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Identification of Critical Factors Influencing Prefabricated Construction Quality and Their Mutual Relationship

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Abstract: Prefabricated construction quality can not only influence the service life and function of buildings, but is also closely associated with the users' safety. Therefore, effective quality management is significant for the development of this type of construction method in this industry. The current research regarding quality management in the field of construction mainly focuses on on-site construction, while lacking extensive attention to prefabricated construction. Based on the existing literature and expert opinions from the construction firms, the government, and academia, this paper summarizes 23 critical factors that affect the quality management of prefabricated construction, adopts the interpretation structure model-matrix cross-reference multiplication applied to a classification (ISM-MICMAC) to analyze the hierarchical relationship between these factors, and further investigates the influence degree of the relationship by using the decision-making trial and evaluation laboratory (DEMATEL). The result shows that the government guidance is the most important influencing factor, and other factors, including integration in the supply chain, laws and regulations, codes and standards for prefabricated components, technology, and professional personnel, etc., also play a critical role in the quality management of prefabricated construction. These factors can affect the quality of raw materials for the production, manufacturing and transport equipment of prefabricated components through assembly and design schemes, ultimately resulting in an influence on the quality of prefabricated construction. The study aims to identify a mutual relationship between the critical factors affecting prefabricated construction quality, which can help managers to have a better understanding of the quality of prefabricated construction, and take effective measures to improve the status quo as well as promote the sustainable development of prefabricated construction.

Keywords: correlation analysis; DEMATEL; influencing factor; prefabricated construction; quality management

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1. Introduction

The construction industry plays an important role in the national economy, which not only provides the most basic material needs for social production and people's lives, but also promotes the development of urban economy and its modernization level [1]. Meanwhile, the booming construction industry has created a large number of job opportunities, which has an irreplaceable role in maintaining the regional economic growth [2]. Taking China as an example, by 2020, the total output value of the construction industry reached CNY 26.4 trillion, a 6.2% increase from 2019; the profit of construction enterprises was CNY 830.3 billion, growing by 0.3% [3]. Therefore, the construction industry has attracted extensive attention from academia and a diversity of research studies have been conducted, including industrial efficiency [4,5], energy consumption [6,7], construction optimization [8], automated construction [9], construction safety management [10,11], etc. However, these studies primarily focus on the traditional operation mode of the construction industry, and the on-site construction method adopted could trigger a series

of problems, such as resource waste, serious environmental pollution, a long construction period, and low energy efficiency [12]. To respond to the need of sustainable development, prefabricated construction is expected to become an alternative and dominating method for this industry in the near future. Basically, prefabricated construction transfers on-site construction works into a climate-controlled factory, where advanced machinery and manufacturing technologies can be utilized to produce prefabricated components in a standardized and efficient manner [13]. These components are required to be processed and produced following the standard design requirements, and then transported to the construction site for assembly and installment [14]. Overall, this prefabricated construction method can help to significantly save labor resources, reduce construction time, and mitigate environmental pollution, waste of water resources, and construction waste [15]. It can also reduce construction safety risks and expand economies of scale, thus reducing the overall cost [16]. Furthermore, the product of prefabricated construction, namely, prefabricated buildings [17], is treated as a new product of industrial reform and upgrading, which can help the construction industry to realize the mode transformation from high energy consumption and extensive management to intensive and highly efficient management [18].

Similarly to on-site construction, the project management of prefabricated construction also involves three primary goals to control, that is, quality, schedule, and cost. Obviously, quality management is essential in the process of implementing prefabricated construction. First, the quality could have a great impact on the daily operation of the prefabricated building itself. Once quality problems occur, extensive expenditure will be spent to address maintenance issues, and the service life of the building may even be shortened. Second, prefabricated buildings are closely related to users, which will not only make the user inconvenient, but also have a negative effect on the personal safety. Third, the frequent occurrence of quality problems will directly influence the market acceptance of prefabricated construction, further affecting the future development of this industry. Therefore, it is necessary to pay enough attention to the quality management of prefabricated construction to facilitate the rapid and stable development of prefabricated buildings in the future.

In terms of on-site construction, the production technology and quality management theories have been relatively mature, since the industry has accumulated rich practical experience, and the academia has also conducted extensive and in-depth research in this field, forming a series of relevant theories. Due to the lack of prefabrication and transportation of these components, the main focus of quality management in on-site construction is the pre-approval, construction control, and completion acceptance [19–21]. By contrast, quality management in prefabricated construction is more challenging because its construction process and technology are different, and there is a lack of sufficient practical experience to refer to. Considering the mismatch of construction characteristics and requirements between the two types of construction methods, it is easy to cause quality problems of prefabricated construction if the on-site quality management mode is directly applied in off-site construction projects. In addition, only several research studies have focused on exploring quality management in prefabricated construction, and a complete and mature theory of quality management in this area has not been formed, which, in turn, seriously restricts the implementation of prefabricated construction [22–24].

To address the above shortcomings, the objective of this study is to investigate the critical factors that affect the quality of prefabricated construction and analyze the mutual relationship between these factors. The findings of this study can put forward some suggestions for quality improvement that can be considered by the relevant practitioners in the construction industry, provide a reference for the policy making of quality management in prefabricated construction, and facilitate the sustainable development and promotion of prefabricated construction.

2. Analysis of Prefabricated Construction Quality and Its Influencing Factors

2.1. Characteristics of Quality Management of Prefabricated Construction

The quality of prefabricated construction can be divided into the following three parts: building entity quality, production process quality, and management system quality [25]. Building entity quality generally refers to the safety and stability of the main structure of the building, which means that the building will not collapse or leak after being put into service, and it is equipped with complete ancillary facilities with good performance to ensure the operation of prefabricated buildings in a safe and feasible manner. Production process quality mainly indicates that the building production process can ensure personal safety, rapid construction, energy conservation, environmental protection, and small impacts on the surrounding environment. Management system quality mainly refers to the service system for quality management in the whole life cycle of the prefabricated building, so that the problems in regard to quality at each stage can be solved efficiently or will be avoided by taking some measures in advance [26]. Therefore, it is essential to strictly control the quality of each part of prefabricated construction. In fact, the largest difference between prefabricated construction and on-site construction is that the former involves two important steps, that is, factory production and on-site assembly of prefabricated components. The factory production of components denotes a building that is split into many different types of components, according to design characteries, and then these components are manufactured in a factory before being transported to the construction site. On-site assembly indicates that workers on the construction site assemble these prefabricated components by means of lap joint and cast-in-place [27]. As such, this type of construction method needs to combine quality management in the production factory and the construction site, instead of solely controlling the on-site quality, which requires cooperative works and strengthens quality management at different working sites to ensure the overall quality of prefabricated construction.

Overall, prefabricated construction has the basic attributes of on-site construction, but also has unique characteristics. The on-site construction projects emphasize quality control in the construction process, which needs to meet the relevant regulation requirements, and satisfy the use purpose and demand of a specific building use. However, applying the on-site quality management methods in prefabricated construction may result in management inefficiency and incomplete identification of quality risk factors, and may even cause safety problems. Therefore, it is necessary and meaningful to conduct a study aiming at quality-related issues in prefabricated construction.

2.2. Factors Influencing Quality of Prefabricated Construction

Currently, some scholars have conducted some analyses on the factors that affect the quality of prefabricated construction, modular construction, or off-site construction, but these influencing factors are relatively scattered and not unified. The prefabricated construction process requires professional workers and management teams. Wuni and Shen [28] stated that prefabricated construction was better than on-site construction when the circumstances and conditions permitted, but it was important to grasp the key factors, including skilled and experienced factory workers, skilled management and supervision of the team, equipment, and transport infrastructure, etc. Hwang et al. [29], El-Abidi, and Ghazali [14] also emphasized the importance of labor force, the problem of labor shortage, and labor cost in the prefabricated construction process. Goodier and Gibb [30] claimed that two urgent problems existed that needed to be solved for off-site market development, that is, information transparency and the lack of professional personnel working in the factories. Furthermore, Abanda et al. [31] and Azam et al. [32] reported that the information technology in management was necessary to help information transmission.

The management of prefabricated components is another critical issue, since there are many challenges in the design and transportation of components. Ansari et al. [33] argued that prefabricated buildings may face challenges of transportation, limited design options, and poor transport facilities, in spite of many advantages. Haron [34] summa-

rized the barriers in the development of prefabricated construction and highlighted some prominent barriers, such as equipment use, lack of knowledge, as well as a lack of plans and regulations. Pan et al. [35] found that housebuilders believed that, in addition to the cost, an inability to determine the design of prefabricated components at the early stage, and a lack of experience and ability would affect their application and development of prefabricated construction technology. Koespiadi et al. [36] designed the prefabricated foundation according to the material properties, to satisfy the expected loads.

The development level of the construction industry also has a significant impact on prefabricated construction management, which is generally reflected in people's perception of this kind of construction method and its technology use. Lovell and Smith [37] suggested that perceptions and culture in the market influenced the development of prefabricated construction. Xu and Zhao [38] showed that the supply chain management and production process in prefabricated construction were different from the on-site ones, and the challenges needed to be taken into consideration in the future. Wuni and Shen [39] summarized the key success factors of modular integrated construction projects, including the equipment and production process, etc. Also, the design and transportation in prefabricated construction are different from on-site construction. Jaillon and Poon [40], and Mao et al. [41] found that the standard modular design was an important part of prefabricated construction, and various modular combinations can be used to construct architectural designs with different characteristics. Nick et al. [42] also pointed out that prefabricated components and raw materials needed to be transported to the site for forming prefabricated buildings.

By analyzing the construction process of prefabricated buildings, Azman et al. [43] highlighted the role of the government, construction technology, and industrial chain in this process in influencing the quality of prefabricated construction. Durdyev and Ismail [44] stressed that off-site manufacturing could indeed improve the production efficiency, but it also faced problems such as personnel shortage, unreasonable planning and methods, and an incomplete industrial chain. Li et al. [45], and Khalfan and Maqsood [46] also believed that the management methods, processes, and assembly plans would influence the management of prefabricated construction.

Many scholars pointed out that the laws and regulations were not comprehensive in the development of prefabricated construction. Navaratnam et al. [47] and Yunus [48] stated that the codes and standards should be regulated in the construction phase and in the factory where the prefabricated components are produced. Furthermore, Zhai et al. [49] mentioned that there was still a lack of relevant laws and regulations to manage the whole process of prefabricated construction.

Moreover, prefabricated construction management should focus on communication among stakeholders. Although the stakeholders of prefabricated construction are different from those of on-site construction, in the whole process, Xin Hu et al. [50,51] demonstrated that the communication and cooperation of participating stakeholders is still needed to achieve the goal of management in prefabricated construction. Jeong et al. [52] also emphasized the necessity of contract signing, and the management should pay attention to the contract part, as well as the distribution of responsibilities of all parties [53]. Tam et al. [54] found that many prefabricated design changes may cause a waste of resources, high cost, and may even affect quality. Lessing et al. [55] explained that the decisions were made upon accurate information and communication was the main principle of lean production.

The government is an indispensable part of prefabricated construction management. Kamar [56], and Rashidi and Ibrahim [57] reported that the guiding role of the government in key decisions should be made as early as possible, and should be understood by all the participants. Mohd et al. [58] and Mao et al. [59] both found that a lack of government incentives was the main barrier of prefabricated construction.

3. Methods

3.1. Research Framework

This study aims to identify the factors affecting the quality of prefabricated construction and determine the relationship between these factors. First, the influencing factor system of prefabricated construction quality is established. Second, expert opinions are collected and data analysis methods are adopted to analyze the factors affecting the quality of prefabricated construction. Currently, there are some methods that are widely used for investigating influencing factors, such as IPA (importance–performance analysis), AHP (analytic hierarchy process), and SEM (structural equation model). IPA and AHP are useful approaches for prioritizing influencing factors and further help decision makers formulate management priorities and allocate resources [60,61], but they fail to explore the relationship among these factors. SEM is an effective method to verify the hypotheses of all relationships between influencing factors that were put forward based on literature review, but it is not suitable for dealing with the correlation among many factors [62]. In fact, the research studies regarding quality management of prefabricated construction are still limited so the existing literature is insufficient to establish the hypotheses among these influencing factors. Considering the above shortcomings, this study will adopt an approach combining ISM-MICMAC (interpretive structural model-matrix cross-reference multiplication applied to a classification) with DEMATEL (decision-making trial and evaluation laboratory) to achieve the research objective. The detailed introduction for the two methods can be found in the following subsections. Specifically, the ISM-MICMAC method is used to analyze the hierarchical relationship among various influencing factors and the dependence power and driving power of these factors, while the DEMATEL method is used to investigate the prominence and relation of each factor. Finally, suggestions for improving quality management of prefabricated construction are put forward. The whole research framework in this study is shown in Figure 1.

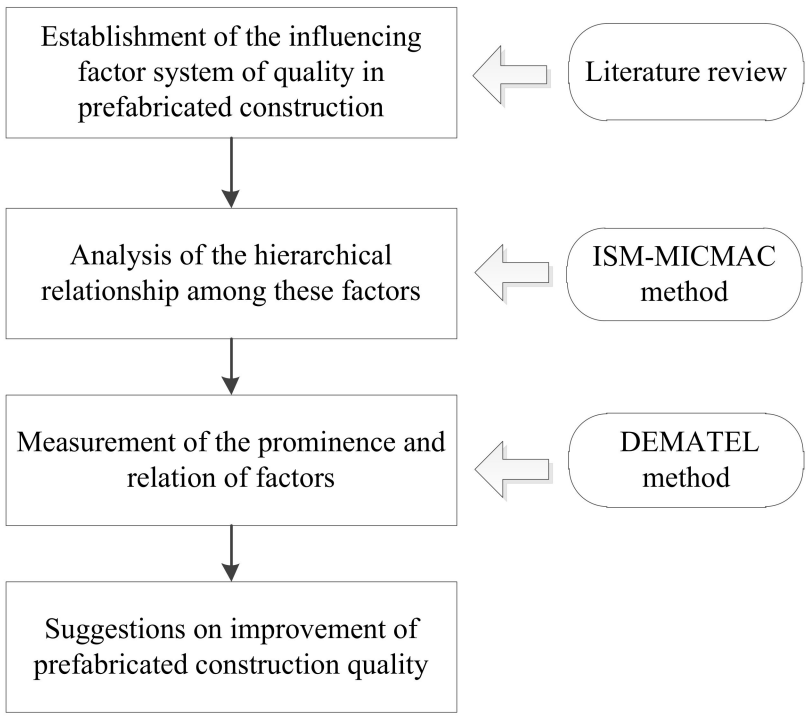


Figure 1. Research framework.

3.2. Influencing Factor System

To sum up, there are many factors affecting the quality of prefabricated construction, which can be summarized into the following five aspects: man, material, machine and equipment, method, and environment (4M1E) [63]. Based on characteristics analysis

of quality management of prefabricated construction and existing literature review in Section 2 and considering the frequency of factors occurring in the previous research, this study finally sorted out 23 critical factors influencing prefabricated construction quality according to the three primary processes (i.e., design, production, transportation and construction), as shown in Table 1.

Table 1. Critical factors affecting prefabricated construction quality.

Category	Factor
Man	Skilled management and supervising team (F1) Availability of experienced workforce (F2) Enough professional designers (F3) Adequate competency of construction workers (F4)
Material	Quality of raw production materials (F5)
Machine and equipment	Manufacturing equipment for producing assembled components (F6) Prefabricated construction equipment (F7) Transport equipment (F8)
Method	Experience in assembly design (F9) Prefabricated construction technology (F10) Information technology (F11) Unreasonable assembly strategies (F12)
Environment	Poor integration in the supply chain (F13) Complete quality management process (F14) Codes and standards for prefabricated components (F15) Stakeholder collaboration and coordination (F16) Efficient communication among professional designers (F17) Government guidance for prefabricated construction (F18) Changes in component design (F19) Standards for construction and acceptance (F20) Complete engineering feasibility study (F21) Reasonable project contracts (F22) Laws and regulations regarding quality management (F23)

Man factor. People who work in the construction industry are responsible for production and operation activities, as well as decision making, management, production, and construction of the whole construction project. Furthermore, the final quality of the construction project could be directly or indirectly influenced by some attributes of labor force, such as the knowledge levels, decision-making ability, organization ability, coordination ability, management levels, physical quality, practical ability, and professional quality [64]. Therefore, it is worthy of implementing enterprise qualification management and personnel certificates in the construction industry to ensure the quality of prefabricated construction. In this context, this paper considers whether there are enough professionals, as an indicator to measure the influence of labor force on prefabricated construction quality, including indicators F1–F4.

Material factor. Construction materials include all raw materials, components, and semi-finished products, which are the basis of construction engineering. In fact, whether to select construction materials reasonably, whether to formulate compliant inspection procedures, whether to store materials in place, and whether to use materials following the specifications will affect the appearance and perception of the building, influence the strength and stiffness of the building structure, and even cause building function and safety problems. Then, F5 is selected as the material factor affecting the quality of prefabricated construction.

Machine and equipment factor. In general, there are three categories of machine and equipment to be widely used in prefabricated construction, which are divided mainly according to the different purposes for dealing with prefabricated components, including production, transportation, and field installation. Whether to select machine and equipment

reasonably, whether the performance is stable, and whether the use complies with the regulations will affect the quality of the construction project. As such, the factors F6–F8 are selected to represent the machine and equipment that will influence prefabricated construction quality.

Method factor. Construction methods include technology, schemes, and operation during construction. Whether the construction technology is advanced, whether the construction scheme is reasonable, or whether the construction operation is correct will have a great impact on the quality of prefabricated construction. As such, the factors F9–F12 are selected to represent the methods that will influence prefabricated construction quality.

Environmental factor. Due to the characteristics of prefabricated components, prefabricated construction has less dependence on the natural environment and working environment than on-site construction, but it will be affected by other environmental factors. The social environment of prefabricated construction, which is formed by government guidance, the laws and regulations, relevant standards, and the integration of industrial chain, etc., has an impact on its quality. Furthermore, the project environment, formed by the quality management process, the feasibility study, contract management, and the communication between stakeholders, will also affect prefabricated construction quality. As such, the influencing factors from the perspective of environment include F13–F23.

3.3. ISM-MICMAC Method

ISM, as a structural model, can enable problems to be systematically analyzed at both macro and micro levels, which is widely used to qualitatively explore the structural relationships among complex elements in social systems [65]. A complex system is divided into several elements and the influencing routes of these elements are established based on experts' knowledge and experience by using some computer-aided tools. Then, a directed graph is constructed to form a multi-level structural model for these elements [66]; for instance, the ISM has been adopted to understand the mutual influences among the barriers to implementing green supply chain management [67] or building information modeling in prefabricated construction [68], and analyze the relationships among critical factors that affect the choice of prefabricated concrete buildings [69]. Based on the ISM, the ISM-MICMAC method proposed by Duperrin [70] uses the hierarchical circulation and reaction path of factors in the system to investigate the diffusion of the interaction between factors, and finally calculate the dependence power and driving power of these factors. Furthermore, the ISM-MICMAC method can transform fuzzy judgments and opinions into models with better structural relationships. Therefore, many research studies have applied this approach to analyzing the correlation of factors within a complex system in different fields [71,72]. In light of this, the present study will utilize the ISM-MICMAC method to explore the hierarchical relationships among various influencing factors of prefabricated construction quality.

Step 1. A structural self-interaction matrix (SSIM) is constructed based on different relationships between factors that influence quality of prefabricated construction (e.g., one-way influence, two-way influence, or no influence). To obtain the SSIM results, the experts invited should reach a consensus following the majority principle. In general, there are four symbols in the SSIM, that is, V, A, X, and O, where V means that factor i has a one-way influence on factor j; A means that factor j has a one-way influence on factor i; X means that factor i has a two-way influence on factor j; O means that no influence relationship exists between factors i and j.

Step 2. According to the SSIM, the reachability matrix is then established to display the hierarchical relationship between these influencing factors. When the system has n elements, the initial reachability matrix is n order. When F_i has an influence on F_j, then $a_{ij} = 1$; otherwise, $a_{ij} = 0$. As such, the final reachability matrix can be obtained by considering the transitivity of the relationship between these factors; for instance, if factor i

has an influence on factor j, and factor j has an influence on factor k, then it is deemed that factor i has a relationship with factor k.

Step 3. The reachability sets and the antecedent sets are obtained according to the final reachability matrix, based on which the intersection of the two types of sets is yielded. The reachability set represents the set of other influencing factors that one factor can affect, while the antecedent set represents the set of other influencing factors that will affect this factor. The factor with the same antecedent and intersection sets is at the highest level of the hierarchical model. Then, this factor will be removed, and the next round of factor determination is made until all factors of each level in the hierarchical model are identified. Based on this, the final directed graph of quality influencing factors in prefabricated construction is drawn based on the results of their hierarchy division.

Step 4. The MICMAC method is used to calculate the sum of row elements and the sum of column elements based on the results of the reachability matrix to obtain the driving power and dependence power of each factor, respectively. Then, the factors that affect the prefabricated construction quality are divided into four categories for the latter analysis based on their driving power and dependence power.

3.4. DEMATEL Method

The DEMATEL method is proposed to screen the primary factors in a complex system and simplify the process of a systematical structural analysis [73]. Aiming at the interrelated problems, the DEMATEL method can obtain the direct influence relationship between factors through group knowledge and opinions. This systematical analysis method is widely used to quantitatively investigate influence intensity information between factors and factor self-reliance information, and then identify the critical ones. Therefore, this study primarily uses the DEMATEL method to determine the influence degree and the importance degree of factors, and classify these factors into two groups (i.e., the cause group and the effect group). The procedure of executing the DEMATEL method is displayed as follows [73]:

Step 1. The expert scoring method is used to determine the influence degree of each factor based on the ISM results. The direct influence between these factors is divided into the following five levels: none, small, general, large, and very large (the corresponding score values are 0, 1, 2, 3, and 4, separately), based on which the matrix S is obtained. Since the influence of factors on itself is not considered, the diagonal element of this matrix is 0. Then, the matrix S is normalized by means of Equation (1):

$$X = S / \max_{1 \le i \le n} \sum_{j=1}^{n} s_{ij} = \left(x_{ij}\right)_{n \times n} \tag{1}$$

where X is the normalized matrix, x is the normalized value that describes that factor i directly affects factor j, and $0 \le x_{ij} \le 1$.

Step 2. The comprehensive influence matrix T is obtained according to the normalized matrix X:

$$T = X(I - X)^{-1} \tag{2}$$

where I is the identity matrix.

Step 3. Four indexes of each influencing factor are calculated according to the results of the composite influence matrix T:

$$r_i = \sum_{j=1}^{n} t_{ij}, (i = 1, 2, \ldots, 23) \tag{3}$$

$$c_i = \sum_{j=1}^{n} t_{ji}, (i = 1, 2, \ldots, 23) \tag{4}$$

where r_i indicates the extent to which factor i affects other factors and c_i is the extent to which factor i is affected by other factors.

In addition, the degree of relation between each factor with others affecting prefabricated construction quality is represented by $r + c$,which is defined as prominence; while $r - c$ represents the severity of influence, which is defined as relation. If the factor has a higher value of $r + c$, it means that it has more relationship with others, and if the factor has a higher value of $r - c$, it means that it has more influence on others. Then, the factor with the value of $r - c$ greater than zero is regarded as the cause factor; otherwise, the factor is treated as the effect factor.

4. Results and Discussion

4.1. Data Collection

The specific values of the influence relationships between these factors are all based on the opinions of experts when using the ISM-MICMAC method. In this study, 15 experts were invited from the government, prefabricated factories, the design institute, construction enterprise, and the university to discuss these factors, and they finally determined their SSIM and reachability matrix. All the experts have more than five years of relevant work experience. The detailed description of these experts can be observed in Table 2.

Table 2. Detailed description for experts.

Expert	Number	Percentage
Gender		
Male	10	67%
Female	5	33%
Age		
Below 30 years old	3	20%
31–40	6	40%
41 years old or above	6	40%
Education		
Bachelor	8	53%
Master	5	33%
Doctor	2	14%
Affiliation		
Design institute	3	20%
Production factory	3	20%
Government	3	20%
Construction enterprise	3	20%
University	3	20%

4.2. Relationship Analysis of Influencing Factors

4.2.1. Development of SSIM

The 23 critical influencing factors in Table 1 are not isolated, but relationships exists between each of them. Before constructing the explanatory structural model for these influencing factors, the SSIM is established upon experts' opinions, as shown in Table 3; For example, the relationship between F1 and F22 is denoted as V, indicating that F1 has an influence on F22, but F22 has no influence on F1. The relationship between F1 and F18 is shown as A, which means that F18 has an influence on F1, but F1 has no influence on F18.

4.2.2. Development of the Reachability Matrix

According to the results of SSIM, the final reachability matrix is established in Table 4. There are only "1" or "0" in the matrix, so if a column of the matrix consists of values that are all zero, this means that this factor is not affected by all the remaining factors. Similarly, if a row of the matrix consists of values that are all one, this factor is affected by the other factors.

Table 3. The results of SSIM.

	F23	**F22**	**F21**	**F20**	**F19**	**F18**	**F17**	**F16**	**F15**	**F14**	**F13**	**F12**	**F11**	**F10**	**F9**	**F8**	**F7**	**F6**	**F5**	**F4**	**F3**	**F2**	**F1**
F1	A	V	V	A	V	A	O	O	A	O	A	V	O	O	O	V	V	V	V	O	O	O	
F2	A	V	V	A	V	A	O	O	A	O	A	V	O	O	O	V	V	V	V	O	O		
F3	A	V	V	A	V	A	O	O	A	O	A	V	O	O	V	V	V	V	V	O			
F4	A	V	V	A	V	A	O	O	A	O	A	V	O	O	O	V	V	V	V				
F5	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	O	O	O					
F6	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	V	V						
F7	A	A	A	A	A	A	A	A	A	O	O	A	A	A	A	V							
F8	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A								
F9	A	V	V	A	V	A	A	A	A	A	A	V	A	A									
F10	A	V	V	A	V	A	O	O	A	O	A	V	O										
F11	A	V	V	A	V	A	V	V	A	O	A	V											
F12	A	A	A	A	V	A	A	A	A	A	A												
F13	O	V	V	O	V	A	V	V	O	V													
F14	O	O	O	O	V	A	V	V	O														
F15	X	V	V	X	V	A	O	O															
F16	O	O	O	O	V	A	X																
F17	O	O	O	O	V	A																	
F18	V	V	V	V	V																		
F19	A	A	A	A																			
F20	X	V	V																				
F21	A	V																					
F22	A																						
F23																							

V means that factor *i* has a one-way influence on factor *j*; A means that factor *j* has a one-way influence on factor *i*; X means that factor *i* has a two-way influence on factor *j*; O means that no influence relationship exists between factors *i* and *j*.

Table 4. The results of the reachability matrix.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**	**F19**	**F20**	**F21**	**F22**	**F23**
F1	1	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0
F2	0	1	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0
F3	0	0	1	0	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1	0
F4	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0
F5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F6	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1	0
F10	0	0	0	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	1	0	1	1	0
F11	0	0	0	0	1	1	1	1	1	0	1	1	0	0	0	1	1	0	1	0	1	1	0
F12	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
F13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	1	0
F14	0	0	0	0	1	1	1	1	1	0	0	1	0	1	0	1	1	0	1	0	1	1	0
F15	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1
F16	0	0	0	0	1	1	1	1	1	0	0	1	0	0	0	1	1	0	1	0	1	1	0
F17	0	0	0	0	1	1	1	1	1	0	0	1	0	0	0	1	1	0	1	0	1	1	0
F18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F19	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
F20	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1
F21	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0
F22	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0
F23	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1

4.2.3. Development of the Hierarchical Model

The reachability set and the antecedent set can be obtained on the basis of the reachability matrix in Table 4, and the intersection of the two sets of each factor can be generated. As such, the factors at each level are selected by the intersection, as shown in Table 5, where the lower-level factors cannot influence the higher-level factors. Finally, the directed graph of factors influencing prefabricated construction quality is displayed in Figure 2. From this figure, the hierarchical relationship among these factors can be analyzed.

Table 5. The hierarchical model for these influencing factors.

	Reachability Set	Antecedent Set	Intersection Set	Level
F1	F1, F5, F6, F7, F8, F12, F19, F21, F22	F1, F13, F15, F18, F20, F23	F1	4
F2	F2, F5, F6, F7, F8, F12, F19, F21, F22	F2, F13, F15, F18, F20, F23	F2	4
F3	F3, F5, F6, F7, F8, F9, F12, F19, F21, F22	F3, F13, F15, F18, F20, F23	F3	4
F4	F4, F5, F6, F8, F12, F19, F21, F22	F4, F13, F15, F18, F20, F23	F4	4
F5	F5	F1, F2, F3, F4, F5, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23	F5	1
F6	F6, F7, F8	F1, F2, F3, F4, F6, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23	F6	1
F7	F7, F8	F1, F2, F3, F4, F6, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23	F7	1
F8	F8	F1, F2, F3, F4, F6, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23	F8	1
F9	F5, F6, F7, F8, F9, F12, F19, F21, F22	F3, F9, F10, F11, F13, F14, F15, F16, F17, F18, F20, F23	F9	3
F10	F5, F6, F7, F8, F9, F10, F12, F19, F21, F22	F10, F13, F15, F18, F20	F10	4
F11	F5, F6, F7, F8, F9, F10, F11, F12, F16, F17, F19, F21, F22	F11, F13, F15, F18, F20	F11	4
F12	F5, F6, F7, F8, F12, F19	F1, F2, F3, F4, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F20, F21, F22, F23	F12	2
F13	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F16, F17, F19, F21, F22	F13, F18	F13	5
F14	F5, F6, F7, F8, F9, F12, F14, F16, F17, F19, F21, F22	F13, F14, F18	F14	4
F15	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F15, F16, F17, F19, F20, F21, F22, F23	F15, F18, F20, F23	F15	5
F16	F5, F6, F7, F8, F9, F12, F16, F17, F19, F21, F22	F11, F13, F14, F15, F16, F17, F18, F21, F23	F16, F17	3
F17	F5, F6, F7, F8, F9, F12, F16, F17, F19, F21, F22	F11, F13, F14, F15, F16, F17, F18, F21, F23	F16, F17	3
F18	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23	F18	F18	6
F19	F5, F6, F7, F8, F19	F1, F2, F3, F4, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, F23	F19	2
F20	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F15, F16, F17, F19, F20, F21, F22, F23	F1, F2, F3, F4, F15, F18, F20, F23	F20, F23	5
F21	F5, F6, F7, F8, F12, F19, F21, F22	F1, F2, F3, F4, F9, F10, F11, F13, F14, F15, F16, F17, F18, F20, F21, F23	F21	3
F22	F5, F6, F7, F8, F12, F19, F22	F1, F2, F3, F4, F9, F10, F11, F13, F14, F15, F16, F17, F18, F20, F21, F22, F23	F22	3
F23	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F15, F16, F17, F19, F20, F21, F22, F23	F15, F18, F20, F23	F20, F23	5

The first level includes F5 (quality of raw production materials), F6 (manufacturing equipment for producing assembled components), F7 (prefabricated construction equip-

ment), and F8 (transport equipment). These are the factors that most directly affect the quality of prefabricated construction.

The second level includes F12 (unreasonable assembly strategies) and F19 (changes in component design). Due to the unreasonable construction schemes and lack of effective guidance for quality management, the two factors will have a negative impact on the prefabricated construction quality.

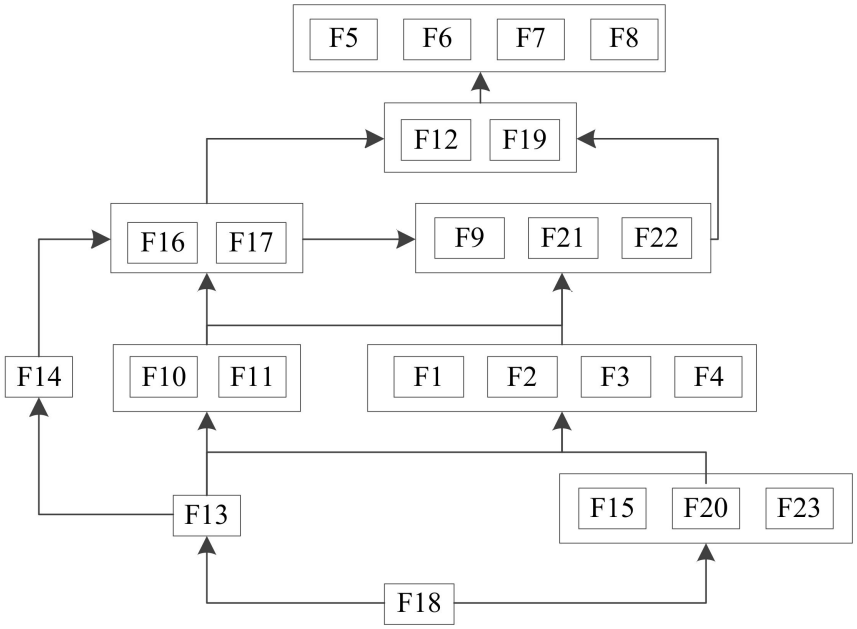


Figure 2. The directed graph of influencing factors.

The third level includes F9 (experience in assembly design), F16 (stakeholder collaboration and coordination), F17 (efficient communication among professional designers), F21 (complete engineering feasibility study), and F22 (reasonable project contracts). The quality management of prefabricated construction is a comprehensive and complex work, which requires the participation of multiple parties and effective communication between all parties to achieve full participation and cooperation, as well as the implementation of various quality regulations. Moreover, the contract is the premise of a given project, through which the quality of the construction project can be effectively controlled, the disputes regarding quality among the construction stakeholders can be reduced, and further quality objectives of the construction project will be completed more smoothly [74].

The fourth level includes F1 (skilled management and supervising team), F2 (availability of experienced workforce), F3 (enough professional designers), F4 (adequate competency of construction workers), F10 (prefabricated construction technology), F11 (information technology), and F14 (complete quality management process). This level of factors is mainly concerned with personnel, technology-related issues, and management regulations. Professionals are the foundation of development and provide backup force for prefabricated quality management. In addition, the development of technology, as well as the specific and standardized management regulations, can have a significant influence on the formulation of subsequent schemes.

The fifth level includes F13 (poor integration in the supply chain), F15 (codes and standards for prefabricated components), F20 (standards for construction and acceptance), and F23 (laws and regulations regarding quality management). It is necessary to strengthen production management, improve laws and regulations, and develop new technology for the industry. In this case, it is helpful to get rid of the quality dilemma encountered in the production of prefabricated components, and resolve the problems in construction, hence promoting the overall quality of prefabricated construction and facilitating the development of construction industrialization [75].

The final level includes F18 (government guidance for prefabricated construction), which affects all the other influencing factors. At present, the cost of prefabricated components is relatively high, but the quality cannot be guaranteed if the cost is reduced. Therefore, national policies directing prefabricated construction are very important for providing guidance for the development of the construction industry [76].

4.2.4. Classification of Influencing Factors

According to the results of driving power and dependence power using the MICMAC method, all the influencing factors are divided into four clusters, which are distributed in four different quadrants, as shown in Figure 3.

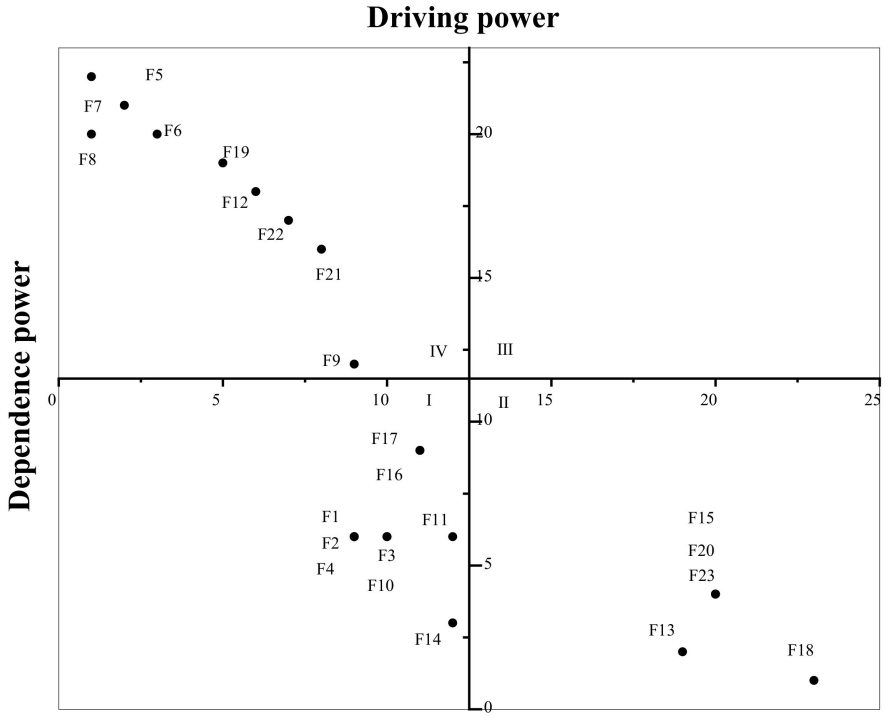


Figure 3. Clusters of factors affecting prefabricated construction quality.

Quadrant I. The influencing factors at the middle levels of the hierarchical model are mostly located in this quadrant, with a lower driving power and dependence power. Such factors play a role in quality management, as a link between the preceding and following factors. The factors in this quadrant include some man factors, such as F1 (skilled management and supervising team), F2 (availability of experienced workforce), F3 (enough professional designers), and F4 (adequate competency of construction workers); the method factors, such as F10 (prefabricated construction technology), and F11 (information technology); and the environment factors, such as F14 (complete quality management process), F16 (stakeholder collaboration and coordination), and F17 (efficient communication among professional designers).

Quadrant II. This quadrant includes the influencing factors at the bottom level of the hierarchical model, including F13 (poor integration in the supply chain), F15 (codes and standards for prefabricated components), F18 (government guidance for prefabricated construction), F20 (standards for construction and acceptance), and F23 (laws and regulations regarding quality management), which all belong to the environmental factors. These factors have a higher driving power and lower dependence power, which can be treated as the primary and basic factors affecting the quality of prefabricated construction, and factors that are less affected by other factors. To mitigate the quality issues, it is necessary to control the factors as much as possible. The government should pay attention to the guidance

of the policy, and promote perfection in the industrial chains, laws, and regulations, to improve the quality of prefabricated construction.

Quadrant III. As can be observed from Figure 3, there are no influencing factors in this quadrant. In other words, for the quality management of prefabricated construction, there are no factors with a strong driving power and dependence power. In this case, all the influencing factors have an impact on the final quality, primarily through mutual correlations.

Quadrant IV. The factors in this quadrant have a higher dependence power and lower driving power, which are easily affected by the changes in other factors. There are the following four categories of factors in this quadrant: the material factor, including F5 (quality of raw production materials); the machine and equipment factors, including F6 (manufacturing equipment for producing assembled components), F7 (prefabricated construction equipment), and F8 (transport equipment); the method factors, including F9 (experience in assembly design) and F12 (unreasonable assembly strategies); and the environment factors, including F19 (changes in component design), F21 (complete engineering feasibility study), and F22 (reasonable project contracts). Also, the changes in these factors in this quadrant can reflect whether other influencing factors are effectively controlled.

4.3. Analysis of the Influence Degree of Critical Factors

After the second-round scoring by the invited experts, the matrix S, describing the direct influence among these critical factors, is determined. After normalizing this matrix, the comprehensive influence matrix T is obtained, according to Equation (2). Finally, the influence degree of each factor can be calculated by means of Equation (3) (see the detailed results in Table 6). Treating $r + c$ and $r - c$ as horizontal and vertical coordinates, respectively, the cause–effect diagram is plotted in Figure 4.

Table 6. Influence degree of factors affecting prefabricated construction quality.

	r	c	$r + c$	$r - c$
F1	0.405	0.143	0.549	0.262
F2	0.405	0.143	0.549	0.262
F3	0.503	0.143	0.646	0.360
F4	0.405	0.143	0.549	0.262
F5	0.000	0.935	0.935	−0.935
F6	0.031	0.921	0.952	−0.891
F7	0.015	1.001	1.016	−0.986
F8	0.000	1.070	1.070	−1.070
F9	0.317	0.488	0.805	−0.171
F10	0.412	0.224	0.636	0.188
F11	0.521	0.209	0.730	0.312
F12	0.171	0.956	1.126	−0.785
F13	0.992	0.061	1.053	0.932
F14	0.428	0.110	0.537	0.318
F15	0.730	0.079	0.809	0.652
F16	0.329	0.355	0.684	−0.026
F17	0.312	0.355	0.667	−0.043
F18	1.407	0.000	1.407	1.407
F19	0.153	0.921	1.074	−0.768
F20	0.644	0.094	0.737	0.550
F21	0.292	0.522	0.815	−0.230
F22	0.259	0.569	0.828	−0.310
F23	0.802	0.094	0.896	0.709

According to the values of $r + c$, the influencing factors of prefabricated construction quality, with the five highest values, include F18 (government guidance for prefabricated construction), F12 (unreasonable assembly strategies), F19 (changes in component design), F8 (transport equipment), and F13 (poor integration in the supply chain); the corresponding values of which are 1.407, 1.126, 1.074, 1.070, and 1.053, respectively. Among all the factors,

these five factors have more of a relationship with other factors and are more prominent in the whole system. The five lowest factors are F1 (skilled management and supervising team), F2 (availability of experienced workforce), F4 (adequate competency of construction workers), F10 (prefabricated construction technology), and F14 (complete quality management process), with values of 0.636, 0.549, 0.549, 0.549, and 0.537, respectively. The relationship between these five factors and other factors is weak.

In terms of $r - c$, a value greater than zero refers to the cause factor, while a value less than zero refers to the effect factor. As can be observed from Figure 4, there are 12 factors with a positive degree, among which the top five factors are F18 (government guidance for prefabricated construction), F13 (poor integration in the supply chain), F23 (laws and regulations regarding quality management), F15 (codes and standards for prefabricated components), and F20 (standards for construction and acceptance), and the corresponding values are 1.278, 0.740, 0.419, 0.351, and 0.340, respectively. These positive factors are more likely to affect other factors. The remaining factors are equipped with a negative degree, among which F5 (quality of raw production materials), F6 (manufacturing equipment for producing assembled components), F7 (prefabricated construction equipment), F8 (transport equipment), F12 (unreasonable assembly strategies), and F19 (changes in component design) have values of $r - c$ that are below -0.5. These negative factors are largely influenced by other factors.

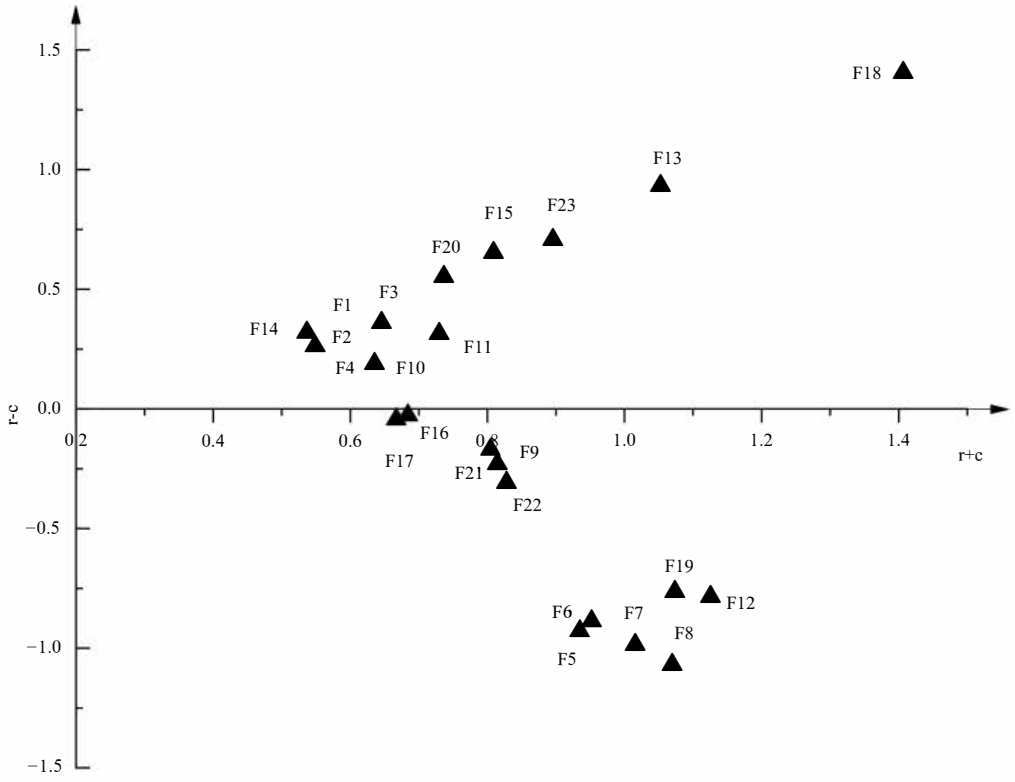


Figure 4. Cause–effect diagram of factors affecting prefabricated construction quality.

Among these factors, F18 (government guidance for prefabricated construction) has the highest values of $r + c$, $r - c$, and r, and the lowest value of c, indicating that this factor plays a significant role in the quality management of prefabricated construction, since it has a large influence on other factors, but is less affected by others. F13 (poor integration in the supply chain) ranks second in $r - c$ values, and also has a higher value of $r + c$. The $r + c$ and $r - c$ values of F15 (codes and standards for prefabricated components), F20 (standards for construction and acceptance), and F23 (laws and regulations regarding quality management) are also high. Furthermore, the results of the MICMAC analysis also show that the above five factors belong to quadrant II, with a strong driving power, but

weak dependence power. As such, the five factors, including F13, F15, F18, F20, and F23, are the most critical factors to be concerned in the quality management of prefabricated construction.

The $r - c$ values of the other factors are greater than zero, such as F1 (skilled management and supervising team), F2 (availability of experienced workforce), F3 (enough professional designers), F4 (adequate competency of construction workers), F10 (prefabricated construction technology), F11 (information technology), and F14 (complete quality management process). The above factors are all located in quadrant I in the MICMAC analysis, which indicates that these factors are relatively important and can have an influence on other factors. Although factors F16 (stakeholder collaboration and coordination) and F17 (efficient communication among professional designers) are also in quadrant I, the value of $r - c$ is less than zero and the r values of the two factors are small. From this point, it can be observed that the two factors belong to independent factors and do not have a notable impact on other factors.

Other factors with $r - c$ values that are less than zero, and that belong to quadrant IV in the MICMAC analysis, should also be paid attention to, including F5 (quality of raw production materials), F6 (manufacturing equipment for producing assembled components), F7 (prefabricated construction equipment), F8 (transport equipment), F9 (experience in assembly design), F12 (unreasonable assembly strategies), F19 (changes in component design), F21 (complete engineering feasibility study), and F22 (reasonable project contracts). Among them, F5, F6, F7, F8, F12, and F19 have a high $r + c$ value and low $r - c$ value, which means that they are closely related to other factors in the system, and are easily affected by other factors, so they have lower priority than other factors, such as F9, F21, and F22. It can also be observed that the prefabricated component is an important part of prefabricated buildings, and the above factors can affect the quality of raw materials, assembly schemes, and the manufacturing and transportation processes, further influencing the prefabricated construction quality. Furthermore, the results of ISM-MICMAC are consistent with those of DEMATEL, and they are complementary to each other. These findings can help the government and project managers to pay attention to the most important factors and make a reasonable decision on the quality management of prefabricated construction.

4.4. Policy Suggestions

First, great attention should be paid to the guiding role of the government, which is a very important factor, no matter whether it be in terms of the degree of influence or the relationship with other factors. The government should formulate and perfect the incentive strategy of prefabricated construction to promote the development of building industrialization [77].

Second, relevant standards and norms should be formulated according to the industrial situation. The government should improve policies and relevant laws and regulations, and enhance the industrial chain, so that quality management has specific rules to follow. The government should encourage the improvement of the industrial chain to lay a good environmental foundation for the quality management and development of prefabricated construction. In particular, the industrial chain needs to be improved due to its prominence in the overall quality management system.

Third, the government should attach importance to the development of technology and the cultivation of talents, and improve the corresponding quality management process, to provide a management basis [78]. The results of the study also show that F1, F2, F3, F4, F10, F11, and F14 belong to the cause group at the middle level of the directed graph. The control of these factors will be related to sufficient personnel and matching ability, and specific regulations for the implementation of quality management [45].

Fourth, the quality of prefabricated buildings should be ensured by the following codes, standards, and relevant plans. In the management process, the enterprise should have clear requirements to execute these regulations for quality inspection. The project

manager should pay attention to the communication with the participants, and try to achieve full participation and cooperation in the construction.

Finally, the details of the construction management of prefabricated construction should be strengthened to ensure quality. The components are an important part of the prefabricated building, and the factors related to the component directly affect the quality, such as production materials and transportation equipment.

5. Conclusions

Prefabricated construction is the development direction of the construction industry in the near future. This study investigates the critical factors influencing the quality management of prefabricated construction, and analyzes the mutual relationships among these factors. First, 23 influencing factors are identified based on a literature review, and the construction characteristics and requirements of prefabricated construction, which can be divided into the following five categories, are also identified: man, material, machine and equipment, method, and environment. To clarify the relationship between the factors, the ISM-MICMAC method is adopted to partition factors into six levels according to the relationship matrix (e.g., SSIM and the reachability matrix) given by 15 experts, and these factors are divided into four quadrants based on the driving power and dependence power of each factor. Then, the DEMATEL method is used to analyze the influencing degree of these critical factors based on the established relationship, which can help managers to grasp the importance degree of these factors more clearly, and their types (i.e., cause or effect factors). In summary, the mutual relationship between these factors affecting prefabricated construction quality is investigated in depth, which strengthens the theoretical basis of the influencing factor analysis by means of a combined approach, and extends the research studies regarding the quality management of prefabricated construction from qualitative analysis to relationship investigation in a quantitative manner. The research results of this study can also have practical guiding significance for the quality management of prefabricated construction, such as helping project managers to take effective measures and helping the government to formulate appropriate policies to guide its quality improvement, further promoting the sustainable development of the construction industry.

According to the research results, F18 (government guidance for prefabricated construction), with a strong driving power and low dependence power, is the most important influencing factor. Five factors, including F18, F12 (unreasonable assembly strategies), F19 (changes in component design), F8 (transport equipment), and F13 (poor integration in the supply chain), have a stronger relationship with other factors, and are more prominent in the whole system. F18, F13, F23 (laws and regulations regarding quality management), F15 (codes and standards for prefabricated components), and F20 (standards for construction and acceptance) are more likely to affect the other factors. F5 (quality of raw production materials), F6 (manufacturing equipment for producing assembled components), F7 (prefabricated construction equipment), F8, F9 (experience in assembly design), F12, F19, F21 (complete engineering feasibility study), and F22 (reasonable project contracts) have a low driving power and strong dependence power, and they are closely related to other factors in the system and are easily affected by other factors. In the management of prefabricated construction quality, paying attention to prominence factors with a high driving power, such as F18 and F13, can achieve better quality management results. By checking some factors that are easily affected by others with a high dependence power, such as F5, F6, F7, and F8, their effects on quality management can be quickly reflected. Among these influencing factors, the man and environment factors should be paid attention to, and efforts are required to mitigate their effects in the long term, to promote the sustainable development of prefabricated construction, while the quality affected by the remaining categories of factors could be improved in the short term.

There are still some limitations in this study. Although 23 critical factors influencing quality of prefabricated construction are analyzed, considering the whole process of prefabricated building (e.g., design, factory production, construction, etc.), the experts did not

participate in the selection of these factors, and how the five categories (4M1E) affected the quality was not investigated. In addition, due to the limitations of the methods used, the internal influencing mechanism of these factors is not completely clear. Future studies can consider identifying the factors affecting the quality of prefabricated construction at each stage, and analyze the effect between the categories (4M1E) and quality in depth. Also, the experts can be involved at the early stage to establish the influencing factor system in future studies, and, further, their internal influencing mechanism will be investigated to better reflect the quality issues of prefabricated structures.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: Authors declare no conflict of interest.

References

1. Wang, N. The role of the construction industry in China's sustainable urban development. *Habitat Int.* **2014**, *44*, 442–450. [CrossRef]
2. Sev, A. How can the construction industry contribute to sustainable development? A conceptual framework. *Sustain. Dev.* **2009**, *17*, 161–173. [CrossRef]
3. National Bureau of Statistics of the People's Republic China. *Statistical Yearbook 2021*; National Bureau of Statistics of the People's Republic China: Beijing, China, 2021.
4. Zhang, J.; Li, H.; Xia, B.; Skitmore, M. Impact of environment regulation on the efficiency of regional construction industry: A 3-stage Data Envelopment Analysis (DEA). *J. Clean. Prod.* **2018**, *200*, 770–780. [CrossRef]
5. Liu, B.; Wang, X.; Chen, Y.; Shen, Y. The energy efficiency of China's regional construction industry based on the three-stage DEA model and the DEA-DA model. *Ksce J. Civ. Eng.* **2016**, *20*, 34–47.
6. Xu, G.; Wang, W. China's energy consumption in construction and building sectors: An outlook to 2100. *Energy* **2020**, *195*, 117045. [CrossRef]
7. Biswas, W. Carbon footprint and embodied energy consumption assessment of building construction works in Western Australia. *Int. J. Sustain. Built Environ.* **2014**, *3*, 179–186. [CrossRef]
8. Daghouri, A.; Mansouri, K.; Qbadou, M. Information system performance evaluation and optimization using AHP and TOPSIS: Construction industry case. In Proceedings of the 4th International Conference on Optimization and Applications (ICOA), Mohammedia, Morocco, 26–27 April 2018; pp. 1–8.
9. Quinn, C.; Shabestari, A.Z.; Misic, T.; Gilani, S.; Mcarthur, J.J. Building automation system—BIM integration using a linked data structure. *Autom. Constr.* **2020**, *118*, 103257. [CrossRef]
10. Chen, T.; Cao, Z. Construction safety: An analysis of the cross-influence of economic, construction, and accident death factors. *Environ. Sci. Pollut. Res.* **2021**, *6*, 1–12.
11. Han, Y.; Jin, R.; Wood, H.; Yang, T. Investigation of demographic factors in construction employees' safety perceptions. *Ksce J. Civ. Eng.* **2019**, *23*, 2815–2828. [CrossRef]
12. Xue, H.; Zhang, S.; Su, Y.; Wu, Z. Factors affecting the capital cost of prefabrication-A case study of China. *Sustainability* **2017**, *9*, 1512. [CrossRef]
13. Yin, X.; Liu, H.; Chen, Y.; Al-Hussein, M. Building information modelling for off-site construction: Review and future directions. *Autom. Constr.* **2019**, *101*, 72–91. [CrossRef]
14. El-Abidi, K.M.A.; Ghazali, F.E.M. Motivations and Limitations of Prefabricated Building: An Overview. *Appl. Mech. Mater.* **2015**, *802*, 668–675. [CrossRef]
15. Liu, G.; Li, K.; Zhao, D.; Mao, C. Business model innovation and its drivers in the Chinese construction industry during the shift to modular prefabrication. *J. Manag. Eng.* **2017**, *33*, 04016051. [CrossRef]
16. Han, Y.; Wang, L. Identifying barriers to off-site construction using grey dematel approach: Case of China. *J. Civ. Eng. Manag.* **2018**, *24*, 364–377. [CrossRef]

17. Dineshkumar, N.; Kathirvel, P. Comparative study on prefabrication construction with cast in-situ construction of residential buildings. *IJISET—Int. J. Innov. Sci. Eng. Technol.* **2015**, *2*, 527–532.
18. Lu, W.; Chen, K.; Xue, F.; Pan, W. Searching for an optimal level of prefabrication in construction: An analytical framework. *J. Clean. Prod.* **2018**, *201*, 236–245. [CrossRef]
19. Pheng, L.S.; Teo, J.A. Implementing total quality management in construction firms. *J. Manag. Eng.* **2004**, *20*, 8–15. [CrossRef]
20. Ma, Z.; Cai, S.; Mao, N.; Yang, Q.; Feng, J.; Wang, P. Construction quality management based on a collaborative system using BIM and indoor positioning. *Autom. Constr.* **2018**, *92*, 35–45. [CrossRef]
21. Ahmed, S.M.; Aoieong, R.T.; Tang, S.L.; Zheng, D.X. A comparison of quality management systems in the construction industries of Hong Kong and the USA. *Int. J. Qual. Reliab. Manag.* **2005**, *22*, 149–161. [CrossRef]
22. Hong, J.; Shen, G.Q.; Li, Z.; Zhang, B.; Zhang, W. Barriers to promoting prefabricated construction in China: A cost-benefit analysis. *J. Clean. Prod.* **2018**, *172*, 649–660. [CrossRef]
23. Li, X.-J. Research on investment risk influence factors of prefabricated building projects. *J. Civ. Eng. Manag.* **2020**, *26*, 599–613. [CrossRef]
24. Arashpour, M.; Kamat, V.; Bai, Y.; Wakefield, R.; Abbasi, B. Optimization modeling of multi-skilled resources in prefabrication: Theorizing cost analysis of process integration in off-site construction. *Autom. Constr.* **2018**, *95*, 1–9. [CrossRef]
25. Yihua, M.; Tuo, X. Research of 4M1E's effect on engineering quality based on structural equation model. *Syst. Eng. Procedia* **2011**, *1*, 213–220. [CrossRef]
26. Hoonakker, P.; Carayon, P.; Loushine, T. Barriers and benefits of quality management in the construction industry: An empirical study. *Total Qual. Manag. Bus. Excell.* **2010**, *21*, 953–969. [CrossRef]
27. Chen, Y.; Okudan, G.E.; Riley, D.R. Decision support for construction method selection in concrete buildings: Prefabrication adoption and optimization. *Autom. Constr.* **2010**, *19*, 665–675. [CrossRef]
28. Wuni, I.Y.; Shen, G.Q. Towards a decision support for modular integrated construction: An integrative review of the primary decision-making actors. *Int. J. Constr. Manag.* **2019**, 1–20. [CrossRef]
29. Hwang, B.G.; Shan, M.; Looi, K.Y. Knowledge-based decision support system for prefabricated prefinished volumetric construction. *Autom. Constr.* **2018**, *94*, 168–178. [CrossRef]
30. Goodier, C.; Gibb, A. Future opportunities for offsite in the UK. *Constr. Manag. Econ.* **2007**, *25*, 585–595. [CrossRef]
31. Abanda, F.H.; Tah, J.H.M.; Cheung, F.K.T. BIM in off-site manufacturing for buildings. *J. Build. Eng.* **2017**, *14*, 89–102. [CrossRef]
32. Haron, N.A.; Abdul-Rahman, H.; Wang, C.; Wood, L.C. Quality function deployment modelling to enhance industrialised building system adoption in housing projects. *Total Qual. Manag. Bus. Excell.* **2015**, *26*, 703–718. [CrossRef]
33. Ansari, W.S.; Thaheem, M.J.; Khalfan, M. Use of offsite construction techniques in Pakistan. *Middle East J. Manag.* **2016**, *3*, 218–229. [CrossRef]
34. Haron, N.A.; Rahman, H.A.; Hanid, M. A literature review of the advances and barriers to the implementation of industrialised building system (IBS) in construction industry. *Malays. Constr. Res. J.* **2009**, *4*, 10–14.
35. Pan, W.; Gibb, A.F.; Dainty, A.R.J. Perspective of UK housebuilders on the use of offsite modern methods of construction. *Constr. Manag. Econ.* **2007**, *25*, 183–194. [CrossRef]
36. Koespiadi, K.; Mudjanarko, S.W.; Rasidi, N.; Utomo, W.M.; Alimudin, A.; Supriyatno, D.; Haksama, S.; Dimyati, L.M.F.; Madun, A.B.; Wiwoho, F.P.; et al. The concrete quality testing for trapezoidal model of the prefabricated foundation. *Int. J. Eng. Technol.* **2018**, *7*, 311–315.
37. Lovell, H.; Smith, S.J. Agencement in housing markets: The case of the UK construction industry. *Geoforum* **2010**, *41*, 457–468. [CrossRef]
38. Xu, X.; Zhao, Y. Some economic facts of the prefabricated housing. In *Industry Report*; Rutgers Business School: Newark, NJ, USA, 2010.
39. Wuni, I.Y.; Shen, G.Q. Critical success factors for modular integrated construction projects: A review. *Build. Res. Inf.* **2020**, *48*, 763–784. [CrossRef]
40. Jaillon, L.C.; Poon, C.S. The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector. *Autom. Constr.* **2009**, *18*, 239–248. [CrossRef]
41. Mao, C.; Xie, F.; Hou, L.; Wu, P.; Wang, J.; Wang, X. Cost analysis for sustainable off-site construction based on a multiple-case study in China. *Habitat Int.* **2016**, *57*, 215–222. [CrossRef]
42. Nick, B.; Ron, W. Drives, constraint and the future of offsite manufacture in Australia. *Constr. Innov. Spec. Ed.* **2007**, *9*, 72–83.
43. Azman, M.N.A.; Ahamad, M.S.S.; Husin, W.M.W. Comparative study on prefabrication construction process. *Int. Surv. Res. J.* **2012**, *2*, 45–58.
44. Durdyev, S.; Ismail, S. Offsite manufacturing in the construction industry for productivity improvement. *EMJ-Eng. Manag. J.* **2019**, *31*, 35–46. [CrossRef]
45. Li, Z.; Shen, G.Q.; Xue, X. Critical review of the research on the management of prefabricated construction. *Habitat Int.* **2014**, *43*, 240–249. [CrossRef]
46. Khalfan, M.M.A.; Maqsood, T. Corrigendum to "Current state of off-site manufacturing in Australian and Chinese residential construction". *J. Constr. Eng.* **2016**, *2016*, 1–5. [CrossRef]
47. Navaratnam, S.; Ngo, T.; Gunawardena, T.; Henderson, D. Performance review of prefabricated building systems and future research in Australia. *Buildings* **2019**, *9*, 38. [CrossRef]

48. Yunus, R.; Yang, J. Critical sustainability factors in industrialised building systems. *Constr. Innov.* **2012**, *12*, 447–463. [CrossRef]
49. Zhai, X.; Reed, R.; Mills, A. Factors impeding the offsite production of housing construction in China: An investigation of current practice. *Constr. Manag. Econ.* **2014**, *32*, 40–52. [CrossRef]
50. Hu, X.; Chong, H.-Y.; Wang, X. Sustainability perceptions of off-site manufacturing stakeholders in Australia. *J. Clean. Prod.* **2019**, *227*, 346–354. [CrossRef]
51. Hu, X.; Chong, H.-Y.; Wang, X.; London, K. Understanding stakeholders in off-site manufacturing: A literature review. *J. Constr. Eng. Manag.* **2019**, *145*, 03119003. [CrossRef]
52. Jeong, J.G.; Hastak, M.; Syal, M. Framework of manufacturer-retailer relationship in the manufactured housing construction. *Constr. Innov.* **2009**, *9*, 22–41. [CrossRef]
53. Wuni, I.Y.; Shen, G.Q.; SAR, H.K. Key success factors for implementing modular integrated construction projects: A literature mining approach. In Proceedings of the 8th International Conference on Construction Engineering and Project Management, Hong Kong, China, 7–8 December 2020; pp. 343–352.
54. Tam, V.W.Y.; Tam, C.M.; Zeng, S.X.; Ng, W.C.Y. Towards adoption of prefabrication in construction. *Build. Environ.* **2007**, *42*, 3642–3654. [CrossRef]
55. Lessing, J.; Stehn, L.; Ekholm, A. Industrialised housing: Definition and categorization of the concept. In Proceedings of the 13th Conference of the International Group for Lean Construction, Sydney, NSW, Australia, 18–21 July 2005; pp. 471–480.
56. Kamar, K.A.M.; Hamid, Z.A.; Alshawi, M. The critical success factors (CSFs) to the implementation of industrialised building system (IBS) in Malaysia. In Proceedings of the 18th CIB World Building Congress, TG57-Industrialization in Construction, Salford, UK, 10–13 May 2010; pp. 64–76.
57. Rashidi, A.; Ibrahim, R. Industrialized construction chronology: The disputes and success factors for a resilient construction industry in Malaysia. *Open Constr. Build. Technol. J.* **2017**, *11*, 286–300. [CrossRef]
58. Nawi, M.M.; Lee, A.; Nor, K.M. Barriers to implementation of the Industrialised Building System (IBS) in Malaysia. *Built Hum. Environ. Rev.* **2011**, *4*, 22–35.
59. Mao, C.; Shen, Q.; Pan, W.; Ye, K. Major barriers to off-site construction: The developer's perspective in China. *J. Manag. Eng.* **2015**, *31*, 04014043. [CrossRef]
60. Xie, L.; Chen, Y.; Xia, B.; Hua, C. Importance-performance analysis of prefabricated building sustainability: A case study of guangzhou. *Adv. Civ. Eng.* **2020**, *2020*, 8839118. [CrossRef]
61. Sevkli, M.; Koh, S.C.L.; Zaim, S.; Demirbag, M.; Tatoglu, E. An application of data envelopment analytic hierarchy process for supplier selection: A case study of BEKO in Turkey. *Int. J. Prod. Res.* **2007**, *45*, 1973–2003. [CrossRef]
62. Ng, S.T.; Wong, Y.M.W.; Wong, J.M.W. A structural equation model of feasibility evaluation and project success for public—Private partnerships in Hong Kong. *IEEE Trans. Eng. Manag.* **2010**, *57*, 310–322. [CrossRef]
63. Zhou, H.; Zhao, Y.; Shen, Q.; Yang, L.; Cai, H. Risk assessment and management via multi-source information fusion for undersea tunnel construction. *Autom. Constr.* **2020**, *111*, 103050. [CrossRef]
64. Lee, T.S.; Kim, D.H.; Lee, D.W. A competency model for project construction team and project control team. *Ksce J. Civ. Eng.* **2011**, *15*, 781–792. [CrossRef]
65. Warfield, J.N. Binary matrices in system modeling. *IEEE Trans. Syst. Man Cybern.* **1973**, *3*, 441–449. [CrossRef]
66. Attri, R.; Dev, N.; Sharma, V. Interpretive structural modelling (ISM) approach: An overview. *Res. J. Manag. Sci.* **2013**, *2319*, 1171.
67. Mathiyazhagan, K.; Govindan, K.; NoorulHaq, A.; Geng, Y. An ISM approach for the barrier analysis in implementing green supply chain management. *J. Clean. Prod.* **2013**, *47*, 283–297. [CrossRef]
68. Tan, T.; Chen, K.; Xue, F.; Lu, W. Barriers to building information modeling (BIM) implementation in China's prefabricated construction: An interpretive structural modeling (ISM) approach. *J. Clean.* **2019**, *219*, 949–959. [CrossRef]
69. Li, D.; Li, X.; Feng, H.; Wang, Y.; Fan, S. ISM-based relationship among critical factors that affect the choice of prefabricated concrete buildings in China. *Int. J. Constr. Manag.* **2019**, 1–16. [CrossRef]
70. Duperrin, J.C.; Godet, M. *Méthode de Hiérarchisation des Eléments d'un Système*; Rapport Economique du CEA: Paris, France, 1973.
71. Chander, M.; Jain, S.K.; Shankar, R. Modeling of information security management parameters in Indian organizations using ISM and MICMAC approach. *J. Model. Manag.* **2013**, *8*, 171–189. [CrossRef]
72. Bux, H.; Zhang, Z.; Ahmad, N. Promoting sustainability through corporate social responsibility implementation in the manufacturing industry: An empirical analysis of barriers using the ISM-MICMAC approach. *Corp. Soc. Responsib. Environ. Manag.* **2020**, *27*, 1729–1748. [CrossRef]
73. Si, S.-L.; You, X.-Y.; Liu, H.-C.; Zhang, P. DEMATEL Technique: A systematic review of the state-of-the-art literature on methodologies and applications. *Math. Probl. Eng.* **2018**, *2018*, 3696457. [CrossRef]
74. Bataglin, F.S.; Viana, D.D.; Formoso, C.T.; Bulhões, I.R. Model for planning and controlling the delivery and assembly of engineer-to-order prefabricated building systems: Exploring synergies between Lean and BIM 1. *Can. J. Civ. Eng.* **2020**, *47*, 165–177. [CrossRef]
75. Liu, Y.; Dong, J.; Shen, L. A conceptual development framework for prefabricated construction supply chain management: An integrated overview. *Sustainability* **2020**, *12*, 1878. [CrossRef]
76. Jing, S.; Zhang, Z.; Yan, J. Government supervision mode selection in the promotion period of prefabricated construction using evolutionary game. *Math. Probl. Eng.* **2020**, *2020*, 1–11. [CrossRef]

77. Cheng, B.; Wei, Y.; Zhang, W.; Zhou, X.; Chen, H.; Huang, L.; Huang, J.; Kang, X. Evolutionary game simulation on government incentive strategies of prefabricated construction: A system dynamics approach. *Complexity* **2020**, *2020*, 8861146. [CrossRef]
78. Zhao, L.; Liu, Z.; Mbachu, J. Development of intelligent prefabs using iot technology to improve the performance of prefabricated construction projects. *Sensors* **2019**, *19*, 4131. [CrossRef] [PubMed]