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Exploring the Impact Mechanism of Interface Management of Prefabricated Construction Projects

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Abstract: Prefabricated construction (PC) is gaining more acceptance worldwide as a sustainable construction method due to its advantages in energy savings, emissions reduction, and cleaner production. However, the inherent geographical and organizational fragmentation of PC projects causes numerous interface issues. Effective interface management is key to the success of PC projects. Thereby, this study aims to explore how interface management is affected by various factors. Based on the literature review, the hypothesis of interaction between different factors is deduced and put forward, and the conceptual model of the interaction path of influencing factors in interface management of PC projects is established. Based on 117 valid questionnaires, an empirical test based on PLS-SEM analysis was conducted. According to the results, 10 paths affecting the performance of interface management were verified. The 7 factors in the conceptual model can all have an impact on the performance of interface management through direct or indirect paths. Among them, information communication, trust and cooperation, technology and management ability have a greater direct impact on interface management, while technical environment, information communication and contract relationship have a greater total impact on interface management. This study reveals the influence mechanism of interface management of PC projects, which can bridge the existing research shortcomings and provide a reference for solving interface management problems in practice to promote the development of PC.

Keywords: prefabricated construction; interface management; influencing factors; structural equation modeling

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1. Introduction

Prefabricated construction (PC) is a well-known approach that can potentially mitigate many of the current construction industry's challenges including, for example, Carbon emissions, poor productivity, shortages in skilled labourers, and poor safety performance [1–3]. Compared with traditional construction projects, PC is highly fragmented geographically and organizationally due to more construction processes, greater specialization, fragmented work sites, numerous stakeholders, and extensive information intersections [4,5]. For most developing countries, PC technology is still in the early stages of development, problems such as inadequate standards and specifications and an imperfect industrial chain may make collaboration between various professions, stages and stakeholders difficult and interface issues abound. According to Gibb and Pavitt, effective management of these issues is critical to PC success [6,7].

Ideally, the PC is a well-integrated construction organization process to achieve continuity of production, which implies a stable flow of materials, standardized workflow, integration of construction process and highly integrated work organization [8,9]. However, PC projects are based on a high degree of division of labor and specialization, resulting in a significant natural boundary between the subsystems and elements of the project [10]. In contrast to traditional construction, the functional modules of PC need to be broken down into components that can be manufactured in a factory and then assembled on-site, with complex physical interfaces between the components or components that need to be seamlessly connected [5,11]. Besides, PC projects created more intricate and diverse interfaces between stakeholders, processes, and products that are geographically and temporally independent yet logically interrelated [9,11]. Consequently, numerous complex and diverse interfaces are created between spatially and temporally independent and logically related stakeholders, processes, etc. The successful delivery of the project will be severely affected if these interfaces are not tightly connected, poorly communicated, or clearly defined [6,7]. According to statistics, 60% of the problems in the construction of PC projects are closely related to the interface [6]. Due to the immature technical system, relatively backward top-level system design, imperfect standards and norms, and imperfect industrial chain, it is difficult to cooperate among various majors, stages and stakeholders, and many interfaces are difficult to be effectively managed [5].

Recently, interface management has been introduced to the construction industry, and is considered to be an effective way to realize harmonious collaboration among project stakeholders [11,12]. Some scholars have been devoted to studying the factors affecting the interface management of construction projects. For example, the comprehensive causes of interface issues were discussed from six interrelated perspectives: people/participants, methods/processes, resources, documentation, project management, and environment [13]. McCarney and Gibb studied the influencing factors of the organizational interface management of prefabricated construction projects from the perspective of people and process, and found that the early intervention of contractors in the design stage and open communication between stakeholders are crucial to solve the problems of organizational interfaces [13]. Weshah et al. took the Alberta construction project as the background and studied and determined six key factors affecting interface management: management, information, contracting mode, standards and norms, technology and site issues [14]. Hazem et al., Sha 'ar et al. and Yeganeh et al. focus on the research of design-construction interface management and identify the causes of design-construction interface issues. They found that poor communication, lack of experience in design and construction management, unreasonable contract design and lack of project management experience are the key influencing factors of interface issues [15–17]. Shokri et al. identified the driving factors of interface management and the impact of interface management on construction projects from a systematic perspective [18]. Zhang et al. investigated the critical factors influencing interface management in PC with a quantitative and qualitative method [5]. Luan et al. analyzed the relationship between influencing factors of interface management and stakeholders in PC projects [9]. These studies have obtained and analyzed the influencing factors of interface management, which provides a reference for this study to identify and analyze the influencing factors of interface management.

Previous studies provide a theoretical basis for this study. However, the research objects of these studies are mostly traditional construction projects. Research on the factors influencing the IM performance of PC is lacking [16,17]. Furthermore, understanding the interaction between these factors can provide a scientific and quantitative decision-making basis for the interface management of PC projects. However, few studies take into account the interaction between these factors in depth.

To address the aforementioned issues, it is necessary to understand how interface management is affected by various factors. A PLS-SEM analysis-based method was conducted to explore the impact mechanism of interface management of PC. The remainder of this study is organized as follows: Section 2 details the methodology and process used in this study; and Section 3 analyzes the results and discusses them in Section 4. Finally, Section 5 summarizes the main findings and limitations of this study.

2. Methodology

In order to achieve the objectives of the study, the following steps were followed: (1) identifying the factors influencing interface management of PC projects through a literature review, questionnaires, and face-to-face interviews, (2) the hypothesis of interaction between different factors put forward, and the conceptual model of interaction path of influencing factors in interface management of prefabricated building projects is established based on literature review, (3) data were collected through questionnaire survey and verified by structural equation model to explore the impact mechanism of interface management of PC project.

2.1. Identify the Influencing Factors of Interface Management

In previous work, we have identified 27 factors affecting the interface management of PC through a literature review, questionnaires, and interviews in their previous work [9]. Meanwhile, using factor analysis, the 27 factors were further divided into 7 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). In this study, we will continue to use this result for further research. A specific list of factors are shown in Table 1.

Table 1. Factors influencing interface management of 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	IF1	Effectiveness of information communication
	IF2	Integrity and Accuracy of Information
	IF3	Timeliness of information communication
Technical and managerial capability	TE1	Timeliness of production and supply of prefabricated components
	TE2	Technical level of operators
	TE3	Accuracy of design
	TE4	Project management experience and ability
	TE5	Reasonableness of production and construction scheme
	TE6	Tracking of component production and installation process
Organizational integration	OR1	Organizational structure
	OR2	Professional differences between organizations
	OR3	Project contracting mode
	OR4	Alignment of stakeholders' goals
	OR5	Professional differences between stakeholders
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

2.2. Hypotheses and Conceptual Model

The organizational integration of the project is conducive to solving the problem of spatial and temporal dispersion of construction activities caused by the specialized division of labor in the construction process and improving the cooperation ability among the participants [19]. According to previous studies, organizational integration management is helpful to improve the interface management of construction projects [20,21]. PC project organizations with high integration can not only strengthen the closeness of inter-organizational relations through the flexibility and openness of organizational structure [22], but also cultivate the partnership between participants through the selection of reasonable project management modes to improve the effect of interface management [6]. In addition, highly integrated organizations emphasize professional collaboration across organizations and strive to promote goal alignment and cultural compatibility among participants to reduce interface conflicts caused by differences in professional and value orientations.

Different project participants are quite different from each other in terms of profession, culture and goals, which makes it difficult to trust each other and develop long-term cooperation [23]. The perception of organizational support is the basis of trust and cooperation between enterprises [24]. Integrated management of project organization is an organizational support strategy for complex construction projects. Efforts in cross-organization professional collaboration, promotion of goal consistency and cultural compatibility, and effective organizational structure can not only reduce interface conflicts but also enhance trust and cooperation between project organizations [25,26].

Hence, the following hypotheses were proposed:

H1a. *Organizational integration positively influences interface management.*

H1b. *Organizational integration positively influences trust and cooperation.*

Trust is mutual, cooperation is reciprocal, cooperation without trust is short, and trust without cooperation is superficial. Trust and cooperation are regarded as the key factor for communication among participants, conflict resolution, and supply chain integration, which are reflected in the understanding, trust, cooperative attitude, communication and learning among organizations. Interdependent interface relationships between project organizations require a high degree of trust and cooperation [27]. A high level of inter-organizational trust and cooperation can break the antagonistic relationship between project participants [26]. In an atmosphere full of trust and cooperation, project participants are more likely to share their valuable information and resources openly, thus making the organizational interface more transparent and flexible [28].

Studies have shown that trust and cooperation can not only directly benefit interface management, but also have a positive impact on interface management by promoting information communication among organizations [28]. The participant will also be more inclined to actively communicate across organizational boundaries [29]. Some studies have proved this point of view. For example, Kadefors believes that despite the existence of an organizational interface, mutual trust can promote organizational flexibility and improve the quality of information exchange [30]. Shen et al. found that the establishment of trust-based cooperation between organizations would encourage participants to actively communicate with the outside world (such as communicating with the outside world about design issues, obtaining feedback, coordinating and negotiating) [27].

Hence, the following hypotheses were proposed:

H2a. *Trust and cooperation positively influence interface management.*

H2b. *Trust and cooperation positively influence information Communication.*

Technical innovation, the degree of perfection of technical standards and norms and the level of standardization of design are the embodiment of the technical environment. From the results of technological innovation, it can be found that technological innovation has a positive impact on interface management. For example, modular preassembly technology greatly reduces the number of on-site physical interfaces. The use of the Internet of Things (IoT), Building information modelling (BIM) and other technologies has broken the boundaries of participants in time and space and provided a unified platform for interface management. Well-developed standards and specifications can help participants clarify technical requirements, standardize work processes, and deliver qualified products. Standardized design is considered a physical interface configuration rule that facilitates the realization of modular coordination [31]. The unification of standardized component rules can reduce the complexity of entity interface tasks and enhance the interoperability of both sides of the interface [32,33].

The technical environment has the most direct impact on information communication. For example, the innovative application of BIM directly changes the way of writing, storing and transmitting building information, and provides a platform for information communication and sharing. Information exchange standards and norms are the basis for information compilation and storage methods among different enterprises. Well-developed information exchange standards and norms can make enterprises tend to adopt standardized information management methods and improve the readability and interoperability of information between enterprises [34].

The more perfect the technical standards and norms, the higher the standardization level [35]. For PC projects, the uniform rules of standardized designed components or parts will also greatly improve the standardization of the interface. Standardized designed components and parts are reproducible in the process of production, construction and installation, and managers usually develop standardized technological processes and management procedures to regulate this repetitive work [36]. Consequently, the technical environment can improve the standardization level of production, information communication, product interface and management through these two factors.

Therefore, the following hypotheses were proposed:

H3a. *Technical environment positively influences interface management.*

H3b. *Technical environment positively influences information communication.*

H3c. *Technical environment positively influences standardization.*

Contract management is mainly reflected in the definition of work content and scope, and the definition of responsibility–power–benefit. PC projects involve professional and complex contractual relationships. The contract should clearly define the content and scope of work, and the boundaries of each profession should be clearly divided and rationally overlapped. This can prevent participants from avoiding responsibilities due to ambiguous interfaces and prevent related interfaces from becoming management blind spots [37]. In addition, contract management helps restrain disputes and promotes a good spirit of trust and cooperation [38]. Clarifying the joint responsibility for the objectives of all parties in the contract terms can prompt all parties to focus on the project as a whole and form an atmosphere of trust and cooperation [39].

Hence, the following hypotheses were proposed:

H4a. *Contract management positively influences interface management.*

H4b. *Contract management positively influences trust and cooperation.*

Standardization is mainly reflected in the standardization of information, standardization of production and construction processes, complexity of connection interfaces between prefabricated components and formal interface management process. The standardization of information is the basis of information communication [40,41]. Lack of standardization is a major barrier to inefficient information reading, sharing, and interoperability among different parties [1]. The standardized technological process and management process can make the participants form a stable information communication mechanism. The higher the degree of standardization, the smoother the information communication. By reducing complexity through standardized interface design, information communication requirements for complex interfaces in production and installation between different specialties can be greatly reduced. Therefore, the improvement of standardization has a positive impact on information communication in PC projects.

Standards serve for technology and management from the moment the capitalist factory was created, and are also the core of PC development [36]. Li et al. systematically introduced the role of standardization in dealing with the comprehensive problems of cross-industry, cross-discipline and cross-field in the contemporary industry [42]. Although the standardization of the research is mainly reflected at the project application level, its role in technical and management capabilities is also crucial. For example, In the production process of standardized prefabricated components, there is a lot of repetitive work. In a standardized process, technical and managerial personnel can constantly learn and improve themselves through repetitive work. Meanwhile, standardization is also an important guarantee for concurrent engineering in the production of prefabricated building components [36].

Based on the analysis, the following hypotheses were proposed:

H5a. *Standardization positively influences information communication.*

H5b. *Standardization positively influences technical and managerial capability.*

The technical and management capability includes the accuracy of design, the experience and capability of participants, the reasonableness of the production and construction plan, and the timeliness of component production and supply. Technology and management capability are an important factor affecting information communication. From the point of view of design ability, design drawing itself is the expression of design information. The accuracy of design is the accuracy of design information expression. The more experienced project participants generally have a high level of information management and communication skills. The reasonable arrangement of process and resource allocation in construction schemes is the basis of orderly information communication. By clearly defining the information requirements, the construction team can efficiently process and transmit information and maintain effective communication with the sender and recipient of information. In addition, on-time delivery can ensure that the production and construction companies will not cause a lot of ineffective communication, or even communication barriers due to the production and construction technology disorder.

The influence of technology and management capability on interface management is more intuitive. For example, the accuracy of design can eliminate the compatibility problem of the component connection interface from the source [43,44]. The project participants with strong management experience and ability are proficient in PC technology and can identify and manage the interface with rich experience [5,45]. Skilled operators can also better handle task cohesion between processes. The timeliness of the supply of prefabricated components and the tracking ability of production and installation are important guarantees for the seamless connection of the delivery interface between the prefabricated component manufacturer and the contractor[5,46].

Therefore, the following hypotheses were proposed:

H6a. *Technology and management capability positively influence information communication.*

H6b. *Technology and management capability positively influence interface management.*

Effective information communication is the key to successful project delivery and is also recognized as an important factor for interface management [43,47]. In construction projects, almost all activities require different degrees of communication on the interface [28]. Frequent and timely cross-interface communication may create more opportunities. For example, accurate contact with scattered professionals can help project participants identify interface problems earlier and improve the decision-making efficiency of interface management [28]. Studies on interface management of PC projects also show that open information communication among stakeholders is the key to improving the effectiveness of interface management [13].

Therefore, the following hypotheses were proposed:

H7. *Information communication positively influences interface management.*

Combined with the above assumptions, the conceptual model of the action path of interface management influencing factors is established, as shown in Figure 1.

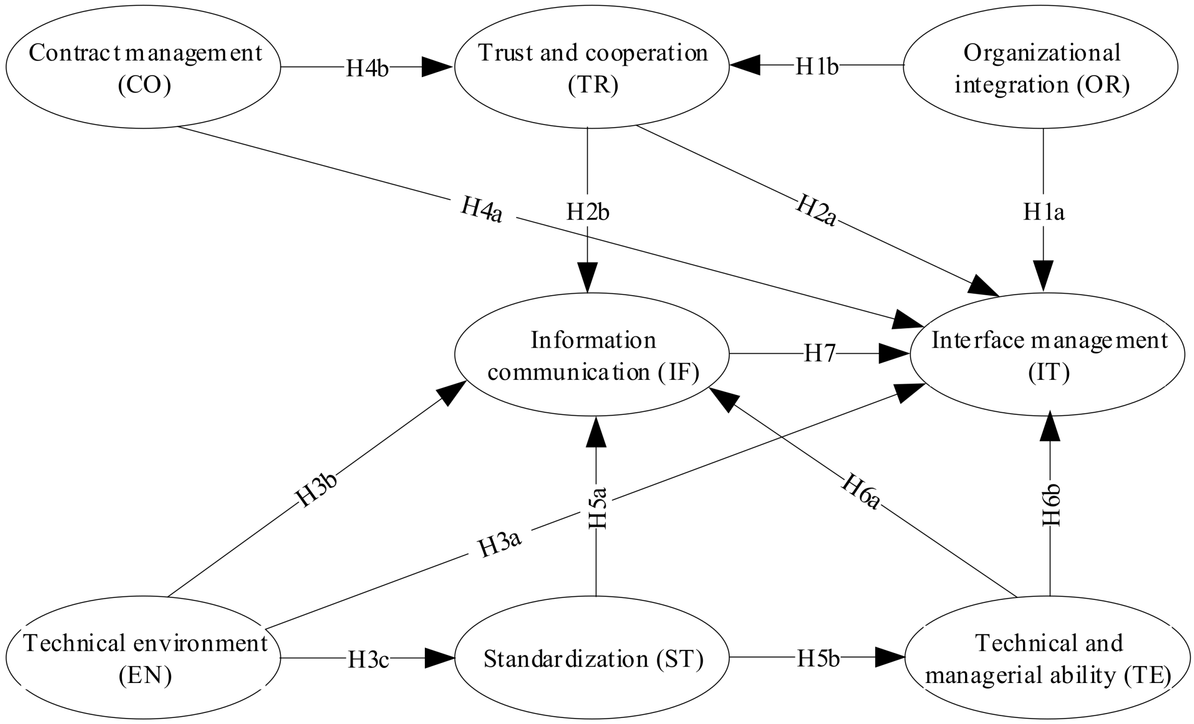

Figure 1. Conceptual model of interaction path of influencing factors for interface management of PC projects.

2.3. Questionnaire Design and Data Collection

In this stage, the 7 unobservable categories were taken as latent variables, and 27 directly observable influencing factors were taken as observed variables. A formal questionnaire survey was conducted to capture the views of the target respondents. The questionnaire was composed of three main parts: (1) Preface. This part introduces the purpose of the survey to the interviewees and defines relevant concepts (2) Respondent's information. This part mainly included the interviewees' career information and educational background, shown in Table 2. (3) Set the observation items according to the observation variables. Before the formal distribution of the questionnaire, 5 experts and 5 experienced respondents were invited to fill in and discuss the questionnaire to ensure that the observation items were reasonably designed and easy to be understood by respondents. Finally, 31 observation items as shown in Table 1 were set. The respondents were asked to answer questions using a five-point Likert scale ("1 = strongly disagree" to "5 = strongly agree") to determine the degree of agreement of the respondents on each item.

Table 2. Measurement items.

Latent Variables	Measurement Items
Organizational integration (OR)	OR1: The organizational structure of the project is conducive to the division of labor and cooperation of the project participants.
	OR2: Participants can effectively handle the transfer, coordination and combination of activities between different specialties.
	OR3: The project adopts a management (contract) mode suitable for PC projects.
	OR4: Participants are aligned in their interests with the project objectives and are keen to achieve common goals.
	OR5: There is little cultural difference and high compatibility between participants, and different organizational cultural backgrounds have little influence on inter-organizational cooperation.
Trust and cooperation (TR)	TR1: Participants have a strong willingness to cooperate with each other.
	TR2: There is mutual understanding and trust among the participants.
	TR3: Participants often hold exchange and learning activities.
	TR4: Participants actively participate in the design stage, cooperate with the designer, and grasp the design intention.
Information communication (IF)	IF1: Participants can understand the information and maintain effective communication during information transmission and communication.
	IF2: Information transfer can maintain completeness and accuracy.
	IF3: Project information can be communicated to relevant parties in a timely manner and feedback will be received.
Technical and managerial ability (TE)	TE1: The component manufacturer has strong supply and delivery ability to ensure the punctual supply and delivery of components.
	TE2: Component production and installation workers with high level of operation.
	TE3: The drawing of the designer is accurate.
	TE4: Participants can accurately obtain the production process, transportation location and construction installation points of components.
	TE5: Participants are experienced in PC projects.
	TE6: The production and construction organization plan is reasonable, the production and construction activities are carried out orderly, the task conflict is less, and the phased products can be delivered in time.
Standardization (ST)	ST1: The standardization degree of information is high, and the project information can be interoperable in the information management system of each participant.
	ST2: The project adopts standardized strategies to unify and simplify the process and operation methods of component manufacturing and installation.
	ST3: The project uses a standardized process to manage interfaces that involve multi-party interactions, such as communication, collaboration, task alignment, and product delivery.
	ST4: The components are connected by unified and standardized interfaces.
Technical environment (EN)	EN1: Projects proactively adopt new technologies to improve efficiency.
	EN2: Relevant institutions have developed standardized norms to guide PC project implementation.
	EN3: The degree of standardization in the design of PC buildings.
Contract management (CO)	CO1: The terms of the contract specify the distribution of responsibilities, rights and interests of each party.
	CO2: The contract terms clearly define the work content and scope of each party

Table 2. *Cont.*

Latent Variables	Measurement Items
Interface management (IT)	IT1: The project organizations can maintain good communication and cooperation, and the inter-organizational conflict is less.
	IT2: In your project, there are few contract disputes such as responsibility, authority and interest caused by unclear division of tasks.
	IT3: In your project, the component connection reliability is high, the physical interface conflict is less.
	IT4: In your project, project participants have strong awareness of interface management, can proactively identify key interfaces, and actively participate in cross-interface coordination work.

In order to ensure the accuracy of the study, most of the questionnaires were distributed one by one to experts in the PC industry by relevant personnel of the research group through face-to-face, WeChat, QQ, email and other ways. In order to expand the sample size, a "snowball" approach was adopted, in which respondents were asked to re-distribute the questionnaire to colleagues or other professionals in the field. 152 questionnaires were collected. However, some respondents' answers may be casual or careless, and the data quality may vary. Therefore, the questionnaires were screened based on the following criteria: ① respondents should spend a certain amount of time reading the items, and the time to answer each item should not be less than 2 s; ② If the respondent gives a series of identical answers, or the length of the series of answers is more than half of the length of the total scale, the respondent is considered to be an underachiever. After screening, 117 questionnaires were considered to be true and effective, with an effective response rate of 76.97%. The specific information of interviewees is shown in Table 3.

Table 3. Respondents' information.

	Type Description	Number of Respondents	Percentage (%)
Professional category	Developer	27	23.08%
	Designer	19	16.24%
	Manufacturer	21	17.95%
	Contractor	29	24.79%
	Consultant	12	10.26%
	Government	9	7.69%
Education	Doctor degree	15	12.82%
	Master degree	36	30.77%
	Bachelor degree	58	49.57%
	Junior college and below	8	6.84%
Years of experience in the construction industry	>10	26	22.22%
	6~10	40	34.19%
	3~5	34	29.06%
	≤3	17	14.53%
Years of experience in PC industry	>10	5	4.27%
	6~10	19	16.24%
	3~5	53	45.30%
	≤3	40	34.19%

2.4. Data Analysis Method

To test the hypotheses in the conceptual model, structural equation modeling (SEM) was used to analyze the empirical data collected from the questionnaire survey. In general, SEM generally includes covariance-based structural equation models (CB-SEM) and variance-based partial least squares structural equation models (PLS-SEM). PLS-SEM is more stable and applicable than CB-SEM. PLS-SEM considers the explanatory variance of the dependent variable, which is suitable for the study of the relationship between multiple groups of variables, and requires a low sample size. Therefore, PLS-SEM is selected for this study [48].

Table 4 shows the criteria and rules used for the measurement model test. Four criteria of reliability or validity should be examined: (1) reliability, and (2)internal consistency reliability, (3) convergent and (4) discriminant validity [48]. The indicator reliability should be tested by the indicator loading. When the factor loading is greater than 0.707 and significant at the level of 5%, the explanatory power of the observed variable can explain at least 50% of each potential variable variance[49]. Cronbach's alpha (CA) is a common criterion for examining internal consistency [50]. Previous studies have shown that if CA > 0.7, the observed variables have good internal consistency. Composite reliability (CR) is also a common criterion for measuring internal consistency. The value of CR should not be less than 0.7 [48]. Fornell and Larcker (1981) suggested the average variance extracted (AVE) as a criterion of convergent validity. The discriminant validity is traditionally examined by the cross-loadings criterion and the Fornell–Larcker criterion. The cross-loadings criterion requires that the observed variable should have the highest loading on the latent variable it intends to measure [49]. The Fornell–Larcker criterion postulates that the correlation coefficient obtained based on the square root of AVE for each latent variable should be higher than its correlation coefficient with any other latent variable [51].

Table 4. Criteria and rules used for measurement model test.

Validity Type	Criterion	Rules of Thumb	Literature
Reliability test	Indicator loadings	Values should be significant at the 5% level and $\leq$0.7	[49]
	Cronbach's alpha (CA)	$\geq$0.7	[50]
	Composite Reliability (CR)	$\geq$0.7	[48]
Validity test	Average Variance Extracted (AVE)	$\geq$0.5	[51]
	Cross-loadings	Each indicator should have the highest loading on the construct it intends to measure	[49]
	Fornell-larcker criterion	The square root of AVE for each construct should be higher than its correlation with any other construct	[51]

After examining the measurement model, the structural model should be examined. The criteria for the structural model include: (1) coefficient of determination (R^2), (2) path coefficient, (3) effect size (f^2), (4) goodness of fit (GoF), and (5) predictive relevance (Q^2). The R^2 measures the variance of the latent variable explained by the observed variable, reflecting the prediction power of the structural model [52]. The f^2 measures the effect degree of an exogenous variable on an endogenous variable. If exogenous variables have an influence on endogenous variables, f^2 should be higher than 0.02 [52]. Path coefficients can be used to test the causal relationship between potential variables, which can be examined by their algebraic sign, magnitude and significance [52]. The bootstrapping resampling technique is used to determine the significance, and the path coefficient should be significant at least at the 5% level. Q^2 can be used to examine the predictive relevance of the model. The higher value of Q^2, the better predictive relevance. A positive Q^2 value indicates the model's predictive relevance is good [51]. The GoF is a global fit measure for PLS-SEM [53], defined as the geometric mean of the average communality and the average R^2 ($GoF = \sqrt{\overline{communality} \times \overline{R^2}}$). Table 5 presents the criteria and rules used for structural model test.

Table 5. Criteria and rules used for the structural model test.

Criterion	Rules of Thumb	Literature
Coefficeients of determination (R^2)	0.67, 0.33 and 0.19 for substantial, moderate and weak exploratory power	[51]
Effect size (f^2)	0.35, 0.15 and 0.02 for substantial, moderate and weak effect and less than 0.02 means no effect	[52]
Q^2	$Q^2 > 0$	[51]
Size and significance of path coefficients	Path coefficients among the latent variables should be checked according to their algebraic sign, magnitude and significance	[52]
Goodness of Fit (GoF)	0.36, 0.25, 0.1 for substantial, moderate and weak GoF	[53]

3. Results

3.1. Measurement Model Test

Smart PLS 3.0 was used for model testing, and the results showed that, except OR5, TE2 and TE4, the factor loads of the other observed variables were greater than 0.7 and significant at the 0.1% level. After deleting indicator OR5, TE2 and TE4, the CA, CR and AVE of the modified model were further calculated, shown in Table 6, indicating that the measurement model's internal consistency and convergent validity meet the test criteria. Additionally, the discriminant validity meet the Fornell–Larcker criterion (Table 7) and cross-loadings criterion (Table 8).

Table 6. Reliability and convergent validity.

Latent Variables	Items	Indicator Loadings	*t*-Value	CA	CR	AVE
OR	OR1	0.771	16.268 ***	0.772	0.854	0.593
	OR2	0.739	14.730 ***			
	OR3	0.710	11.561 ***			
	OR4	0.778	15.654 ***			
	OR5	0.695	11.429 ***			
TR	TR1	0.772	19.410 ***	0.731	0.832	0.555
	TR2	0.785	15.403 ***			
	TR3	0.759	16.057 ***			
	TR4	0.758	15.428 ***			
EN	EN1	0.810	21.890 ***	0.771	0.868	0.686
	EN2	0.840	23.520 ***			
	EN3	0.834	21.597 ***			
CO	CO1	0.835	13.507 ***	0.773	0.858	0.752
	CO2	0.898	36.923 ***			
ST	ST1	0.735	11.039 ***	0.797	0.868	0.622
	ST2	0.820	22.198 ***			
	ST3	0.812	22.294 ***			
	ST4	0.785	15.719 ***			
IF	IF1	0.802	14.626 ***	0.817	0.892	0.734
	IF2	0.858	28.324 ***			
	IF3	0.907	45.144 ***			
TE	TE1	0.725	13.827 ***	0.799	0.869	0.624
	TE2	0.626	7.947 ***			
	TE3	0.825	22.829 ***			
	TE4	0.630	7.626 ***			
	TE5	0.766	18.307 ***			
	TE6	0.763	19.202 ***			
IT	IT1	0.806	18.168 ***	0.789	0.863	0.612
	IT2	0.791	20.025 ***			
	IT3	0.748	10.860 ***			
	IT4	0.783	17.164 ***			

Note: *** means $p < 0.001$.

Table 7. Cross-loading criteria.

	TR	IF	CO	TE	EN	ST	IT	OR
CO1	0.424	0.459	0.835	0.339	0.447	0.400	0.466	0.336
CO2	0.454	0.510	0.898	0.472	0.604	0.550	0.644	0.478
EN1	0.390	0.520	0.578	0.369	0.810	0.590	0.513	0.413
EN2	0.507	0.569	0.466	0.345	0.840	0.584	0.589	0.425
EN3	0.503	0.519	0.487	0.492	0.834	0.550	0.627	0.580
IF1	0.544	0.800	0.552	0.486	0.537	0.595	0.591	0.443
IF2	0.455	0.860	0.381	0.549	0.531	0.611	0.634	0.458
IF3	0.615	0.907	0.509	0.602	0.594	0.582	0.686	0.484
IT1	0.582	0.611	0.536	0.625	0.521	0.538	0.806	0.575
IT2	0.606	0.616	0.511	0.519	0.653	0.580	0.793	0.479
IT3	0.475	0.509	0.488	0.460	0.469	0.503	0.746	0.459
IT4	0.540	0.586	0.498	0.553	0.528	0.545	0.784	0.571
OR1	0.492	0.344	0.356	0.501	0.444	0.502	0.503	0.759
OR2	0.524	0.535	0.461	0.578	0.537	0.599	0.558	0.790
OR3	0.396	0.394	0.247	0.490	0.362	0.499	0.464	0.733
OR4	0.472	0.378	0.385	0.527	0.401	0.542	0.526	0.797
ST1	0.471	0.465	0.351	0.507	0.505	0.731	0.481	0.530
ST2	0.478	0.587	0.424	0.452	0.554	0.821	0.572	0.517
ST3	0.539	0.599	0.473	0.540	0.580	0.812	0.601	0.609
ST4	0.433	0.531	0.501	0.452	0.547	0.787	0.524	0.540
TE1	0.464	0.567	0.393	0.769	0.339	0.491	0.568	0.475
TE3	0.454	0.496	0.332	0.834	0.452	0.499	0.534	0.583
TE5	0.421	0.401	0.367	0.782	0.426	0.512	0.533	0.617
TE6	0.447	0.543	0.405	0.773	0.322	0.453	0.550	0.487
TR1	0.775	0.518	0.505	0.510	0.470	0.475	0.591	0.473
TR2	0.784	0.457	0.412	0.447	0.454	0.482	0.523	0.522
TR3	0.756	0.426	0.300	0.298	0.401	0.412	0.490	0.421
TR4	0.657	0.468	0.261	0.412	0.346	0.445	0.492	0.406

Table 8. Fornell-Larcker criterion.

	TR	IF	CO	TE	EN	ST	IT	OR
TR	0.745							
IF	0.63	0.857						
CO	0.507	0.56	0.867					
TE	0.567	0.639	0.475	0.790				
EN	0.565	0.648	0.614	0.485	0.828			
ST	0.61	0.694	0.556	0.619	0.694	0.789		
IT	0.707	0.745	0.65	0.692	0.697	0.693	0.783	
OR	0.615	0.539	0.477	0.682	0.571	0.698	0.668	0.77

3.2. Structural Model Test

In this study, IT showed the highest R^2 value (0.736), followed by IF (0.601), ST (0.477), TR (0.426) and TE (0.377). These R^2 values confirmed the structural model's prediction power. All endogenous variables showed positive Q^2 values (TR = 0.223, IF = 0.418, TE = 0.234, ST = 0.292, and IT = 0.424), confirming the structural model's predictive relevance. All exogenous variables had influence on endogenous variables, except for OR on IT, with f 2 values of 0.019 (Table 9). The GoF value is 0.428, indicating the complete model performs very well. The results of hypotheses testing are shown in Table 10 and Figure 2. In total, 13 of 14 hypotheses were confirmed.

Table 9. Effect size f^2.

	TR	IF	CO	TE	EN	ST	IT	OR
TR		0.054					0.08	
IF							0.081	
CO	0.105						0.063	
TE		0.096					0.064	
EN		0.072				0.928	0.055	
ST		0.064		0.621				
IT								
OR	0.32						0.019	

Table 10. Results of hypotheses testing.

Path	Path Coefficient	*t*-Value	Inference
H1a OR -> IT	0.107	1.475	Rejected
H1b OR -> TR	0.183	6.217 ***	Supported
H2a TR -> IT	0.204	3.109 ***	Supported
H2b TR -> IF	0.197	2.143 **	Supported
H3a EN -> IT	0.177	2.053 **	Supported
H3b EN -> IF	0.239	2.240 **	Supported
H3c EN -> ST	0.694	11.657 ***	Supported
H4a CO -> IT	0.168	2.634 **	Supported
H4b CO -> TR	0.276	2.849 ***	Supported
H5a ST -> IF	0.250	2.147 **	Supported
H5b ST -> TE	0.619	10.619 ***	Supported
H6a TE -> IT	0.194	2.540 **	Supported
H6b TE -> IF	0.257	2.517 **	Supported
H7 IF -> IT	0.266	2.046 **	Supported

Note: *** means $p < 0.001$, ** means $p < 0.05$.

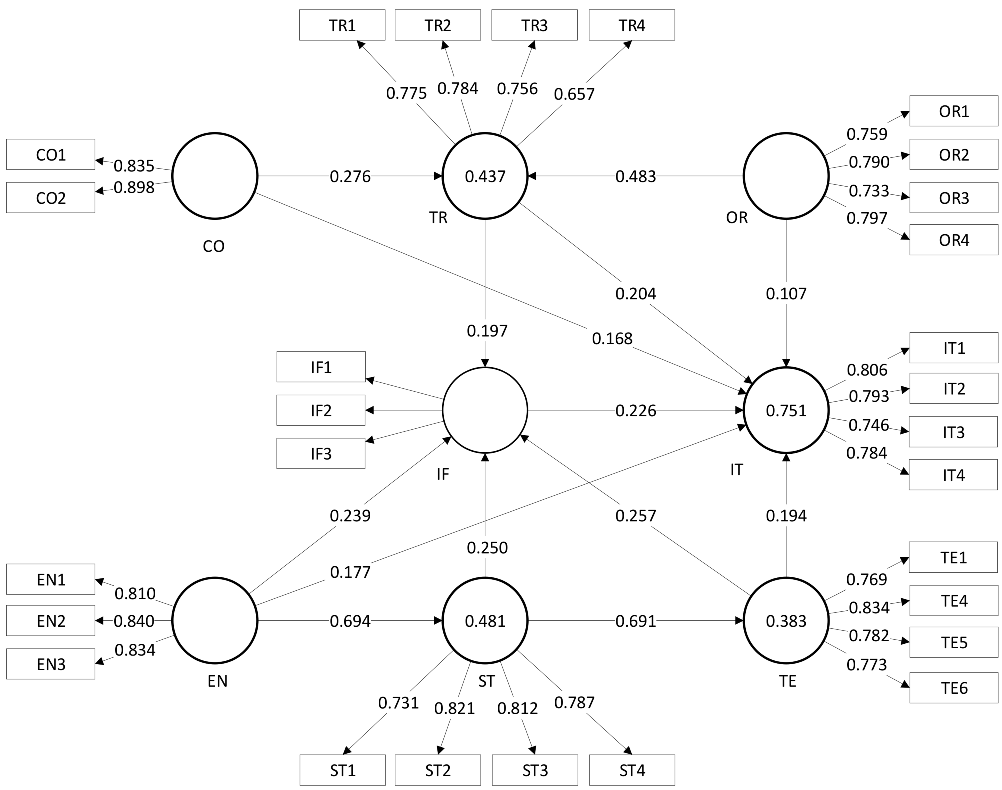

Figure 2. Results of the structural model.

It can be seen from the conceptual model that factors not only directly affect interface management, but also do so indirectly through mediation variables. Therefore, this study further verified the existence of these indirect pathways by mediating effect test. According to Table 11, among the 22 indirect paths, 10 paths meet the mediating effect test. However, only 4 of these indirect paths have a significant impact on interface management.

Table 11. Indirect effect coefficient and significance testing.

Path	Indirect Path Coefficient	*t*-Value	Inference
TR -> IF -> IT	0.044	1.332	Rejected
OR -> TR -> IF	0.095	2.096 **	Supported
TE -> IF -> IT	0.058	1.635	Rejected
EN -> ST -> TE -> IF	0.110	2.253 **	Supported
EN -> ST -> TE -> IF -> IT	0.025	1.505	Rejected
ST -> TE -> IF -> IT	0.036	1.578	Rejected
EN -> ST -> TE -> IT	0.083	2.284 **	Supported
EN -> ST -> IF	0.173	2.168 **	Supported
EN -> IF -> T	0.054	1.334	Rejected
EN -> ST -> TE	0.429	6.786 ***	Supported
OR -> TR -> IT	0.099	2.523 *	Supported
CO -> TR -> IF -> IT	0.012	1.059	Rejected
EN -> ST -> IF -> IT	0.039	1.542	Rejected
ST -> TE -> IF	0.159	2.382 **	Supported
CO -> TR -> IF	0.054	1.487	Rejected
CO -> TR -> IT	0.056	2.119 **	Supported
ST -> TE -> IT	0.12	2.317 **	Supported
OR -> TR -> IF -> IT	0.021	1.343	Rejected
ST -> IF -> IT	0.056	1.579	Rejected

Note: *** means $p < 0.001$, ** means $p < 0.05$, * means $p < 0.5$.

4. Discussion

According to the direct effect results in Table 10 and indirect effect results in Table 11, all paths with significant effect were sorted out, as shown in Table 12. In general, all the seven factors in the conceptual model can influence interface management through direct or indirect paths. From the perspective of direct effect, the order of influence degree from high to low was IF, TR, TE, EN, CO, OR, ST. From the perspective of the total effect, EN, IF, CO, ST, TR, TE, OR. Further, in order to clearly analyze the influencing mechanism of factors, this study will successively explain from the shortest path in the following section.

(1) Information communication

By examining the structural model, it is confirmed that information positively influences interface management (H7, 2.66). These findings echo previous studys' argument that Information communication is the key of interface management. Timely and effective cross-interface information communication can improve the decision-making efficiency of interface management [47]. The design, production and construction of PC projects are fragmented, and many participants are scattered in time and space. Information communication is an important method to achieve seamless docking among participants across the space-time interface. In the research on interface management of PC projects, Mccarney and Gibb argued that open information communication can effectively improve interface management performance [13].

(2) Trust and cooperation

The positive influence of trust and cooperation on interface management was also verified (H2a, 0.204). The success of prefabricated building projects requires broad and deep cross-organizational interdependence based on trust and cooperation. Existing studies show that trust and cooperation can not only directly benefit interface management, but also have a positive impact on interface management by enhancing the permeability and flexibility of organizational interface [28]. However, trust between organizations does not naturally exist, and the temporary and adversarial nature of the traditional construction industry makes it difficult to establish long-term partnerships between project participants who have just entered the field of PC. It is of great significance to promote the integration of the PC supply chain and encourage the establishment of long-term and stable cooperative relations between enterprises to enhance mutual trust and improve interface management.

Table 12. The path with significant effect.

	Path	Direct Effect	Indirect Effect	Total Effect
OR	-> TR	0.183		0.183
	-> TR -> IF		0.095	0.095
	-> TR -> IT		0.099	0.099
	-> IT		0.120	0.120
EN	-> ST	0.694		0.694
	-> ST -> TE		0.429	0.429
	-> ST -> TE -> IF		0.110	0.110
	-> ST -> TE -> IT		0.083	0.083
	-> ST -> IF		0.173	0.173
	-> IF	0.239	0.284	0.523
	-> IT	0.177	0.201	0.378
CO	-> TR	0.194		0.194
	-> TR -> IT		0.056	0.056
	-> IT	0.168	0.069	0.237
ST	-> TE	0.619		0.619
	-> TE -> IF		0.159	0.159
	-> TE -> IT		0.120	0.120
	-> IF	0.250	0.159	0.409
	-> IT		0.213	0.213
TR	-> IF	0.197		0.197
	-> IT	0.204		0.204
TE	-> IF	0.257		0.257
	-> IT	0.194		0.194
IF	-> IT	0.266		0.266

(3) Technical and management ability

It is confirmed that technology and management ability positively influence interface management (H6a, 0.194). The influence of technology and management ability on interface management is relatively intuitive. For example, accurate design can eliminate the compatibility problem of component connection from the root [44]. Participants with strong management experience and ability, who are proficient in the relatively new technology of prefabricated construction, can identify and manage interfaces with their rich experience; The timeliness of component supply and the tracking ability of production and installation are important guarantees for the seamless connection of the delivery interface between the component manufacturer and the on-site contractors.

(4) Standardization

There is a significant direct positive influence of standardization on technical and management ability (H5b, 0.619), and it can also affect interface management through an indirect path (standardization -> technical and management ability -> interface management (0.083)). Standardization is the core of PC technology and management [36]. In the production process of repetitive PC components, the process of standardization is a process of continuous learning and improvement by technical and managerial personnel through repetitive work.

(5) Organizational integration

The positive influence of organizational integration on interface management was rejected (H1a, 0.107). Given this result, the authors communicated with the interviewees and found that most of the prefabricated building participating enterprises tried to adopt advanced technical tools and called for win-win cooperation. However, in practice, most of the projects did not completely get rid of the traditional project organization mode, and it was difficult to close the institutional distance between them. In such a context, simply improving the organizational integration of a project may not be sufficient to meet the interface management requirements of a more complex PC project. The interviewees also reported that the current enterprises involved in the PC projects are generally inexperienced, and the temporary project team lacks long-term cooperation experience, which makes the participants still face a series of challenges in terms of the high organizational integration requirements of PC projects. For example, BIM is still mainly used for design optimization and rarely plays the role of collaboration. Therefore, the organizational integration of current PC projects has complex influences on interface management. The linear relationship between organizational integration and interface management is not obvious.

There are indirect effects of organizational integration on interface management, among which, the path of organizational integration -> trust and cooperation -> interface management (0.099) is the main source of indirect effects. Along this path, organizational integration positively influences trust and cooperation (H1b, 0.183), trust and cooperation positively influence interface management (H2a, 0.204), and the mediating effect of the variables trust and cooperation is significant. Therefore, although the influence of organizational integration degree on interface management of current prefabricated construction projects is complex, the positive influence of organizational integration on trust and cooperation between project participants is certain [25,26].

(6) Technical environment

The technical environment was confirmed to significantly affect interface management (H3a, 0.177). The use of BIM and other technologies breaks the boundaries of participants in time and space and provides a unified platform for interface management [54]. Technical standards and specifications provide standards for interface management. Standardization facilitates the management of physical interfaces and the management of dependent interfaces between installation activities [32,33]. Therefore, enhancing the ability of technological innovation, improving technical standards and norms, and improving the level of standardized design all have a direct effect on improving interface management performance.

The technical environment also has indirect effects on interface management: technical environment -> standardization -> technical and management ability -> interface management (0.083) is significant. On this path, the technical environment has a significant positive impact on the standardization level (H3c, 0.694), and the standardization level has a positive impact on interface management (H5a, 0.250). The mediating effect of mediating variables on this path is significant. The technical environment provides a standard and normative basis for the standardization of production and construction technology, information communication, component connection and management. It is an important guarantee for the improvement of standardization.

(7) Contract management

Contract management is particularly important in the literature on interface management of both traditional and PC projects [6,13]. Contract management also influences interface management through a direct path and an indirect path. On the direct path, contract management positively influences interface management (H4a, 0.168). A clear division of work scope and reasonable allocation of responsibilities and rights in contract management can effectively reduce interface conflicts on contract boundaries [37], which has been repeatedly confirmed in the relevant literature on contract interface management [55]. Meanwhile, this is also in line with the basic views of the existing literature on interface management of PC projects [6,13].

Contract management also indirectly influences interface management through trust and cooperation. The action path is: contract management -> trust and cooperation -> interface management (0.056). According to the structural model test, contract management was confirmed to positively affect trust and cooperation (H4b, 0.276). This finding echoes Zhong et al.'s view that Contracts help to restrain disputes and promote a good spirit of trust and cooperation. In PC projects, the contractual relationship is more complex. Successful contract management can avoid the mutual buck-passing caused by the fuzzy interface, which makes the relevant interface become the blind spot of management.

5. Conclusions

This study aims to explore how interface management is affected by various factors. The hypothesis of interaction between different factors is deduced and put forward based on the literature review, and the conceptual model of the interaction path of influencing factors for interface management of PC projects is established. Finally, the hypothesized interaction relationships embedded in the proposed research model were empirically evaluated with survey data using the PLS-SEM technique.

The findings indicate that information communication, trust and cooperation, technology and management ability, standardization, technical environment, contract management and interface management have a significant positive correlation, forming 6 direct paths affecting interface management. Combined with the mediating effect analysis, 4 indirect paths that are significantly correlated with interface management were also identified: Standardization -> technical and management ability -> interface management, Organizational integration -> trust and cooperation -> interface management, Contract relationship -> trust and cooperation -> interface management, Organizational integration -> trust and cooperation -> interface management; Technical environment -> standardization -> technical and management ability -> interface management. All 7 latent variables in the conceptual model can influence interface management through direct or indirect paths. Among them, information communication, trust and cooperation, technology and management ability have a greater direct effect on interface management, while technical environment, information communication and contract management have a greater total effect on interface management.

This study reveals the influence mechanism of interface management of PC projects, which can bridge the existing research shortcomings and provide a reference for solving interface management problems in practice to promote the development of PC.

However, there are some limitations in this study. The experts investigated in this study mainly were from prefabricated concrete projects, not covering the whole industry. In the future, more extensive investigations can be carried out in the whole industry to increase the depth of research. Besides, influence mechanism among factors analyzed. However, the acquisition of research data mostly depends on the experience and knowledge of experts. A system case base is still lacking to support PC projects' interface management research. Thereby, we will build a PC projects case library and universal interface management model to provide project managers with a retrieval program and analysis tool. Further, the data sources are limited to Chinese PC project practitioners and scholars. In the future, the scope of data sources can be further expanded to compare and verify the results obtained in this study.

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Informed Consent Statement: Not applicable.

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

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