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Exploring the Impact Mechanism of Interface Management Performance of Sustainable Prefabricated Construction: The Perspective of Stakeholder Engagement

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Abstract: Prefabricated construction (PC) activities are geographically fragmented, temporally disrupted, resulting in numerous and complex interfaces. It is stakeholder collaboration by integrating diverse resources within the PC industry to potentially address the factors that impact interface management performance. Previous studies have explored the impact factors of interface management performance without deeply considering the stakeholder and their linkages with the impact factors of interface management. Therefore, this study used a two-mode social network to investigate the impact of the interface management performance of sustainable PC from a stakeholder perspective. Firstly, 24 factors impact interface management of sustainable PC, as well as 12 stakeholders with power to address the factors, were identified based on a literature review and interviews with experts. Subsequently, Stakeholder-factors relationships were judged by a designed questionnaire. Then, the centrality and core-periphery structure analysis methods were adopted to study the network. The findings revealed that developers, general contractors, subcontractors, designers, and suppliers are the core stakeholders, with improved collaboration between these five stakeholders (42%) able to address 18 core factors (75%). The factors that have the most significant impact on the interface management performance of prefabricated construction include understanding and trust, communication and learning, and cooperative attitudes among participants, the effectiveness and timeliness of information communication, formal interface management processes, technical innovation, and the perfection of standards and specifications. By prioritizing these factors, the complexity of the network can be successfully decreased and interface management performance can be improved. This study not only contributes to identifying the impact mechanism of stakeholders on the factors of interface management performance, but also contributes to promoting stakeholder cooperation to improve the sustainability of prefabricated construction.

Keywords: prefabricated construction; sustainable development; interface management; stakeholder; two-mode social network

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1. Introduction

In the construction industry, some drawbacks of traditional construction methods are accumulated and are difficult to improve. The lack of flexibility and adaptability of traditional construction methods can lead to a short service life of buildings, the demolition of which will lead to considerable consumption of resources and energy, and the generation of waste [1,2]. On the other hand, traditional construction methods have a negative influence on the natural environment, producing a large amount of greenhouse gases and polluting gases, as well as dust pollution and noise pollution [3]. At the same time, it should also be noted that the on-site environmental conditions of traditional construction methods are harsh, which may easily lead to frequent accidents [4]. Therefore, it is critical to innovate construction technology to improve the above problems. Prefabricated construction (PC) refers to a modern construction method that is manufactured in a factory and then transported to the construction site for assembly [5]. Compared with traditional construction methods, PC moves the production site to a factory with a controlled environment and adopts a mechanized and standard assembly line production method, which facilitates the mass production and automation of components [6,7]. Because of this, prefabricated construction has some advantages over traditional construction methods, including shorter construction times, less labor, less material waste, increased site safety, increased production efficiency, standardized production processes, reduced energy use, and lower emissions [8,9]. These advantages are in line with the concept of sustainable development of the construction industry, which has attracted many countries to adopt PC to promote the sustainable development of the construction industry.

However, PC has highly decentralized and fragmented attributes, with dispersed workplaces, fragmented construction processes, numerous stakeholders, a wide range of information crossover, and a high degree of specialization, when compared to traditional construction [10–13]. This brings a higher level of complexity to the construction process. Specifically, interfaces exist when projects are discontinuous in time, space, technology, or organization, resulting in breakpoints between construction activities [14]. Consequently, the complexity of interface management (IM) increases due to large and various of construction activities and the multiple stakeholders involved [15–17]. To meet the continuity and integration requirements of PC and ensure the smooth delivery of prefabricated components, it is necessary to ensure a "seamless" interface between fragmented processes and stakeholders.

In the construction sector, the term "interface" refers to "the common boundary between independent but interacting systems, organizations, project phases, and construction components" [18]. Compared with traditional construction projects, PC projects created more intricate and diverse interfaces between stakeholders, processes, and products that are geographically and temporally independent yet logically interrelated. These interfaces can put projects at risk if they are not adequately managed, including but not limited to design mistakes, component failures, schedule delays, rework, etc. [17,19,20]. The presence of these issues has a substantial impact on the IM performance of PC. Therefore, it is critical to handle PC interface problems to improve these issues and enhance the successful of PC.

Previous studies mainly focused the IM challenges from certain perspective, such as design interface management [21–24], construction interface management [16,25–27], and BIM-based interface management [26,28]. However, research on the factors influencing the IM performance of PC is lacking, and few studies take into account interface management issues comprehensively. Furthermore, it is crucial to note that stakeholders undertake all production and construction tasks in PC projects and have the power to directly or indirectly affect IM [29]. In other words, stakeholders can improve and address the IM influence factors of PC to increase its performance. However, the impact mechanism between stakeholders and the IM factors of PC, and the collaborative relationship between stakeholders, are not clear.

To address the aforementioned issues, it is necessary to identify the PC stakeholders and influence factors of PC interface management. According to [30,31], a two-mode social network analysis was used to explore the relationship between stakeholders and factors. The remainder of this study is organized as follows: Section 2 provides an overview of the interface management, PC stakeholders, and social network analysis methods; Section 3 details the methodology and process used in this study; and Section 4 analyzes the results obtained from the two-mode social network and discusses them in Section 5. Finally, Section 6 summarizes the main findings, implications, and limitations of this study.

2. Literature Review

2.1. Interface Management in the Construction Industry

In the construction industry, the amount of literature on IM is relatively small, and the understanding of IM is limited. As defined by Verma (1995), IM in construction projects is the management of communication, coordination, and responsibility for a common boundary between two interdependent organizations, phases, or entities. Additionally, IM happens outside of the project team, across members, departments, and disciplines [32]. Therefore, interfaces in the construction industry involve multiple types, including but not limited to organizational interfaces, system interfaces, temporal interfaces, geographic interfaces, and technical interfaces [33,34]. As the complexity of the project grows, the number of interfaces that must be handled grows exponentially, and managing them gets more and more challenging [35]. Information technologies, such as BIM (building information modeling) and IoT (internet of things), are utilized for IM during the construction process to better manage the interfaces in the construction industry [26,28]. Zhang et al. developed an interface management performance assessment framework for sustainable prefabricated construction that takes into account physical, informational, relational, and logistic interfaces [36]. Refs. [29,37,38] all highlight the significance of stakeholders to IM, contending that formal governance and social norms have a favorable influence on individual behavioral attitudes and that promoting trust, communication, and cooperation among stakeholders significantly enhances the performance of IM. Design structure matrix (DSM), multilevel interface matrix, and work breakdown structure (WBS) matrix are also used to optimize the process of IM [22,24,27,39]. Additionally, it is important to comprehend the root causes and influence factors of interface issues before implementing effective IM in construction projects. For instance, Shar'ar et al. explored the reasons for design–construction interaction issues in large building construction projects [40]. Weshan et al. identified 10 interface issues that affect IM performance and 6 influence factors of IM that affect construction project performance, and then examined the linkages between the issues and factors [41]. From six interconnected perspectives—people/participants, methods/processes, resources, documentation, project management, and environment—Chen et al. examined the reasons for interface issues [42]. Furthermore, Zhang et al. identified 27 crucial factors influencing PC interface management performance [43]. It can be seen that there is still a lack of understanding of how stakeholders deal with factors that affect the IM performance of sustainable PC.

2.2. Stakeholders in Prefabricated Construction

PC projects are made up of a series of distinct but interdependent activities carried out by professional organizations, which create several interfaces in time and space [34]. At the same time, the success of PC projects requires communication and cooperation among all stakeholders (e.g., developers, contractors, designers, etc.) [19,29]. To facilitate communication and cooperation among the stakeholders, it is essential to identify the PC stakeholders, and explain how they impact the factors of IM performance. At present, there is a large body of studies that have examined the stakeholders in PC. This study summarizes the stakeholders involved in these studies and the results are shown in Table 1.

Table 1. Stakeholders in prefabricated construction.

Reference	Study Theme	Quantity	Stakeholders
[13]	Stakeholder relationships in the industry chain of industrialized building	13	Developers, Designers, Users, Capital providers, Research institutions, Contractors, Module suppliers, Material and Equipment suppliers, Supervisors, Sales agent, Facility managers, Surveyors, Waste management organizations
[30]	Overcoming barriers to off-site construction through engaging stakeholders	15	Government, Developers, Designers, Contractors, Professional subcontractors, Supervisors, Manufacturers, Researchers, Education institutions, Consultants, Suppliers of equipment and materials, Financial institutions, the Public, Logistic enterprises, the Media.

Table 1. *Cont.*

Reference	Study Theme	Quantity	Stakeholders
[44]	Stakeholders in prefabricated construction supply chain	7	Client, Designer, Main contractor, Manufacturer, Transporter, Assembly subcontractor, and Government
[45]	Stakeholders in prefabricated housing supply chain	15	developer, General contractor, Subcontractors, Local government, Architect, Surveyor, Consultants, Supervision company, Components suppliers, Materials suppliers, Logistic company, Financial institution, Residents (End users/Occupiers), Sales agent, Property management company
[46]	Stakeholders in building energy performance	12	Owner, Designer, Contractor, Subcontractor, Supervision, Manufacturer, Commissioning agent, Energy manager, Occupant, Policymakers and government agencies, Media, Researcher
[47]	Stakeholders in prefabrication housing production	7	Client, Designer, Main contractor, Manufacturer, Transporter, Assembly subcontractor, and Government
[48]	Understanding stakeholders in off-site manufacturing	8	manufacturers, Suppliers, Owners, Designers, Contractors, Clients, Governments, and the Public
[49]	Stakeholders in sustainable construction	7	Government organization, Owners, Designers, Contractors, End users, Nongovernmental organizations, other relevant groups (e.g., material/technology providers)
[50]	Influence of different stakeholders on quality defects of off-site construction projects	6	Developer, Designer, PC manufacturer, Transportation company, Contractor, and Engineering supervisor
[51]	Sustainability in construction through stakeholder engagement	22	Sustainability Consultant, Contractor, Employee, Client, Engineers, Trade subcontractor, Archaeologist, Development manager, Local government, Design coordinator, Regulatory agency, Managing director, Technical director, Conservationist, Environmentalist, Project manager, Area manager, Material supplier, Subcontractor, Architect and Quantity surveyor, and other specialist consultants
[52]	Stakeholders in modular integrated construction	12	Designers, Engineers, Architects, Manufacturers, Suppliers, Logistics companies, Developers, Clients, Contractors, Project managers, Academics, and Local government

2.3. Social Network Analysis

Social network analysis (SNA) is the main technique used to evaluate project performance in complex collaborative systems. It can not only determine the network structure by identifying the connections and elements involved, but also analyze the network by finding the importance of the relationships between the elements and the attributes of the nodes [53,54]. SNA has been utilized extensively in the construction industry, including but not limited to supply chain management [44,45], sustainable construction [46,54], and off-site construction management [30,47,55]. Social networks are generally divided into two types: one-mode social networks and two-mode social networks, depending on the number of node types that make up the network. One-mode social networks can only analyze the relationships between homogeneous nodes, while two-mode social networks are able to study the connections between two sets of heterogeneous nodes with different attributes, and these connections can only exist between distinct sets [30]. Two-mode social networks have been used in the construction industry to study the relationship between stakeholders and off-site construction obstacles [30], stakeholders' power over social responsibility issues [31], and stakeholders' power over the impact issues of building energy performance gaps [46].

3. Methodology

The purpose of this study is to illustrate the impact mechanism of stakeholders on IM performance factors of sustainable PC by establishing the network between stakeholders and factors. To achieve this, this study followed three steps: (1) identifying PC-related stakeholders and influence factors of IM performance through a literature review and semi-structured interviews; (2) ascertaining the association between stakeholders and factors through semi-structured interviews; and (3) visualizing and analyzing the two-mode social network of stakeholder-factors. The detailed flow of this study is depicted in Figure 1.

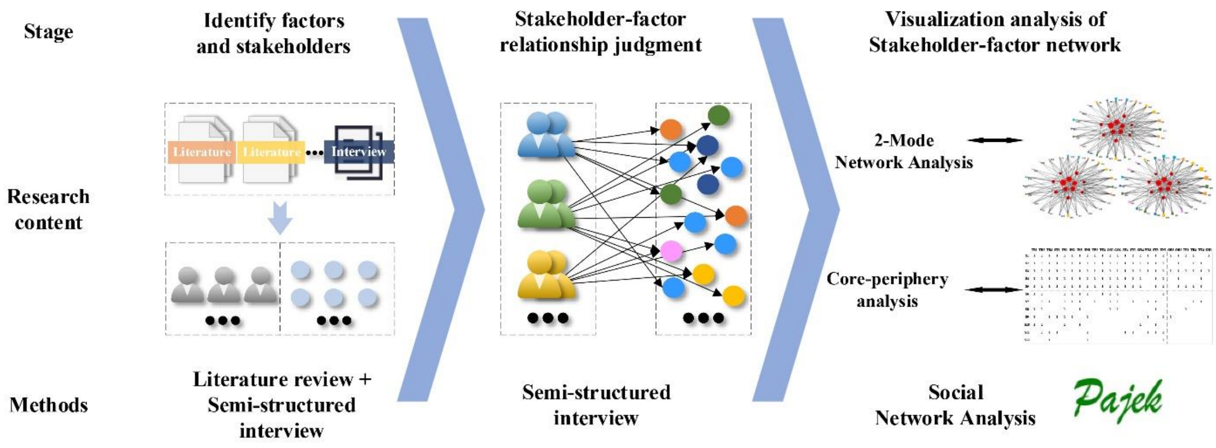


Figure 1. Research Framework.

In the first stage, Zhang et al. identified 27 critical factors affecting the IM performance of sustainable PC through a literature review, questionnaires, and face-to-face interviews in their previous work [43]. Meanwhile, using factor analysis, the 27 factors were further divided into seven categories: trust and cooperation (TR), information communication (IN), technical and managerial ability (TE), organizational integration (OR), standardization (ST), technical environment (EN), and contract management (CO). On this basis, exploratory factor analysis and confirmatory factor analysis were examined to test the structure of seven dimensions composed of 27 factors, of which three factors that did not meet the test requirements were deleted. Therefore, the remaining 24 factors were used as the influence factors of IM performance in this study, and the specific list of factors is shown in Table 2.

Table 2. Influence factors of interface management performance in sustainable PC.

Dimension	Code	Factors
Trust and cooperation	TR1	Cooperative attitude of the participants
	TR2	Understanding and trust of the participants
	TR3	Communication and learning of the participants
	TR4	Degree of participant involvement in design
Information communication	IN1	Effectiveness of information communication
	IN2	Integrity and Accuracy of Information
	IN3	Timeliness of information communication
Technical and managerial ability	TE1	Timeliness of production and supply of prefabricated components
	TE2	Accuracy of design
	TE3	Project management experience and ability
	TE4	Reasonableness of production and construction scheme
Organizational integration	OR1	Organizational structure
	OR2	Professional differences between organizations
	OR3	Project contracting mode
	OR4	Alignment of stakeholders' goals

Table 2. *Cont.*

Dimension	Code	Factors
Standardization	ST1	Standardization of information
	ST2	Standardization of production and construction processes
	ST3	Formal interface management process
	ST4	Complexity of the connection interface between components
Technical environment	EN1	Technical innovation
	EN2	Perfection of standards and specifications
	EN3	Industry design standardization
Contract management	CO1	Reasonableness of work content and scoping
	CO2	Rationality of the definition of responsibilities, powers and interests

Furthermore, to reasonably identify the stakeholders in PC projects, this study reviewed the relevant literature involving the stakeholder research of PC to identify a preliminary list of stakeholders, which is shown in Table 1. Building upon this, the stakeholders initially identified in this study include developers, designers, general contractors, subcontractors, manufacturers, suppliers, consultants, logistics, government, supervisions, industry associations, media and other social groups, research units, and users. Then, a pilot study based on semi-structured interviews was conducted to further determine the relevance and reliability of the aforementioned stakeholders. In the pilot study, 12 experienced experts discussed and analyzed each of the 14 identified stakeholder groups to confirm the final list of PC-related stakeholders. The specific information of these 12 experts is shown in Table 3. The interviews revealed that while research units can support some industry-academia-research collaboration in PC projects with technical and decision-making support, they are rarely involved in engineering practice. Consequently, it was decided to remove the research units. Additionally, although users are regarded as important stakeholders in much of the literature, in reality they have not been able to participate substantially in the construction process. Therefore, users are excluded from the final stakeholders of PC. In summary, developers (S1), designers (S2), general contractors (S3), subcontractors (S4), manufacturers (S5), suppliers (S6), government (S7), consultants (S8), supervisors (S9), logistics (S10), industry associations (S11), media, and other social groups (S12) are identified as the final stakeholder groups in PC.

Table 3. Profiles of respondents.

Categories	Respondent Types	Number of Respondents	Percentage (%)
Occupation type	Developers	3	25%
	Designers	1	8.3%
	Manufacturers	1	8.3%
	Contractors	2	16.7%
	Consultants	2	16.7%
	Research units	3	25%
Educational background	Ph.D.	3	25%
	Master's degree	2	16.7%
	Undergraduate or below	7	58.3%
Years of experience in PC	>10	1	8.3%
	6~10	5	41.7%
	3~5	4	33.3%
	< 3	2	16.7%

In the second stage, semi-structured interviews were used to gather data. It is the interviews conducted with individuals who have extensive expertise and experience that can better cover knowledge gaps in complex research issues [56]. On the other hand, the interviews are flexible, which allows in-depth analysis and discussion between the researcher and the respondents to provide new information [57]. For example, Ref. [46] identified stakeholders and factors related to building energy consumption and the relationships between them through semi-structured interviews. Due to the lack of prior experience [58], conducted 19 semi-structured interviews with customers and suppliers involved in the modern technology adoption process to fully understand the respondents' descriptions of the technology adoption process. To ascertain the relationship between the 12 stakeholders and the 24 factors, the 12 experts from Table 3 are once more invited to take part in the interviews. These experts are asked to assess whether the 12 stakeholders have influence over each of the 24 factors during the interviews. The score is 1 if there is an impact. Otherwise, the result is 0. Table 3 shows that respondents included stakeholders from many fields, with 83.3 percent of them having experience of three years or more. As a result, the data of this study are valid and representative.

In the third stage, the stakeholder-factor adjacency matrix created in the first and second stages was loaded into Pajek software for network visualization and analysis. Subsequently, the structure of the two-mode social network is analyzed using four network indicators: degree centrality, betweenness centrality, eigenvector centrality, and core-periphery structure. Table 4 displays the specific explanation of four indicators.

Table 4. Social Network Analysis Measurement Metrics.

Indicators	Definition	Reference
Degree centrality	In a two-mode social network, the degree centrality of a node is determined by the number of linkages it has to the nodes in the other set. Stakeholders with high centrality have more authority to deal with factors, and factors with high degree centrality need to be solved by more stakeholders.	[30,46,59]
Betweenness centrality	Betweenness centrality determines the occurrence that a specific node will be between other node pairs based on the shortest path. Stakeholders with high betweenness centrality can manage more coupled factors. Factors with high betweenness centrality imply that require more cooperation among stakeholders, and raise the complexity of the network.	[46,47,54]
Eigenvector centrality	For eigenvector centrality, if the neighbours connected to a certain node are significant, then this certain node is also significant. Stakeholders with higher eigenvector centrality can manage critical factors. Factors with higher eigenvector centrality need to be addressed by critical stakeholders, and have a significant impact on the network.	[46,54,60]
Core-periphery network structure	The core-periphery structure can decompose social networks into a cohesive core and a loosely connected periphery. Core stakeholders play a critical role in coordinating social networks, and core factors greatly affect the performance of the social network.	[30,46,61]

4. Results and Analysis

4.1. Matrix Analysis of Stakeholders-Factors

The stakeholder-factor adjacency matrix identifies whether the stakeholder has an influence on each factor. Suppose that the stakeholder-factor adjacency matrix is A, where the set of stakeholders is denoted by X, and X_i represents each of the 12 stakeholders; the set of factors is denoted by Y, and Y_j represents each of the 24 factors. The matrix A is shown in Equation (1).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2j} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mj} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

where a_{ij} represents whether stakeholder X_i can influence factor Y_j, and m, n represent the number of stakeholders and factors, respectively.

The relationship between stakeholders and factors can be divided into two categories; if stakeholder X_i can influence the factor Y_j, then a_{ij} = 1; otherwise, a_{ij} = 0. According to the "majority rule" adopted in previous studies [62,63], it is considered that a_{ij} = 1 when six or more experts believe that stakeholder X_i can influence Y_j.

Based on the results of semi-structured interviews, the stakeholder-factor adjacency matrix obtained in this study is shown in Table 5. Among them, the row elements are the stakeholder groups and the column elements are the influence factors of IM performance. From the perspective of stakeholders, S3 (general contractors) can participate in addressing the most influence factors of IM performance with 24, followed by S1 (developers), S2 (designers), and S5 (manufacturers), which can address 23, 21, and 21 factors, respectively. It is clear that these four stakeholders have a significant impact on the IM performance of sustainable PC. With regard to the factors of IM performance, TR2 (understanding and trust of the participants) and IN1 (effectiveness of information communication) demand the most stakeholders involvement addressed with 10, followed by TR1 (cooperative attitude of the participants), TR3 (communication and learning of the participants), IN3 (timeliness of information communication), ST3 (formal interface management process), EN1 (technical innovation), and EN2 (perfection of standards and specifications), all of which require nine stakeholders to address. Moreover, each stakeholder must handle at least three factors, and each factor requires collaboration from two or more stakeholders.

Table 5. Adjacency Matrix of Stakeholder-Factor.

	TR 1	TR 2	TR 3	TR 4	IN 1	IN 2	IN 3	TE 1	TE 2	TE 3	TE 4	OR 1	OR 2	OR 3	OR 4	ST 1	ST 2	ST 3	ST 4	EN 1	EN 2	EN 3	CO 1	CO 2	Total
S1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	23
S2	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	21
S3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
S4	1	1	1	0	1	1	1	0	1	1	1	0	1	0	1	1	1	1	1	1	1	0	1	1	19
S5	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	1	1	21
S6	1	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	10
S7	0	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	1	1	0	0	0	1	1	1	13
S8	1	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	8
S9	1	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0	9
S10	1	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	6
S11	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	9
S12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3
Total	9	10	9	5	10	8	9	4	6	6	5	2	5	3	6	7	7	9	6	9	9	6	8	8	

Additionally, the stakeholder-factor adjacency matrix can be converted into a stakeholder-stakeholder adjacency matrix, as well as factor-factor adjacency matrix. If two stakeholders are able to address the same factor, it can be considered that the two stakeholders need to collaborate in addressing this factor [64]. Therefore, the number of factors that stakeholders can address together can be further revealed by the stakeholder-stakeholder adjacency matrix, as illustrated in Table 6. In comparison to other paired stakeholders, S1 and S3 have the largest need for collaboration in IM of PC, jointly addressing 23 factors. More than 20 factors are handled collectively in the stakeholder pairs of S1–S2, S1–S5, S2–S3, and S2–S5, as well as S3-S5, indicating a high demand for collaboration among them. In contrast, there is no need for collaboration between S8 (logistics)–S12 (media and other social groups), and S10 (supervisions)–S12 (media and other social groups).

Table 6. Adjacency Matrix of Stakeholder-Stakeholder.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
S1	23											
S2	20	21										
S3	23	21	24									
S4	18	19	19	19								
S5	20	20	21	19	21							
S6	10	10	10	10	10	10						
S7	12	13	13	11	12	6	13					
S8	8	7	8	7	8	6	6	8				
S9	9	8	9	7	7	5	4	2	9			
S10	6	6	6	6	6	4	4	5	2	6		
S11	9	9	9	8	8	3	5	2	5	2	9	
S12	3	3	3	3	3	2	1	0	3	0	3	3

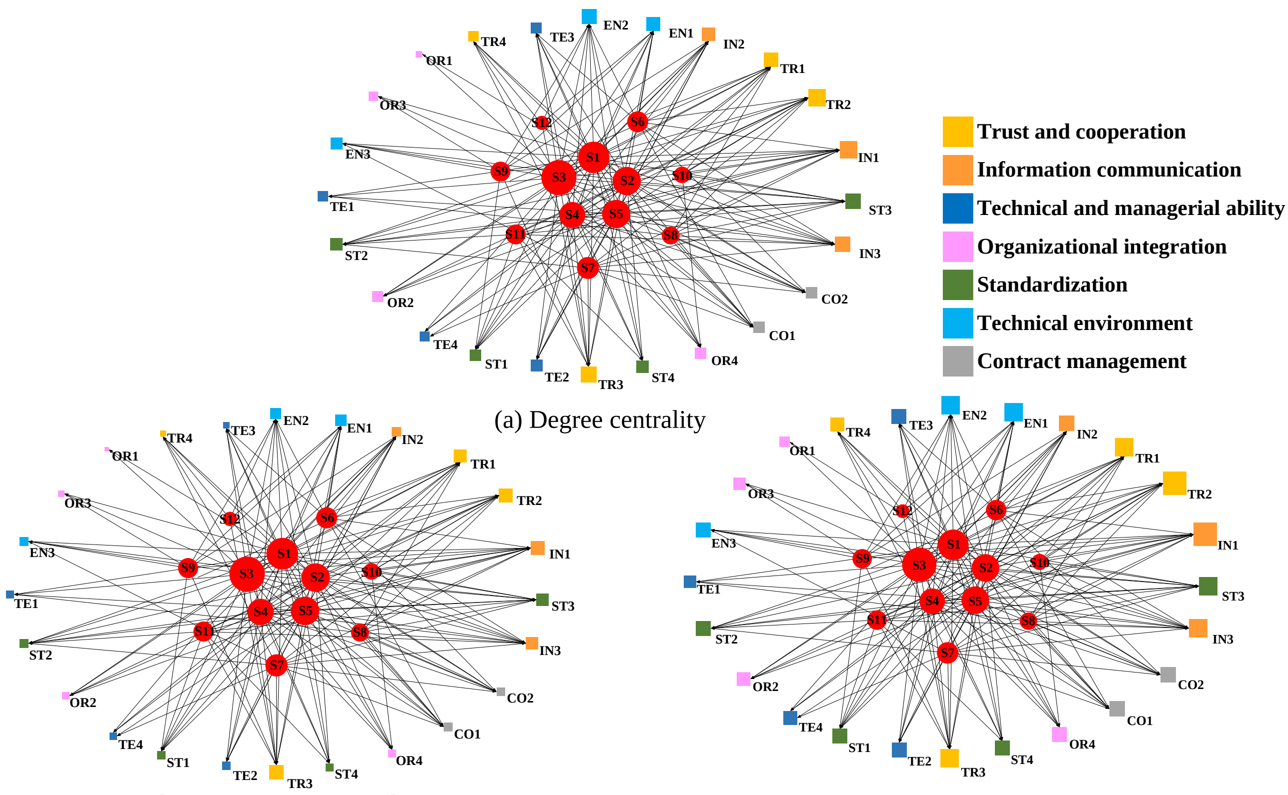
Similarly, the factor-factor adjacency matrix in Table 7 can further reflect how many stakeholders need to be jointly addressed the factor. If two factors can be jointly addressed by more stakeholders, the more similar the two factors are in terms of management resource requirements. For instance, the six factor pairs TR1 and IN1, TR2 and IN1, TR2 and IN3, TR2 and ST3, IN1 and IN3, and EN1 and EN2 all call for the collaboration of nine or more stakeholders, demonstrating these pairs of factors have high similarity in their resource demands on stakeholders.

Table 7. Adjacency Matrix of Factor-Factor.

	TR1	TR2	TR3	TR4	IN 1	IN 2	IN 3	TE1	TE2	TE3	TE4	OR1	OR2	OR3	OR4	ST1	ST2	ST3	ST4	EN1	EN2	EN3	CO1	CO2
TR1	9																							
TR2	8	10																						
TR3	6	7	9																					
TR4	4	5	5	5																				
IN1	9	9	7	5	10																			
IN2	7	7	7	5	8	8																		
IN3	8	9	6	5	9	7	9																	
TE1	4	4	3	3	4	3	4	4																
TE2	5	6	6	5	6	6	6	3	6															
TE3	6	6	5	4	6	6	6	3	5	6														
TE4	4	5	5	4	5	5	5	2	5	4	5													
OR1	2	2	2	2	2	2	2	2	2	2	1	2												
OR2	5	5	5	4	5	5	5	3	5	5	4	2	5											
OR3	3	2	3	2	3	3	2	2	2	2	1	2	2	3										
OR4	6	6	5	4	6	5	6	3	5	5	4	2	5	2	6									
ST1	6	6	7	4	6	6	5	3	5	5	4	2	5	3	5	7								
ST2	5	7	7	5	6	6	6	3	6	5	5	2	5	2	5	6	7							
ST3	7	9	7	5	8	6	8	4	6	5	5	2	5	2	6	6	7	9						
ST4	5	6	6	4	5	5	5	3	5	5	4	2	5	2	5	6	6	6	6					
EN1	7	7	8	4	7	7	6	3	5	6	4	2	5	3	5	7	6	6	6	9				
EN2	7	7	8	4	7	7	6	3	5	6	4	2	5	3	5	7	6	6	6	9	9			
EN3	4	5	6	4	5	5	4	2	4	3	3	2	3	3	3	5	5	5	4	5	5	6		
CO1	7	8	6	5	8	7	8	4	6	6	5	2	5	2	5	5	6	7	5	6	6	4	8	
CO2	7	8	6	5	8	7	8	4	6	6	5	2	5	2	5	5	6	7	5	6	6	4	8	8

4.2. Visualizing the Stakeholder-Factors Network

The stakeholder-factor adjacency matrix was transformed into a two-mode social network with 36 nodes and 166 edges by Pajek software, as shown in Figure 2. The red circular nodes represent each stakeholder, and the square nodes represent influence factors of IM performance, with different colors used to distinguish the factors in different dimensions. The stakeholders who have an impact on the influence factors of IM performance are shown by the lines connecting the circular nodes and square nodes. Based on this, the study computes the properties of each node in the two-mode social network using degree centrality, betweenness centrality, and eigenvector centrality, as illustrated in Tables 8 and 9.



(a) Degree centrality

(b) Betweenness centrality

(c) Eigenvector centrality

Figure 2. Two-Mode Social Network Measured by Centrality.

Table 8. Social Network Indicator Measurement of Stakeholders.

	Degree Centrality	Ranking	Eigenvector Centrality	Ranking	Betweenness Centrality	Ranking
S1	0.958	2	0.407	2	0.150	2
S2	0.875	3	0.397	3	0.096	4
S3	1.000	1	0.422	1	0.166	1
S4	0.792	5	0.368	5	0.074	5
S5	0.875	3	0.393	4	0.099	3
S6	0.417	7	0.207	7	0.017	8
S7	0.542	6	0.250	6	0.033	6
S8	0.333	10	0.161	10	0.010	10
S9	0.375	8	0.166	9	0.019	7
S10	0.250	11	0.126	11	0.005	11
S11	0.375	8	0.174	8	0.015	9
S12	0.125	12	0.062	12	0.001	12

Combining Figure 2 and Table 8, it can be found that S1 (developers), S2 (designers), S3 (general contractors), S4 (subcontractors), and S5 (manufacturers) are all located in the core of the network and have relatively consistent ranking in the top five of the three metrics. It also shows that the five stakeholders are not only able to address multiple factors but also have a high influence on those factors. The dominance of general contractors (S3) and developers (S1) in PC projects is consistent with S3 and S1 consistently ranking in the top two of the three centrality indicators. General contractors are responsible for the full implementation and management of the construction site. They must oversee the subcontractors and carry out their commitments under the subcontract in addition to having full legal and financial accountability to the developers. At the same time, general contractors are responsible for allocating resources and coordinating interfaces between manufacturers, subcontractors, and designers [13,45,65]. In addition, in recent years, many large developers have participated in the construction process of PC projects. For instance, enterprises like Country Garden and Vanke have been devoted to the integration of the PC industrial chain to have the ability to coordinate the design, manufacture, construction and other stages and manage multiple interfaces between the essential stakeholders in the process of project implementation [13].

Table 9. Social Network Indicator Measurement of Factors.

	Degree Centrality	Ranking	Eigenvector Centrality	Ranking	Betweenness Centrality	Ranking
TR1	0.750	3	0.235	5	0.025	6
TR2	0.833	1	0.258	1	0.030	5
TR3	0.750	3	0.234	6	0.034	1
TR4	0.417	19	0.166	19	0.003	20
IN1	0.833	1	0.257	2	0.031	4
IN2	0.667	9	0.231	7	0.014	11
IN3	0.750	3	0.242	3	0.022	8
TE1	0.333	22	0.123	22	0.003	19
TE2	0.500	14	0.198	14	0.004	18
TE3	0.500	14	0.195	15	0.005	17
TE4	0.417	19	0.162	20	0.003	21
OR1	0.167	24	0.074	24	0.000	24
OR2	0.417	19	0.176	18	0.002	22
OR3	0.250	23	0.088	23	0.002	23
OR4	0.500	14	0.187	17	0.008	15
ST1	0.583	12	0.206	13	0.010	12
ST2	0.583	12	0.214	12	0.009	14
ST3	0.750	3	0.239	4	0.024	7
ST4	0.500	14	0.192	16	0.006	16
EN1	0.750	3	0.230	10	0.034	2
EN2	0.750	3	0.230	10	0.034	2
EN3	0.500	14	0.161	21	0.009	13
CO1	0.667	9	0.231	8	0.014	9
CO2	0.667	9	0.231	8	0.014	9

Combining Figure 2 and Table 9, it can be observed that the ranking of the influence factors of IM in the three centrality measures is not constant. First of all, TR2 and IN1 rank highest in terms of degree centrality, followed by TR1, TR3, IN3, ST3, EN1, and EN2. The higher degree centrality illustrates that these factors require a larger number of stakeholders to collaborate on them, reflecting the complexity of these factors. Second, the high eigenvector centrality of TR2, IN1, IN3, ST3, and TR1 indicates that these factors have a considerable influence on the IM performance of sustainable PC. In addition, they have a high degree centrality, which reflects that the stakeholders dealing with these issues not only need to collaborate with each other, but also to have a high position of influence themselves. Finally, TR3, EN1, EN2, IN1, and TR2 have the prioritization in betweenness centrality, reflecting their need for closer cooperation among stakeholders, and prioritizing these five factors is most conducive to the reduction in network complexity.

4.3. Core-Periphery Structure of Stakeholder-Factor Network

The core-periphery structure can be used to pinpoint the primary PC stakeholders and the core influence factors of IM performance. Figure 3 displays the core-periphery structure created in this study using the Pajek software, and Table 10 displays the corresponding density matrix and final fitness. According to Table 10, there are strong connections between core blocks, as evidenced by the density of core stakeholders and core factors, which is 0.977. The density between core stakeholders and peripheral factors and between peripheral stakeholders and core factors are 0.690 and 0.426, respectively, which are both significantly lower than the core block, demonstrating that they are relatively loosely connected to each other. Particularly, there is essentially little connection and only a 0.07 density between peripheral stakeholders and peripheral factors. Finally, the final fitness of the core-periphery structure is 0.894. Accordingly, the validity of the two-mode social network structure of stakeholder-factor is reflected in these positive statistics.

	TR1	TR2	TR3	ST1	IN1	IN2	IN3	EN1	TE2	TE3	CO1	CO2	ST4	ST2	OR4	EN3	ST3	EN2	OR3	OR2	TE1	TR4	TE4	OR1
S1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
S2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1		1	1	
S3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		1			1	
S5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		1	1	1	1	
S6	1	1			1	1	1	1		1	1	1						1						
S7		1	1		1	1	1		1		1	1		1		1	1					1	1	
S8	1	1			1		1				1	1					1				1			
S9	1		1	1	1	1		1								1		1	1					
S10	1	1			1		1								1		1							
S11		1	1	1				1					1	1		1	1	1						
S12			1					1										1						

Figure 3. Core-Periphery Structure of Stakeholder-Factor.

Table 10. Density Matrix and Final Fitness of Stakeholder-Factor Network.

		Factors	
		Core	Periphery
Stakeholders	Core	0.977	0.690
	Periphery	0.426	0.077
	Final fitness	0.894	

The upper left corner of Figure 3 shows the stakeholders and factors located in the core block, including five stakeholders and 18 factors. The factors of information communication, standardization, technical environment, and contract management dimensions are all located in the core block, indicating that these dimensions have a greater impact on the IM performance of sustainable PC. In addition, stakeholders in the core block account for approximately 42% of the total, while factors account for 75%. It is evident that less than half of the stakeholders hold the resources and capabilities to deal with the vast majority of influence factors of IM performance. Strengthening the mutual collaboration of these five critical stakeholders will be beneficial to defuse the adverse impact of the influence factors of IM performance in the core block. The relationship between the core stakeholders and the peripheral factors is relatively loose, and the way in which these factors are handled reflects the necessity for cooperation with some of the core stakeholders. For instance, the factors of the organizational integration dimension can be effectively addressed by strengthening the collaboration between S1 (developers) and S3 (general contractors). Moreover, peripheral stakeholders are loosely associated with the core factors, demonstrating that the resolution of the core influence factors of IM performance requires the participation and cooperation of peripheral stakeholders. In summary, maintaining a strong collaborative relationship among core stakeholders is essential to IM, and timely participation and intervention of peripheral stakeholders in dealing with specific issues is an important guarantee for successful IM.

It is significant to note that according to prior research, government is one of the primary managers of IM and plays a crucial role in PC projects [30,48,66]. However, government is not one of the main stakeholders. An in-depth analysis of Figure 3 reveals that the factors of trust and collaboration (TR1, TR3), information communication (IN1, IN2), and technical environment (EN1, EN2, EN3) are most closely associated with the government. Its impact on IM is mainly reflected in industrial policies and systems that foster innovation, and strengthen trust and cooperation among enterprises within the PC industry, as well as develop information and technical standards, etc. [49,67]. While government can influence IM through these industrial policies and systems, they are less directly involved in the interface management activities of PC projects.

5. Discussion

The relationship between PC stakeholders and the influence factors of IM performance is captured by the stakeholder-factor adjacency matrix. Based on the findings of the analysis in the previous section, it can be seen that a factor requires a minimum of two stakeholders to collaborate (i.e., OR1) and up to ten stakeholders to collaborate (i.e., TR2, IF1), indicating that strengthening collaborative relationships among stakeholders is a crucial prerequisite for enhancing the IM performance of sustainable PC [29]. In addition, more than half of the stakeholders must participate in the influence factors of trust and cooperation, information communication, technical environment, and contract management. This can be explained by the fact that facilitating effective and accurate information communication among stakeholders can help stakeholders effectively alleviate the problem of information asymmetry. At the same time, it can enhance the trust and cooperation among stakeholders and improve the IM performance of sustainable PC [28]. The technical environment mainly reflects the prefabricated technology itself, and solving the problems therein can facilitate the articulation of the physical interface in PC [25]. Additionally, each stakeholder performs their duties in line with the contracts can successfully mitigate conflicts and foster collaboration among the stakeholders [68]. Therefore, these issues require the joint participation of more stakeholders.

It should be highlighted that there is an extreme demand for collaboration among developers (S1), designers (S2), general contractors (S3), subcontractors (S4), and manufacturers (S5). If a good interface cannot be formed between these stakeholders, the sustainability of prefabricated buildings will be compromised. First, during the design stage, the designers need to create the scheme in accordance with the requirements of the developers, and the contractors and manufacturers need to participate in determining the constructability of the scheme. The lack of good IM between the developers and the designers will lead to repeated design schemes and the lack of IM between the designer-contractor-manufacturer will cause problems such as difficulty in realizing the design scheme, design errors, and scheme changes [40]. Second, during the construction stage, the general contractors, subcontractors, and manufacturers need to coordinate and cooperate, and the lack of good IM will lead to problems such as extra costs, quality defects, waste of resources, and schedule delays [28].

In the two-mode social network of stakeholder-factor, there are a number of factors that need attention. TR3, EN1, EN2, IN1, TR2 shows with high mediation centrality among the factors, which means closer cooperation among stakeholders required to handle them. Thereby, prioritizing these factors is conducive to simplifying the complexity of stakeholders-factor dual-mode social networks. For example, the application of new technologies is frequently accompanied by technical uncertainty, and stakeholders must seek technical and knowledge support across interfaces because of a lack of knowledge and experience [69]. Thus, by encouraging technological innovation and standardization of PC interface management design, the level of dependency between prefabricated components installation operations and the complexity of physical interface management can be decreased [70,71]. For the factors with high eigenvector centrality (i.e., TR2, IF1, IF3, ST3, TR1), these factors have a considerable impact on the IM performance of sustainable

PC and prioritizing these influence factors can significantly improve the IM performance of sustainable PC. For instance, it is important to establish cross-interface communication mechanisms between organizations to obtain information or knowledge from other organizations [38]. In addition, due to the greater number of participants, higher professional barriers, and more complicated conflicts of interest in PC, differences in attitudes toward cooperation may result in more serious interface issues [43]. Meanwhile, numerous studies have demonstrated that different cooperative attitudes are the root cause of interface conflicts in construction projects [72,73]. Accordingly, these factors deserve the attention of the stakeholders. For stakeholders, S1, S2, S3, S4, and S5 have the ability to process the factors under the trust and cooperation (TR1, TR2, TR3), information communication (IN1, IN2, IN3), standardization (ST1, ST2, ST3, ST4), and contract management dimensions (CO1, CO2). They can also process part of the factors under the technical and managerial ability, organizational integration, and technical environment dimensions. Further, collaboration-based partnerships between general contractors and developers, designers and manufacturers can enhance trust, cooperation and information communication among them. And on that basis, a systematic industry chain from upstream to downstream will be formed, which can reduce construction costs and improve construction efficiency [74].

6. Conclusions

Due to the fragmented work sites, disrupted construction process, and various stakeholders, prefabricated construction projects have established complicated and numerous interfaces. The IM performance is affected by the factors in trust and cooperation, information communication, technical and managerial ability, organizational integration, standardization, technical environment, and contract management dimensions, while having a sizable impact on the sustainability of PC [43]. This study aims to improve the IM performance of sustainable PC by exploring the impact mechanisms of stakeholders on the factors of IM performance. First of all, by analyzing the relevant data in the two-mode social network of stakeholder-factor, we get the following conclusions.

(1) In the matrix analysis, each stakeholder must handle at least three factors, and each factor requires collaboration from two or more stakeholders, indicating that the IM of sustainable prefabricated construction requires extensive collaboration of stakeholders. Among them, S1, S2, S3, and S5 have high influence on IM, and there is a high demand for cooperation among them. TR1, TR2, TR3, IN1, IN3, ST3, EN1, and EN2 are affected by more stakeholders, implying the complex collaboration needs of stakeholders in dealing with these issues.

(2) In the stakeholder-factor network, S1, S2, S3, S4, and S5 occupy an important position, which can participate in the processing of multiple IM influence factors, and have a high influence on the factors to be processed. The eigenvector centrality scores of IN1, IN3, ST3, and TR1 are in the top five of all factors, which reflects that the stakeholders dealing with these issues not only need to collaborate with each other, but also to have a high position of influence themselves. The betweenness centrality of TR3, EN1, EN2, IN1, and TR2 ranks in the top five, indicating that they are on the shortcut of paired stakeholders and prioritizing these five factors is most conducive to the reduction of network complexity.

(3) In the core-peripheral structure, the five core stakeholders (42%) can manage 18 elements (75%), and the coordination and cooperation of the five core stakeholders need to be strengthened. Therefore, maintaining a strong collaborative relationship among core stakeholders is crucial to IM, and the timely participation and intervention of peripheral stakeholders in dealing with specific issues is an important guarantee for the success of IM.

Secondly, by analyzing the impact mechanism between the stakeholder-IM performance factor of sustainable prefabricated construction, this study also provides some suggestions for future research work and industry practitioners. First, improve the efficiency of problem solving. Stakeholders should address issues based on how similar the resources demand. For instance, the resolution of EN1 and EN2 requires the participation of nine common stakeholders. To increase the efficiency of IM, these stakeholders should complete and perform the corresponding standards and specifications (EN2) while carrying out technological innovation (EN1). Second, improve the efficiency of collaboration among stakeholders. Protocol-based partnerships can drive long-term interests, ensuring trust and cooperation for one or more projects. This mechanism of trust and cooperation ensures the establishment of stable trust and cooperation between stakeholders in the entire prefabricated supply chain, so that transactions can be carried out in a coherent manner. Finally, enhance the IM technical environment. Stakeholders should actively embrace and innovate technology to improve the technological environment through collaborative innovation. Changes in the technical environment often require government authorities, industry associations and stakeholders who master core technologies to jointly formulate corresponding technical standards and specifications. Therefore, collaboration between project stakeholders, government departments, and industry associations is the key to improving the technological environment.

Thirdly, this study offers theoretical contributions and practical insights for research related to improving the IM performance of sustainable PC. Theoretically, this study explores in an innovative way how 12 stakeholders can manage 24 influence factors of IM performance from the perspective of stakeholders. And it identified the attributes of stakeholders and influence factors, the cooperative relationship between stakeholders, and the complexity of factors. The primary stakeholders and factors are also recognized in this study, which provides a theoretical basis for researchers and industry practitioners to address the influence factors of IM performance and promote the sustainability of PC. Practically, the impact mechanism identified by this study helps project participants gain a better understanding of themselves and other stakeholders. And it can promote the quality of the relationship between stakeholders by adopting more scientific method, and ensure the IM performance of the prefabricated construction. As a result, this study has significant practical implications for prefabricated building, which in fact is highly dispersed but has high integration requirements.

However, there are some limitations in this study. For one thing, the focus of this study is the impact mechanism of the IM performance of sustainable prefabricated construction from the perspective of stakeholders. When determining the influencing factors of IM performance, it mainly considers the management behaviors and relationships among stakeholders and the macro-environmental level, ignoring the impact of materials and structures on IM performance in sustainable prefabricated buildings. Therefore, this is also the direction that needs to be further studied in future research. For another thing, since there are still few studies on the IM performance of PC, the literature reference is scant, and the scope of data sources is relatively narrow, so the results obtained are limited. Future research should further expand the scope of research and investigation to increase the sample and applicability of the study.

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