated construction. It is necessary to create nationwide standardization for prefabricated construction, which includes modular coordination and standardized design components [34]. Today, there are not enough progressive laws, regulations, codes, or standards especially addressing prefabricated construction practices in China [31].

2.4. Process

The design is the most important stage of construction. The prefabricated building design departs entirely from conventional design. The prefabricated building design is more complex and labor-intensive. The designer must consider the specific modules and component constitutions as well as their precise assembly [39]. Complex modules need more design work because they produce more subsequent prefabrication work, transportation work, assembly work, and coordination work [32]. A good design can enhance the value of the building while an incompetent design may lead to poor construction quality (e.g., cracks, leakage, joint failure) [34]. The components, modules, and an assembly process are determined in the design stage and are nearly impossible to change at the construction stage [40]. Design specifications should be "frozen" as early in the design stage as possible, but designers may struggle to accomplish this in practice [41]. The conventional monitoring process is not suited to prefabricated construction since it assumes the construction stage is fully separate from the design stage [42].

2.5. Knowledge

It is generally agreed upon that lack of experience currently prevents the further development of prefabricated construction [41]. Different types of knowledge are necessary throughout the entire construction process. Designers need certain skills. Manufacturers need the knowledge to improve productivity and quality. Assemblers must have the unique capacity to work with the demands of prefabricated versus conventional construction [25]. Prefabricated components are produced in the factory and assembled on site under minimized uncertainties, which makes the project schedule more specific and predictable compared to conventional construction. However, lack of expertise in prefabricated construction may eliminate this advantage entirely. The lack of expertise in design may create severe conflicts between manufacturers and designers. The lack of competence in prefabrication can cause mistakes in the production of components and modules and/or delay the schedule. Lack of competence in the assembly may result in quality problems and schedule delays as well as greater cost expenditures [33]. In prefabricated construction, the mixture of necessary labor skills is totally different from conventional construction. Machine-oriented skills are needed both in the prefabricated component factory and construction site and the labor force must be trained appropriately. Skilled workers are required in the factory and for the on-site assembly and joining of prefabricated units [35]. In a survey conducted by Polat, most respondents reported that academic programs in the structural, architectural, and managerial aspects of prefabricated concrete systems are not satisfactory [34].

3. Research Methodology

The research methodology of this paper includes a literature review, semi-structured interviews, questionnaire design and survey, data collection, and data analysis. The roadmap of this research is shown in Figure 1.

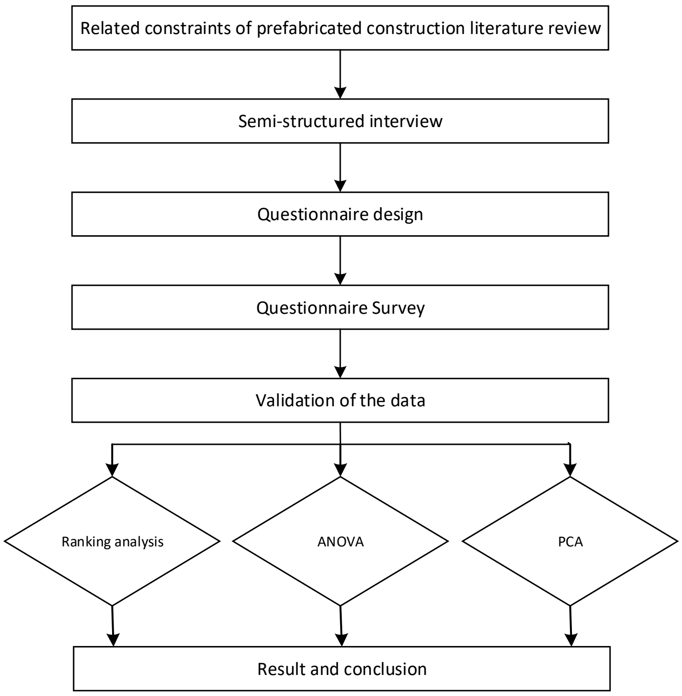

Figure 1. The research roadmap.

3.1. Literature Review

A wide-ranging literature review was conducted to fully understand the development processes of prefabricated construction in China as well as the constraints on prefabricated construction conducted as they stand today. We conclude that the factors inhibiting the promotion of prefabricated construction include cost, supply chain, policies and regulations, process, and knowledge.

3.2. Semi-Structured Interviews

Semi-structured interview questions were conducted to define the constraints on the promotion of construction in practice. We conducted interviews with 20 individuals including three developers, three contractors, four engineers, four designers, three manufacturers, and three property managers. All of these individuals have more than five years of experience in prefabricated construction. The interviews were completed either face-to-face or by video conference. The interviews included six open-ended questions [43], which are outlined below:

(1) Could you talk about the development situation of prefabricated construction in China at present?
(2) Would you like to participate in a prefabricated construction project or a traditional construction project? Why?
(3) What are the major challenges you encounter in implementing prefabricated construction?
(4) What are the main factors that inhibit the promotion of prefabricated construction?
(5) What do you think each stakeholder should do to support prefabricated construction development?
(6) Are there any additional opinions or advice you can offer regarding prefabricated construction development in China?

The results of a semi-structured interview support the conclusion made by literature review. The major factors interviewers encounter in implementing prefabricated construction are illustrated in the literature review except “quality problems due to an excessive pursuit of assembly rate”. Six interviewers stated that an excessive pursuit of the assembly rate exists in prefabricated construction, which may directly lead to quality problems.

3.3. Questionnaire Design

We completed a detailed online questionnaire based on the semi-structured interviews and literature review. The questionnaire, which consists of two parts, was designed to investigate the stakeholder’s perspective regarding the importance of the variables outlined above. Part one involves gathering basic information for the respondents (work, organization, and experience). In part two, respondents were asked to score from 1–5 a total of 23 variables selected from constraints through a literature review and semi-structured interviews. In the second part, 1 represents the least important, 2 represents fairly important, 3 represents important, 4 represents very important, and 5 represents the most important. The factors are listed in Table 1.

Table 1. List of variables.

Code	Variables	Reference
V01	Lack of comprehensive understanding of prefabricated construction	[23,40,44]
V02	Lack of relative policies, laws, and standards	[23,25,30,31,44]
V03	Disapproval by the market	[23,25,30,31,44]
V04	Lack of governmental incentives	[23,30,33,34,44]
V05	Quality problems due to excessive pursuit of assembly rate	Added after interview
V06	High cost due to discordant scale	[23,44]
V07	Unintegrated industry chain	[25,30,40,41,44]
V08	High initial cost	[20,25–31,40,44]
V09	Potential costs increased due to uncertainties	[44]
V10	High employee training cost	[44]
V11	Higher average cost compared to traditional building	[25,29,35,37]
V12	Potential delays of manufacturers’ limited capacity	[23,44]
V13	Lack of durability, leakage, and cracks	[25,31,33,34,37]
V14	Insufficient construction capacity	[23,30,44]
V15	Lack of well-developed technical system	[23,31]
V16	Lack of R&D input	[31]
V17	Insufficient integrated design capacity	[23,25,33,34,40]
V18	Low-level of whole-decoration	[23]
V19	Low-level of general contracting	[23]
V20	Lack of industry team	[23,31]
V21	Lack of practice and experience	[25,30,31,33,34,41]
V22	Lack of new management method for prefabricated construction	[37,40,44]
V23	Lack of a synergetic information platform	[33,34,40]

Over six-hundred questionnaires were sent to developers, contractors, engineers, designers, manufacturers, and property managers. We used a snowball sampling technique to ensure efficient, valid responses to our investigation [30,44,45]. This method ensures wide and extensive delivery to similar people. The 72 initial respondents included 12 developers, 12 contractors, 12 engineers, 12 designers, 12 manufacturers, and 12 property managers, which were selected from the Prefabricated Building Industrial Base of China and China Property Management Institute via email, QQ, WeChat, and an online survey. All the respondents were also requested to forward the email or questionnaire link to their colleagues or other experts who have had rich experience in the prefabricated construction field.

3.4. Data Analysis Methods

Our questionnaire was distributed to six different types of stakeholder (developers, designers, contractors, engineers, manufacturers, and property managers) who may have different attitudes. An Analysis of Variance (ANOVA) is a collection of statistical models that allows researchers to analyze the differences between group means and their associated procedures [46]. We conducted ANOVA to test whether different participants presented significantly different variable scores. When the p-value of ANOVA is smaller than 0.05, there is a statistically significant difference among the different groups. When the p-value of ANOVA is larger than 0.05, there is no statistically significant difference among different groups [47]. We also used the mean score method to explore the total importance of the factors. If two or more factors have the same mean score, the one with the lower standard deviation (SD) is assigned a higher rank [30,44].

Reliability analysis is used to check the resulting consistency of the variables. Since the variables in our questionnaire may be related in some way or share certain general characteristics, we conducted a factor analysis to determine the variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called "factors" [48]. The most commonly used factor analysis method is Principal Component Analysis (PCA), which is a multivariate statistical analysis method through which several important variables are selected by a linear transformation. We used PCA to search the related links among the variables we identified.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and the Bartlett Test of Sphericity were conducted before PCA to compare simple correlation and partial correlation coefficients among variables as well as the independence of the variables. The KMO statistic varies between 0 and 1. If the simple correlation coefficient among all variables is far greater than the sum of the partial correlation coefficients, the KMO value is close to 1. This indicates a strong correlation among variables and a good fit for factor analysis. If the simple correlation coefficient between all variables is approximately 0, the KMO value is close to 0. There is a low correlation among variables and factor analysis is infeasible [49]. According to Kaiser, values greater than 0.5 indicate that the questionnaire has construct validity and the sample is acceptable for factor analysis [50].

We also ran Bartlett's Test of Sphericity to examine whether a variance-covariance matrix of a covariate is an identity matrix. When the variance-covariance matrix of a covariate is an identity matrix, there is no correlation between the variables and it is not suitable for factor analysis. When the variance-covariance matrix of the covariate is not an identity matrix, there is a correlation between the variables. When the p-value of Bartlett's Test of Sphericity is larger than 0.05, it is not suitable for factor analysis [51].

4. Data Collection and Analysis

4.1. Data Collection

Among the total 676 questionnaires distributed, 160 were returned with valid responses at a response rate of 23.67%, which is shown in Table 2. The 160 valid responses came from 26 provinces in China, which is shown in Figure 2. There are 28 designers, 28 developers, 21 contractors, 38 engineers, 25 manufacturers, and 20 property managers in the valid response category, which is recorded in Table 3. Of the total number of respondents, 11 had more than 35 years of work experience, 23 people had 26–30 years of work experience, 52 people had 21–25 years of work experience, 31 people had 16–20 years of work experience, 19 people had 11–15 years' work of experience, and 16 people had 6–10 years of work experience. A total of eight people had less than five years of work experience in the construction industry, which is illustrated in Table 3. In short, most respondents have rich work experience in the construction industry and, therefore, provided well-informed responses to the questionnaire.

Table 2. Valid questionnaires.

Item	Value
Total valid	160
Total distributed	676
Response rate	23.67%

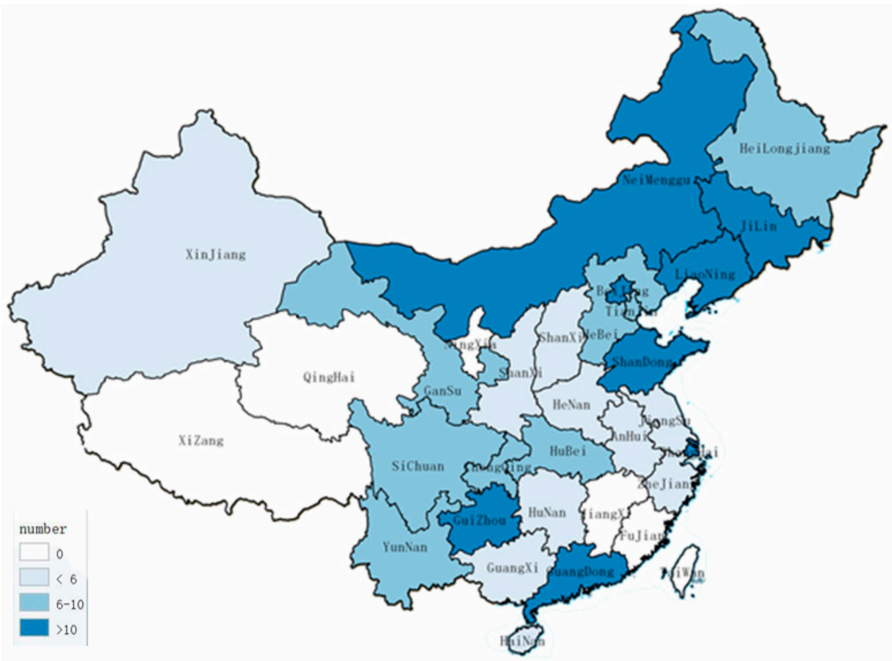

Figure 2. Number of the valid response from different provinces in China.

Table 3. Profile of respondents.

Characteristic	Indicator	Amount of Responses	Percentage
Job category	Developers	28	17.50%
	Designers	28	17.50%
	Contractors	21	13.13%
	Engineers	38	23.75%
	Manufacturers	25	15.63%
	Property managers	20	12.50%
Working experience	<5 years	8	5.00%
	6–10 years	16	10%
	11–15 years	19	11.88%
	16–20 years	31	19.38%
	21–25 years	52	32.50%
	26–30 years	23	14.38%
	31–35 years	11	6.88%

China is a vast country covering an area of 9.6 million square kilometers. Unbalanced economics have led to disequilibrium in the development of prefabrication construction among regions. Key regions for prefabrication construction are Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta. Remaining regions are areas "encouraged" to embrace prefabrication. Among China's 34 provinces, we have collected data from 26 regions including both key regions and encouraged regions. To this effect, our survey encompasses the entirety of China's prefabricated construction environment.

4.2. Data Analysis

Statistical Product and Service Solutions (SPSS) is a useful statistical product and service solution widely applied in the natural science, technology, and social sciences field [49,52]. We used SPSS 24.0 to analyze our data.

4.2.1. ANOVA

The mean scores from different stakeholders differed across the 23 variables, which is shown in Table 4. We ran a Levene Variance Equality Test to determine whether homogeneity of variance was satisfied. The variance difference of 23 variables was not significant. The smallest *p*-value of the 23 variables is 0.074, which is larger than 0.05. We next performed ANOVA to determine if the six stakeholders had any statistically significant effect on the collected data [53]. Each of the 23 variables was compared across the six participants. As shown in Table 4, there was no statistical difference among the six stakeholders since none of the *p*-values exceed 0.05. Therefore, the stakeholder data was deemed suitable for further analysis.

The mean scores and ranking of the 23 variables are shown in Table 4. Mean scores of 21 factors were higher than three, i.e., are classified as "important". Table 4 also shows that the highest mean score is V07, "unintegrated industry chain", which has an SD of 1.089. In effect, stakeholders consider V07 to be the main factor constraining the development of prefabricated construction in China consistently. The other top five factors are V02 (lack of relative policies, laws, codes, and standards), V03 (disapproval by the market), V15 (lack of well-developed technical system), and V06 (high cost due to discordant scale).

4.2.2. PCA

We conducted an initial reliability test to examine the reliability, consistency, and stability of our data. A Cronbach's alpha was adopted to test the reliability of the 160 valid responses. The Cronbach's alpha of the data is 0.915, which is higher than 0.9. This indicates very strong data reliability.

In the first factor analysis, the KMO measure was calculated to be 0.890, which falls between 0.8 and 0.9. This indicates a good fit. The associated Bartlett's test significance level is 0.000, which is less than 0.05. Therefore, the original hypothesis is refused. The coefficient matrix is not an identified matrix, which means a correlation exists among the original variables. Therefore, it is suitable for factor analysis and the validity of the questionnaire is acceptable. PCA was adopted to carry out factor analysis. Five factors were extracted, which account for 60.615% of the variance. This is shown in Table 5. Factor 5 has only one variable known as Variable 13, which covers too few aspects to be significant and was deleted.

We calculated the KMO measure and Bartlett's test values again after deleting V13. The resulting KMO measure is 0.892 and the associated Bartlett's test significance level is 0.000, which indicates that it is suitable for factor analysis and that the data is valid. Four factors were extracted, which accounted for 56.862% of the variance. This is shown in Table 6.

Table 4. ANOVA results.

Code	Mean							Overall Standard Deviation	Rank	F	P
	Developers	Designers	Contractors	Engineers	Component Supplier	Property Managers	Overall				
V01	3.18	3.39	3.48	3.82	3.7	3.36	3.5	1.138	11	1.294	0.269
V02	3.79	3.82	3.57	3.87	3.7	3.56	3.74	1.13	2	0.354	0.879
V03	4.07	3.57	3.95	3.55	3.8	3.64	3.74	1.151	3	0.977	0.434
V04	3.86	3.36	3.52	3.58	3.5	3.48	3.56	1.238	8	0.501	0.775
V05	3.64	3.29	3.29	3.05	3.2	3.4	3.3	1.148	18	0.92	0.47
V06	3.93	3.61	3.9	3.74	3.4	3.56	3.7	1.154	5	0.734	0.599
V07	4.07	3.64	3.76	3.92	3.65	3.96	3.85	1.089	1	0.674	0.644
V08	3.57	3.43	3.81	3.26	3.45	3.44	3.47	1.143	12	0.688	0.648
V09	3.71	3.18	3.43	3.21	3.45	3.52	3.4	1.106	16	0.969	0.439
V10	2.68	2.71	2.52	2.79	2.8	2.48	2.68	1.147	23	0.34	0.888
V11	3.5	3.11	3.05	3.29	3.45	3.24	3.28	1.274	19	0.478	0.792
V12	3.07	3.04	3.33	3.13	3.2	2.84	3.09	1.08	21	0.541	0.745
V13	3.32	2.86	2.76	2.74	2.9	3.2	2.94	1.245	22	1.536	0.182
V14	3.64	3.57	3.62	3.26	3	3.68	3.46	1.16	13	2.053	0.074
V15	3.71	3.96	3.71	3.63	3.55	3.56	3.71	1.042	4	0.741	0.594
V16	3.54	3.64	3.57	3.66	3.4	3.4	3.55	1.132	9	0.261	0.934
V17	3.5	3.43	4	3.58	3.5	3.6	3.59	1.107	7	1.463	0.205
V18	3.43	2.96	3.33	3.18	3.25	3.28	3.23	1.15	20	0.514	0.765
V19	3.61	3.5	3.57	3.37	3.05	3.32	3.41	1.151	15	0.706	0.62
V20	3.57	3.21	3.38	3.42	3.35	3.4	3.39	1.144	17	0.277	0.925
V21	3.75	3.57	3.81	3.68	3.5	3.72	3.68	0.988	6	0.302	0.911
V22	3.64	3.5	3.62	3.29	3.05	3.36	3.43	1.097	14	2.027	0.078
V23	3.64	3.68	3.62	3.42	3.2	3.48	3.51	1.121	10	0.594	0.705

Table 5. Rotated factor matrix of the first-factor analysis.

Code	Factors					Communality
	1	2	3	4	5	
V17	0.741	0.222	0.056	−0.010	0.004	0.601
V19	0.719	0.285	0.134	0.159	−0.142	0.662
V20	0.696	−0.019	0.119	0.361	0.05	0.632
V18	0.685	0.237	0.003	0.011	0.015	0.525
V23	0.681	0.034	0.204	0.135	0.191	0.561
V14	0.678	0.137	0.062	0.024	0.458	0.693
V22	0.676	0.139	0.049	0.29	0.255	0.628
V21	0.666	−0.066	0.246	0.157	0.225	0.584
V15	0.644	0.113	0.268	−0.006	0.21	0.543
V16	0.582	0.296	0.353	−0.152	0.234	0.628
V07	0.561	0.366	0.281	0.188	−0.224	0.614
V06	0.511	0.414	0.244	0.298	−0.192	0.619
V08	0.259	0.753	0.091	0.082	0.02	0.65
V11	0.066	0.717	0.035	0.137	0.086	0.546
V10	0.141	0.658	0.134	0.211	0.079	0.521
V02	0.276	−0.24	0.741	0.067	0.158	0.656
V01	0.097	0.13	0.731	0.201	−0.176	0.616
V04	0.081	0.399	0.65	−0.019	0.124	0.604
V03	0.248	0.361	0.471	0.056	0.116	0.43
V05	0.145	0.184	0.092	0.837	−0.018	0.764
V09	0.095	0.426	0.093	0.538	0.334	0.6
V12	0.224	0.371	0.142	0.477	0.176	0.466
V13	0.262	0.152	0.073	0.149	0.824	0.799
Eigenvalues	5.565	2.818	2.278	1.788	1.492	
Percentage of variance	24.198	12.250	9.904	7.775	6.488	
Cumulative percentage of variance	24.198	36.448	46.352	54.127	60.615	

Table 6. The rotated component matrix of the second-factor analysis.

Code	Factors				Communality
	1	2	3	4	
V14	0.754	0.155	0.044	0.051	0.596
V17	0.725	0.227	0.054	0.01	0.58
V22	0.704	0.144	0.044	0.31	0.614
V23	0.699	0.042	0.204	0.145	0.553
V21	0.698	−0.059	0.236	0.173	0.576
V20	0.689	0.021	0.117	0.376	0.63
V15	0.681	0.123	0.249	0.021	0.541
V19	0.669	0.282	0.145	0.17	0.577
V18	0.666	0.242	0.009	0.023	0.504
V16	0.621	0.311	0.338	−0.127	0.612
V07	0.499	0.358	0.292	0.199	0.501
V06	0.453	0.404	0.253	0.311	0.529
V08	0.25	0.752	0.085	0.11	0.647
V11	0.066	0.716	0.036	0.155	0.543
V10	0.144	0.656	0.13	0.231	0.522
V01	0.06	0.006	0.741	0.19	0.589
V02	0.306	−0.018	0.736	0.068	0.641
V04	0.103	0.405	0.646	−0.012	0.592
V03	0.262	0.366	0.47	0.065	0.427

Table 6. *Cont.*

Code	Factors				Communality
	1	2	3	4	
V05	0.119	0.163	0.099	0.844	0.762
V09	0.146	0.423	0.08	0.562	0.522
V12	0.238	0.367	0.144	0.489	0.45
Eigenvalues	5.588	2.791	2.256	1.875	
Percentage of variance	25.401	12.688	10.253	8.521	
Cumulative percentage of variance	25.401	38.089	48.341	56.862	

Table 6 also shows that 12 variables (V06, V07, V14–V23) belong to Cluster 1, three variables (V08, V10, V11) belong to Cluster 2, four variables (V01–V04) belong to Cluster 3, and three variables (V05, V09, V12) belong to Cluster 4. According to the PCA results and considering the implications and characteristics of each variable, the four factors were defined as follows. The final results are shown in Table 7.

Factor 1: Industry chain; Factor 2: Cost; Factor 3: Social climate and public opinion; Factor 4: Risk.

Table 7. Final results of PCA.

Factors	Variables
Industry chain	High cost due to discordant scale Unintegrated industry chain Insufficient construction capacity Lack of well-developed technical system Lack of R&D input Insufficient integrated design capacity Low-level of whole-decoration Low-level of general contracting Lack of industry team Lack of practice and experience Lack of new management method for prefabricated construction Lack of a synergetic information platform
Cost	High initial cost High employee training cost Higher average cost compared to traditional building
Social climate and public opinion	Lack of comprehensive understanding of prefabricated construction Lack of relative policies, laws, and standards Market disapproval Lack of governmental incentives
Risk	Quality problems due to excessive pursuit of assembly rate Potential costs increased due to uncertainties Potential delays of manufacturers' limited capacity

5. PCA Results

5.1. Factor 1: Industry Chain

The "industry chain" factor consists of 12 variables, which includes V06 (high cost due to discordant scale), V07 (unintegrated industry chain), V14 (insufficient construction capacity), V15 (lack of well-developed technical system), V16 (lack of R&D input), V17 (insufficient integrated design capacity), V18 (low-level whole-decoration), V19 (low-level general contracting), V20 (lack of industry team), V21 (lack of practice and experience), V22 (lack of new management methods for prefabricated construction), and V23 (lack of a synergetic information platform). These variables account for 25.401% of the total variance among all the variables, which is shown in Table 6.

The prefabricated construction industry is in its infancy in China. There are a series of issues impeding further development of this industry across design, construction, decoration, technology, labor, information, scale, R&D, management, experience, and other aspects. Despite some larger enterprises such as Country Garden, Vanke, China State Construction Engineering, and China Railway Engineering, most prefabricated construction enterprises in the market are smaller-scale companies (SMEs). The cost of these SMEs is higher, which means the scale of the prefabricated construction economy is discordant.

The integrated design capacity for structures, components, mechanical and electrical equipment, assembly work, and decoration are inadequate at present. These inadequacies create problems in subsequent construction stages and cause cost increases and schedule delays. The assembly process is more difficult than conventional construction and the low level of the prefabrication rate creates insufficient construction capacity. The integral decoration of design and construction is not available currently. The main structure is difficult to cohesively establish due to the issues with decoration, which makes decoration an important target for improvement.

Existing construction companies have not yet extensively explored new organization modes and are generally unwilling to invest capital in new equipment and technology, which has resulted in a lack of any well-developed technical system. The common technical systems for prefabricated construction include shear-wall, frame, and frame shear-wall systems. The shear-wall system has developed rapidly in recent years for use in high-rise buildings. The frame system is mainly used in low-rise, multi-story buildings such as factories, warehouses, shopping malls, office buildings, schools, and hospitals, which have open spaces and flexible housing layouts. The frame shear-wall system mainly depends on conventional cast in-situ methods and is highly challenging to assemble on site.

Experience and practice are essential for the application of any new technology. Whether developer or designer, contractor or engineer, manufacturer or property manager, experience and practice in prefabricated construction is generally insufficient, which leaves industry teams largely unstaffed.

The contract is a regular executive mode among international projects, which is widely used in prefabricated construction. China does not yet have an enterprise organizational structure for massive contracting. Traditional management methods do not readily apply to the design, fabrication, assembly, or operation of prefabricated buildings and are not supported by any coherent or efficient information management platform.

An effective industry chain is crucial for the development of new construction practices especially when a new technology is applied. In our semi-structured interviews, most respondents stated that the developer, designer, manufacturer, contractor, engineer, and property manager of a given project work separately. This reflects inefficiency and a lack of process continuity. For example, if the designer does not consider the manufacture and construction stages, issues with an on-site assembly such as scheduled delays and unexpected costs are likely to arise.

5.2. Factor 2: Cost

There are three variables in the "cost" factor: V08 (high initial cost), V10 (high employee training cost), and V11 (higher average cost compared to traditional building), which account for 12.688% of the total variance among all the variables. This is shown in Table 6.

In the prefabrication stage, manufacturers need a high initial investment to construct their factory and buy the necessary machines. On-site assembly is totally different from in-situ casting. As such, contractors must put in a substantial investment to incorporate vertical movement and horizontal movement [54]. A warehouse is needed to store prefabricated components and modules of different sizes and types away from the elements. Specialized appliances and tools are also needed for the assembly of prefabricated components.

It is necessary to provide special training to employees for work in prefabricated component factories and on-site assembly locations. They must master the use of new tools and equipment, learn how to effectively join components, and be capable of organizing, supervising, and managing the construction project appropriately. Providing such training to a large number of employees is very costly.

The average cost of prefabricated construction is higher than that of conventional construction. The average incremental cost is related to the prefabrication rate [29]. In addition to costly initial investment and employee training, the transportation of components and modules to the site is very expensive. Design costs, component costs, and additional procurement costs are also high. The cost of labor is relatively low in China, which means the cost of prefabricated construction is higher than that of conventional construction. That being said, cost should not be the only criterion for the selection of an appropriate construction method. Quality, schedule, and environment also merit careful consideration.

5.3. Factor 3: Social Climate and Public Opinion

The "social climate and public opinion" factor includes four variables, which are V01 (lack of comprehensive understanding of prefabricated construction), V02 (lack of relative policies, laws, and standards), V03 (disapproval by the market), and V04 (lack of governmental incentives), which account for 10.253% of the total variance among all the variables. This is shown in Table 6.

Despite the fact that prefabricated construction is popular worldwide, in-situ casting still dominates the construction market in China. Many stakeholders lack a comprehensive or systematic understanding of prefabricated construction with regard to safety, durability, and fireproofing. More importantly, numerous enterprises involved in exploitation, design, component and module production, assembly and construction, and supervision and testing do not recognize this new construction mode and simply lack the capacity to upgrade their technologies accordingly.

China is in the initial stages of adopting prefabricated construction practices and does not yet have a sophisticated market for new construction methods. Most developers still choose traditional construction over prefabricated construction, but this is likely to change as the market matures.

Relative policies, laws, and standards are the foundation for steady and healthy development in any industry. At present, there is a basic framework for such policies, laws, and standards but no specific path towards implementation. There is demand for integrated policies and comprehensive standardization within the burgeoning prefabricated construction industry.

Prefabricated construction is currently more expensive than traditional construction, which makes developers unlikely to adopt it in the absence of government incentives such as financial subsidies or tax preferences. Preferential policies for planning approval, land supply, finance, and component production are unattractive, which leads to enterprises within the construction industry lacking enthusiasm for prefabricated construction.

5.4. Factor 4: Risk

V05 (quality problems due to excessive pursuit of assembly rate), V09 (potential costs increased due to uncertainties), and V12 (potential delays of manufacturers' limited capacity) belong to the factor "risk", which accounts for 8.521% of the total variance among all the variables. This is shown in Table 6.

Using the maximum number of prefabricated components allows for the effective exploitation of prefabricated construction's advantages. The low prefabrication rate is not nearly as effective. Considering the situation in China's prefabricated construction industry today, it is not feasible to pursue high prefabrication rates due to the threat of quality problems such as cracks, leakage, and joint failures.

Immature technology and inexperienced employees also threaten a variety of problems such as the low strength of materials, unstable joints, and cracks in critical positions. Solving these problems is potentially very costly, which may make prefabricated construction very unattractive to stakeholders.

The immature market has also resulted in a lack of prefabricated component manufacturers. Existing manufacturers have relatively low production capacity for large projects and may struggle to accommodate growth in the market under increased demand. The manufacturers represent potential delays that can throw off the whole construction project schedule.

6. Discussion

Because the main factors of constraints on the promotion of prefabricated construction in China are analyzed, it's urgent for us to find the solutions. For the "industry chain" factor, the government and enterprises should increase investment in scientific research and improve the technological system that suits China's national conditions. Meanwhile, new management method and information platform should be studied. Then the capacity of enterprises will be enhanced, which will lead to the cooperation of enterprises and the integration of the industry chain.

Whether in the literature review or the PCA of this paper, cost is an important factor to solve [24]. As a new industry in China, the government should offer subsidies in the initial stage [31]. When prefabricated construction is developed to a certain extent, there will be economies of scale effect and cost reduction. At present, choosing a prefabricated component rationally is another way to be economic.

For the "social climate and public opinion" factor, there should be more publicity to the characteristic of prefabricated building such as energy saving, environmental protection, and excellent performance. The government should make appropriate policies, laws, and standards at the national level to form the frame. The enterprises should pay more attention toward improving enterprise standards. With the government incentive and policy development, prefabricated construction will become more popular.

To reduce the risk of prefabricated construction, designers should choose the proper assembly rate according to the technical level. More attention should be paid to the design stage to reduce problems emerging in the prefabrication and assembly stage. Prefabrication factory should be encouraged to enhance the production of components.

7. Conclusions

Prefabricated construction is undoubtedly the future of China's construction industry. However, there are many constraints impeding its development that have to be fully understood. Twenty-three variables restricting the development of prefabricated construction were identified in this study through a literature review and a semi-structured interview. One-hundred and sixty valid questionnaires were collected from developers, designers, contractors, engineers, manufacturers, and property managers. The results can be regarded as a solid reference to recognize the constraints on the promotion of prefabricated construction in China today.

The conclusion is elaborated below.

- The Analysis of Variance indicated no statistical differences in the data provided by six stakeholders, which means the resulting 23 variables were ranked by using the mean score. The top five variables are the unintegrated industry chain, the lack of practice and experience, insufficient construction capacity, market disapproval, and insufficient construction capacity.
- Principal Component Analysis was employed to reduce dimensionality. Four factors were extracted including industry chain, cost, social climate and attitudes, and risk. An industry chain including 12 variables was found to be the most important factor, which comprised 25.401% of the total variance among all the variables. Cost (three variables) is the second-most important factor at 12.688% of the total variance among all the variables. Social climate and public opinion (four variables) followed at 10.253% of the total variance among all the variables and risk (three variables) was fourth. The fourth was the most important due to being 8.521% of the total variance among all the variables.
- Although cost is often considered an important constraint on the development of prefabricated construction [1,44], the analysis results reveal that the industry chain is actually more significant.

Insufficient enterprise capacity, technology, integrated design capacity, integral decoration, gross contracts, information platforms, and managerial methods prevent the further development of prefabricated construction in China. Lack of experience and shortage of industry teams are also common. In addition, most construction enterprises are small medium enterprises with a discordant style. Generally speaking, the prefabricated construction industry chain of design, prefabrication, assembly, and operation is not integrated to its disadvantage.

- Risk, which is the final factor we assessed, is rarely mentioned in the literature since prefabricated construction is typically considered to reduce uncertainty in construction. However, it is risky in terms of the market and building quality. This may be a very useful direction for further research.
- The solutions for the constraints on the promotion of prefabricated construction in China are discussed, which need the joint efforts and collaboration of government and business. This study may be a foundation for a more detailed solution in further research.

China is in the initial stages of prefabricated construction. This situation is expected to change continually and the constraints will also change. There is a limitation to this research. The collection and analysis of all data is a reflection of the current state. Old constraints may be eliminated and new constraints are likely to emerge. A continuous tracking study is necessary. However, further research is necessary to identify solutions to these and other constraints through the quantification method. Case studies will also provide detailed and reliable analyses for future research.

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