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Influence Mechanism of Construction Supply Chain Information Collaboration Based on Structural Equation Model

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Abstract: The construction supply chain has many stakeholders and complex and diverse information, which cause various information exchange problems that diminish project management efficiency. Thus, information collaboration is an important factor in the construction supply chain. This study aims to improve the efficiency of project management by analyzing the factors hindering information collaboration in the construction supply chain in order to determine their internal influencing mechanisms. The relevant data of 281 construction employees is collected by questionnaire survey. The relationship among stakeholders (SH), information technology (IT), external stability mechanism (ESM), and information collaboration is then quantitatively evaluated based on the structural equation model (SEM). The results show that stakeholders, information technology, and the external stability mechanism have an influence on information collaboration, while stakeholders do not have a significant influence. Information technology and the external stability mechanism significantly influence information collaboration and provide a mediation role between stakeholders and information collaboration. The innovation of this work is the quantification of information collaboration influencing factors in the construction supply chain and the analysis of its potential path relationship according to the mediating effect test. Its theoretical contribution is to address the research gap in construction supply chain information collaboration and expand the research scope of construction project collaborative management regarding information collaboration. Finally, this work has a practical contribution by providing suggestions for improving the efficiency of building supply information collaboration.

Keywords: construction supply chain; information collaboration; structural equation model (SEM); mediating effect

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1. Introduction

Despite the significant impact of the COVID-19 epidemic on the Chinese economy, the construction industry has continued to maintain itself as an important national pillar industry. According to the macro data released by the National Bureau of Statistics, the GDP of China's construction industry from 2018 to 2021 was USD 3.27 trillion, USD 3.60 trillion, USD 3.83 trillion and USD 4.25 trillion, respectively. China's total GDP in 2021 was USD 16.58 trillion, with the construction industry accounting for 25.6% [1]. Although the global economic impact of COVID-19 has not subsided, China's construction industry is still developing steadily. China's construction projects have gradually diversified and become more complicated as the industry continues to develop. At the same time, because construction projects have the characteristics of high investment, long cycles, many participants, the same source of heterogeneous information, etc., timely sharing of project information data between stakeholders is difficult. This diminishes the efficiency of project management due to creating information islands. In order to realize the effective utilization of construction project information, it is necessary to combine scientific management modes to effectively manage the information among stakeholders [2]. Therefore, construction supply chain management is an effective means to improve management efficiency, with significant research significance [3].

All participants in the construction supply chain require the sharing of information and logistics to jointly promote the operation efficiency of the construction supply chain [4]. Supply chain integration and collaboration improve performance by establishing close relationships and activities between upstream and downstream participants [5]. In the construction sector, integration and collaboration can improve the efficiency and quality of production processes [6]. Information exchange and coordination along the entire supply chain play a decisive role not only in the successful operation of a specific node but of the success of the whole supply chain. Therefore, effective supply chain management can expand the logical boundaries of an organization and is an important strategy to maintain the effectiveness of the entire supply chain to ensure efficient information flow [7].

Information collaboration is a key element of any supply chain system [8]. Information collaboration is to improve the efficiency of information transmission, enhance the sharing of information resources, and integrate disordered information in an orderly way under the joint action of information elements to achieve information collaboration [9]. A lack of real-time information sharing will result in fragmented and discontinuous activities by different participants [10]. The construction industry has been relatively slow in its adoption of advanced technology, resulting in data collection and sharing that is often inaccurate and incomplete [11,12]. As orderly construction activities require the sharing of large amounts of information, poor communication between project participants often leads to ineffective project management and project failure [13]. Distorted information will also affect an enterprise's judgment of emergencies, reducing flexibility and agility in the supply chain [14]. Previous studies have largely focused on developing technical tools to promote the circulation, sharing, and transmission of information, with less focus on information collaboration in the construction supply chain. Thus, the main factors affecting information collaboration in the construction supply chain have not been systematically analyzed. However, research on the influencing factors that hinder information collaboration in construction supply chain management is critical for improving the efficiency of project management. Therefore, this paper analyzes what factors influence the information collaboration effect of the construction supply chain and identifies the internal influence mechanisms between these factors. The factors that hinder information collaboration in the construction supply chain are summarized, and the internal influence mechanism is revealed by constructing a structural equation model between each influencing factor and information collaboration, aiming to improve the efficiency of project management. The innovation of this paper is to quantify the influencing factors of information collaboration in the construction supply chain and analyze its internal relations through the mediating effect. Theoretically, this paper not only addresses the lack of research into construction supply chain information collaboration but also expands the research scope of construction project collaborative management regarding information collaboration. In practice, this study provides valuable suggestions for improving the efficiency of construction supply chain information collaboration.

The introduction of the article on the construction supply chain provides the research background and significance of a brief discussion. The literature review part summarizes the research status in the field of construction supply chain. The research hypothesis is based on a large number of literatures. In the research design and method, the technical route is proposed, and the questionnaire survey method and structural equation model method used in the research are introduced. The reliability and validity test, model fitting test, hypothesis test and intermediary effect test in a structural equation model are used to obtain the research results. Based on the test results, the similarities and differences between the results and previous studies are discussed and compared. Finally, the conclusion summarizes the theoretical contribution, practical significance, research limitations and future research directions of this paper.

2. Literature Review

Using the Web of Science database as the data source and "construction supply chain" and "information collaboration" as the keywords, we first searched 48 SCI core literature. As the information collaboration referred to in this paper mainly involves information sharing and information transfer, in order to effectively expand the scope of research, "construction supply chain" and "information synergies," "construction supply chain" and "information sharing," "construction supply chain" and "information transfer" were, respectively, used as the subject words for searching. The second search totaled 98 articles (three for "construction supply chain" and "information synergies," 78 for "construction supply chain" and "information sharing," and 17 for "construction supply chain" and "information transfer"). We collected 146 relevant articles by conducting two literature searches. Documents labeled "Article," "Review article," "Early access," and "Proceeding paper" were retained, papers in the field of construction projects were limited, and documents that were inconsistent with the theme (25), missing information (0), and duplicate documents (5) were screened. Finally, 116 documents were retained. Keyword co-occurrence analysis was then conducted using VOS viewer visual analysis software to summarize the current research status of information collaboration in the construction supply chain (see Figure 1). The four clusters of management, collaboration, supply chain, and performance can be identified in Figure 1.

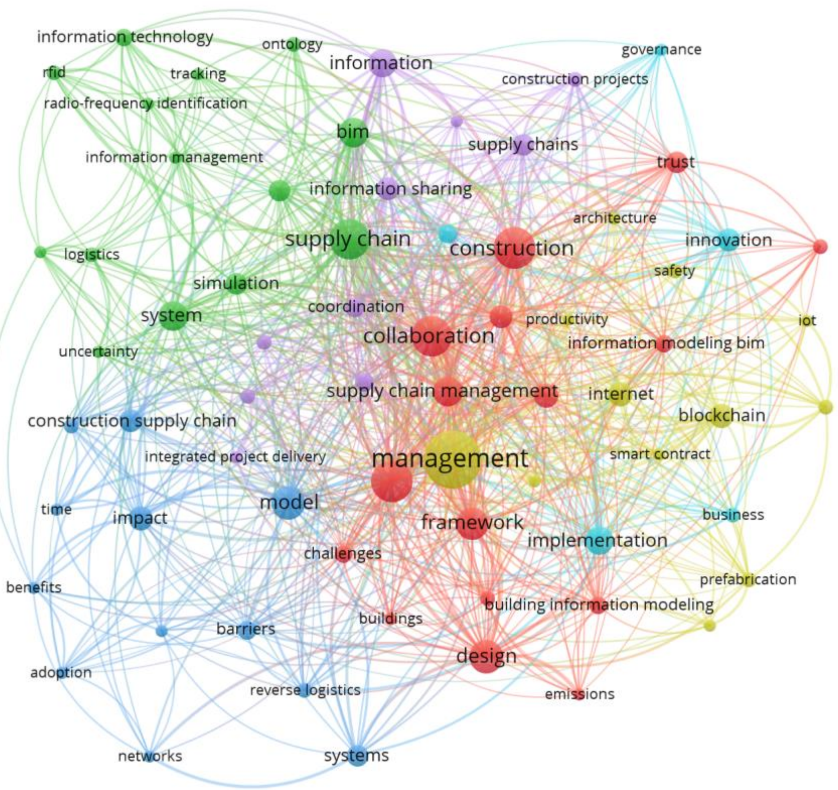


Figure 1. Co-occurrence of keywords (keyword co-occurrence threshold is 3).

The key factors of collaborative technology and the obstacles of information management in the construction supply chain are analyzed by using the model of system dynamics method [15], which mainly highlights the impact of the complexity of information, top management support, trust and cooperation of the three factors on construction supply chain information management. However, it was not suggested that the safeguard mechanism might have an impact on information management. The web services framework promotes the storage and sharing of information in a distributed manner through ontology-based web services to solve the problem of data heterogeneity and data sharing in the construction industry [16]. It mainly provides a new method for the storage and sharing of information in the construction supply chain, and does not comprehensively analyze the factors affecting information coordination. The system framework for the Context-Aware Cloud Computing Building Information Modeling (CACCBIM) for prefabrication supply chain management was developed to address issues such as lack of integration, poor coordination, lack of good communication between parties, and poor control and supervision that may adversely affect the objectives and success of prefabrication projects [17]. However, the possible relationship between various influencing factors is not proposed. A customer-oriented intelligent building supply chain information integration management framework based on radio frequency identification and wireless sensor network (RFID/WSN) technology is constructed [18]. It provides a new technology for construction supply chain information management, and does not analyze more factors affecting information collaboration. According to our analysis, the current research on the direction of information collaboration in the construction supply chain is largely focused on promoting information circulation, information-sharing methods, and tools. There is a lack of systematic analysis of the factors that hinder information collaboration in the construction supply chain, an absence of research on the collaborative management of construction projects, and less work directly related to information collaboration in the construction supply chain.

The construction industry is information-intensive from start to implementation [19]. The construction supply chain is dominated by the needs of the owners. Through the control of information flow, logistics and capital flow, a functional network chain structure is formed around the construction project by stakeholders such as construction parties, suppliers and designers [20]. Information flow in the construction supply chain is a two-way flow, which not only reflects but also controls and directs the logistics and capital flow. Only when the information flow is efficient and smooth, the logistics and capital flow can be efficient and smooth, and the implementation process of the project construction can be smooth and efficient. Information plays an important role in enterprise benefit and supply chain integration [15]. The construction process is information-centric, and project-related information is managed by managers, which directly affects the performance of the construction supply chain [21]. Therefore, information collaboration in construction supply chain is of great significance to construction project management.

The structural equation model employs a multiple regression method. Multiple relationships between independent variables and dependent variables are modeled by structural equation modeling, and aggregate dependencies are simultaneously accommodated in a comprehensive model [22]. This method examines the complex relationship between a set of variables that cannot be tested by regression analysis [23]. In some cases, the relationships between variables are so complex that causal flows may exist between observed variables [24]. All the following studies use a structural equation model to study the influence mechanism: study on the influence mechanism of highway project investment risk factors [25]; examining the impact of digital transformation on sustainable supply chain performance [26]; study on the influencing factors of effective public participation in sustainable energy projects [27]; study on the impact of sustainable infrastructure evaluation on the success of construction projects [28]. Similarly, in the construction supply chain, there are many factors that affect information coordination. Therefore, it is of great significance to study the influence mechanism of construction supply chain information collaboration using the structural equation model.

3. Research Hypothesis

3.1. Determination of Influencing Factors

By consulting the relevant literature, this paper systematically studies the information collaboration of the construction supply chain from four aspects: information collaboration, stakeholders, external stability mechanism, and information technology.

3.1.1. Information Collaboration

The improvement of information quality can alleviate the adverse effects of information silos [14,29], while information visualization and delivery timeliness can measure levels of information collaboration [30]. Information sharing plays a key role in supply chains [31]. Continued research on the use, effects, and prospects of information technology will improve productivity further [32]. The use of the software also affects the transmission of information [33]. Therefore, this paper selects six observation variables to measure information collaboration in the construction supply chain, as detailed in Table 1.

3.1.2. Stakeholders

Trust is a prerequisite for a successful supply chain [34], where early stakeholder participation in a project helps to achieve supply chain integration and collaboration [35,36]. The early participation and cooperation of stakeholders and increased levels of trust between them are also conducive to removing some implementation barriers [37]. Based on the above literature, we select three observation variables to measure stakeholders, as detailed in Table 1.

3.1.3. External Stabilization Mechanism

Clear contract terms reflecting project processes and as-built specifications are essential [38]. To promote the healthy operation of the project and maintain social stability and development, relevant government departments should constantly optimize the supervision mechanism [39]. In the realization of green building supply chain information sharing, the corresponding incentive and constraint mechanism can be designed to improve the enthusiasm of green building supply chain enterprises to participate in supply chain coordination and green practice [40]. To achieve information collaboration, it is necessary to set up cooperation mechanisms to ensure the stability of the cooperative relationships, which mainly include risk management and conflict management mechanisms [14]. Therefore, based on the above literature, four observation variables are selected to measure the external stability mechanism, as detailed in Table 1.

3.1.4. Information Technology

The exchange of information between different software is an important area of information technology [41]. A collaborative platform combining cloud computing technology and building information modeling (BIM) can improve the efficiency of design and construction [42]. The database is the most basic link in the information flow network, where all parties can access and read data [43]. Building information must also be integrated or compatible with relevant information systems [44]. We employ four observation variables to measure information technology in this work, as detailed in Table 1.

Table 1. Variable Selection.

Latent Variable	Observational Variable	Code	Reference
Information collaboration (IC)	Timely update of information transmission	IC1	[30]
	The quality of information	IC2	[14,29]
	using easily of software	IC3	[33]
	Information visualization	IC4	[30]
	Information sharing	IC5	[31]
	Development and application of information technology	IC6	[32]
Stakeholders (SH)	Early (pre-planning stage) engagement and collaboration among project stakeholders	SH1	[35]
	Cooperation among project stakeholders	SH2	[35,36]
	Trust among project stakeholders	SH3	[34]

Table 1. *Cont.*

Latent Variable	Observational Variable	Code	Reference
External Stability Mechanism (ESM)	Risk management mechanism	ESM1	[14]
	Supervision mechanism	ESM2	[39]
	Restrictive mechanism	ESM3	[40]
	Perfect legal provisions system	ESM4	[38]
Information technology (IT)	Information interoperability between different software	IT1	[41]
	Collaborative management platform	IT2	[42]
	Building BIM database	IT3	[43]
	Compatibility of information transmission	IT4	[44]

3.2. Proposed Hypothesis

3.2.1. Stakeholders and External Stability Mechanisms

Information sharing provides different benefits to stakeholders. In the face of emergencies, without strong enterprise coordination and a stable cooperation mechanism, conflicts of interest will hamper project coordination [14]. Thus, guidance is required to assist multiple stakeholders to obtain updated project governance through effective participation and full consultation [45]. To maximize interests, major problems among stakeholders must be identified, and a corresponding coordination mechanism should be constructed [46]. Therefore, our first hypothesis is that stakeholders have a positive impact on the external stability mechanism.

3.2.2. Stakeholders and Information Technology

Information technology tools are indispensable for stakeholder communication. The early participation and cooperation of stakeholders will both enhance mutual trust and help to eliminate obstacles in the implementation of BIM technology [37]. For the success of BIM technology, communication between project participants should be maintained on a single shared data platform, and all stakeholders must participate in the project as early as possible [47]. Data must also be processed on a specific information data management platform [42] to achieve barrier-free information exchange among project participants [48]. Therefore, our second hypothesis is that stakeholders have a positive impact on information technology.

3.2.3. Stakeholders and Information Collaboration

Information sharing among stakeholders is the basis for realizing information collaboration in the construction supply chain [41], whereby effective communication, trust, and respect are key factors for successful teamwork [30]. The success of information sharing depends on high-quality and real-time-updated information access among many stakeholders [49]. Conversely, distrust and bad cooperation among participants will reduce the level of information sharing [50]. In this information-intensive industry, communication and cooperation among stakeholders are a strong driving force [32], while the fragmentation of stakeholders in construction projects will hinder high-quality information collaboration [49]. The early participation of key participants in project construction can reduce feedback problems and errors that may arise in the process of information transmission [51]. Cultivating trust between participants will support an environment of data exchange and communication in the supply chain [52]. Thus, supply chain integration and collaboration are required to establish close relationships and activities among stakeholders to improve the degree of information collaboration [53]. Therefore, our third hypothesis is that stakeholders have a positive impact on information collaboration.

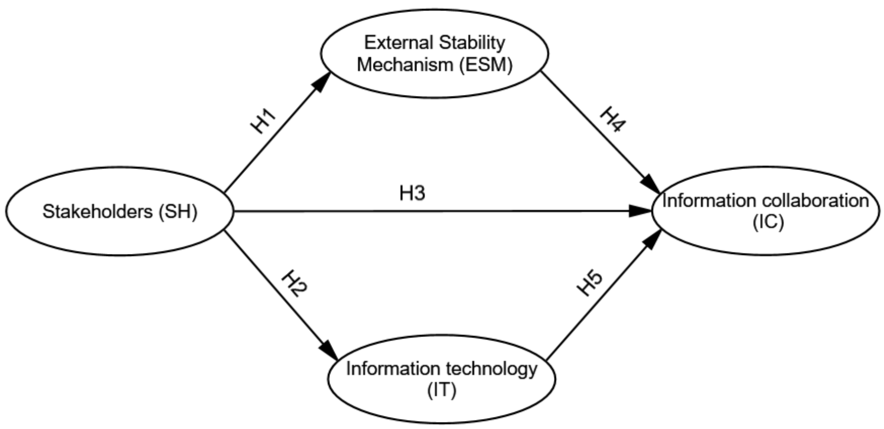
3.2.4. External Stability Mechanism and Information Collaboration

The external stability mechanism provides guarantees for supply chain applications. An information supply chain that employs effective supervision, constraint, and management mechanisms in relevant departments as the intermediary will improve the quality of information transmission [54]. Thus, within the context of the rapid development of information technology, the realization of information collaboration requires a stable cooperation mechanism [14]. Formulating and implementing information-sharing mechanisms and contract agreements according to practice will increase project information integration [51]. Therefore, our fourth hypothesis is that the external stability mechanism has a positive impact on information collaboration.

3.2.5. Information Technology and Collaboration

Information technology is an important factor affecting the success of construction supply chain management [8]. The BIM F-PSC model based on blockchain can solve the problems of automated information sharing, information transparency, and reliability in the supply chain [10]. The collaborative design of construction projects is based on the same data collaboration platform, which can realize real-time information sharing among all parties involved [42]. Digital twin technology has great potential to support information sharing among project participants [49]. Therefore, advanced information technologies, such as building information modeling (BIM) and virtual reality (VR), can be used to improve workspace planning and construction activities, share safety information among all partners, and realize the information representation and integration of multidimensional project models [55]. Information-sharing support technology is mainly based on advanced manufacturing technology and emerging supply chain management information technology applications, which can strengthen information sharing among partners [8]. Thus, information technology plays a positive role in supply chain information collaboration, such as the relationship model between RFID technology and information sharing [56]. Therefore, our fifth hypothesis is that information technology positively impacts information collaboration.

We select the above five assumptions according to the literature. A conceptual model is then constructed based on the assumptions to depict the direct impact relationship between stakeholders, the external stability mechanism, information technology, and information collaboration (see Figure 2).



Note: H1 = Hypothesis 1:Stakeholders have a positive impact on the external stability mechanism;
H2 = Hypothesis 2:Stakeholders have a positive impact on information technology;
H3 = Hypothesis 3:Stakeholders have a positive impact on information collaboration;
H4 = Hypothesis 4:The external stability mechanism has a positive impact on information collaboration;
H5 = Hypothesis 5:Information technology positively impacts information collaboration.

Figure 2. Conceptual model.

4. Research Design and Method

4.1. Technical Route

We determine the impact mechanism of stakeholders, information technology, and external stability mechanism on information collaboration in construction supply chain management according to previous research. The technical route of this article is illustrated in Figure 3. Firstly, the factors affecting information collaboration in the construction supply chain are determined by literature induction, a research hypothesis is put forward, and the conceptual model is established. Secondly, the questionnaire survey method is used to investigate the industry practitioners, whereby effective samples are retained after data screening. The validity of the data is tested by normal distribution, homology deviation, and non-response deviation tests, and descriptive statistical analysis is performed on the data. Reliability, validity, and model fitting tests are then carried out via the structural model equation, and the conceptual model is verified by hypothesis and intermediary tests. Finally, based on the results of previous studies, we discuss whether our hypotheses are established and summarize the conclusions.

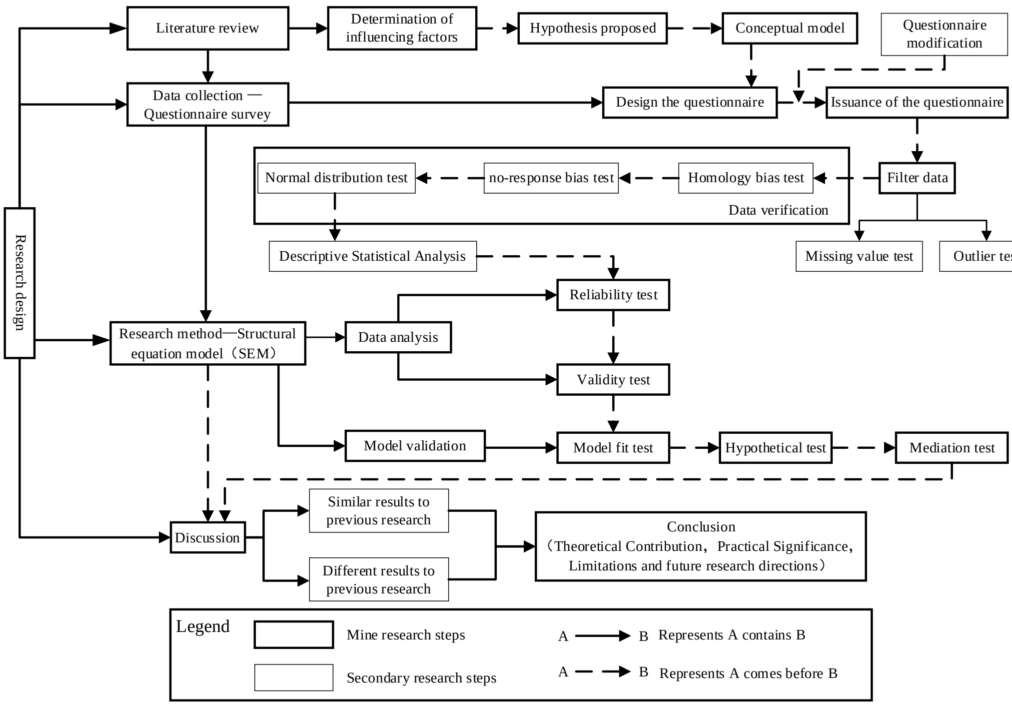


Figure 3. Technical route.

4.2. Questionnaire Design

According to the literature induction method, this paper initially proposed 17 factors that most significantly affect information collaboration in the construction supply chain. The preliminary designed questionnaire was distributed to two construction units for trial filling and revised accordingly. A formal questionnaire was then created and distributed. The questionnaire was distributed according to three main methods: (1) We collected the contact information of authors published in CNKI, WANFANG, CQVIP, and other core journals with research related to the subject. The corresponding industry practitioners and researchers were then invited to fill out a mail questionnaire; (2) We obtained the contact information of practitioners and researchers by participating in relevant conferences and forums in the construction industry. Questionnaires were then issued using a combination of online and offline methods; (3) Questionnaire invitations were issued to the staff of the professional practice base and previous graduates engaged in the industry. Data collection was conducted from December 2021 to March 2022, and a total of 309 questionnaires were collected. The questionnaire data were screened by the missing value and abnormal value tests, providing 281 complete and valid data that were retained. Thus, the effective response rate of the questionnaire was 90.94%.

The five-point Likert scale was employed to design a questionnaire for measurement, whereby 1 represented a large negative impact, 2 represented a small negative impact, 3 represented no impact, 4 represented a small positive impact, and 5 represented a large positive impact [57,58]. The selection of potential variables and observation variables is shown in Table 1.

4.3. Structural Equation Modeling (SEM) Method

Structural equation modeling (SEM) is a multivariate data analysis tool [59] with integrated confirmatory factor analysis and path analysis [60] that facilitates the exploration of potential structures through multiple observation variables. As the interaction among stakeholders, information technology, the external stabilization mechanism, and information collaboration is a multi-factor analysis problem; it can be studied in depth using SEM. The system dynamics model [61], grey cluster analysis [62], social network analysis [63], and other methods can also be employed to explore the problem of multivariate analysis. However, we employ structural equation modeling in this work as it can process multiple factors simultaneously and allows a certain amount of error when determining the underlying relationship between variables. Thus, SPSS 25.0 and AMOS 24.0 were used to analyze the collected data, including the reliability, validity, model fitting, hypothesis, and mediating effect tests. The following are the concepts and criteria of each test method.

(1) Reliability test

The reliability test mainly analyzed the consistency and stability of the questionnaire's statistical scale to describe the degree of data response to the actual situation. We predominantly used Cronbach's α value to test the reliability of the data in this work. When Cronbach's α value was greater than 0.7 [64], the reliability of the survey sample was considered to be very high.

(2) Validity test

The validity test reflected the accuracy of the survey sample data. We predominantly used composition reliability (CR) and average variance extraction (AVE) in this work. When the CR value was greater than 0.7 [65] and AVE was greater than 0.5 [66], the validity of the survey sample was considered good.

(3) Model fitting test

The fitting test established a structural equation model with the optimal fitting degree according to the criterion of the fitting index (Table 2).

Table 2. Standard of fitting index.

Fitting Index	Code	Judgment Standard	Reference
Chi-square/Degree of freedom	X2/df	The smaller the value, the better the fitting effect. When X2/df $\leq$ 2, the fitting effect is good.	[67]
Goodness-of-fit index	GFI	When GFI $\geq$ 0.85, it is considered that the fitting degree of the model is good.	[68]
Root mean square error of approximation	RMSEA	When RMSEA < 0.08, it indicates that the model fits well.	[69]
Norm fitting index	NFI	When NFI $\geq$ 0.90, the model fit well.	[66]
Adjusting goodness of fit index	AGFI	When AGFI $\geq$ 0.80, it is considered that the model fitting degree is good.	[68]
Comparative fit index	CFI	When CFI $\geq$ 0.90, it is considered that the model fitting degree is good.	[70]

(4) Hypothesis testing

The p-value is an important indicator in hypothesis testing. When the p-value was greater than 0.05, the factor was considered to have no significant influence; when the p-value was less than 0.05, the factor was considered to have statistical significance [57].

(5) Mediating effect test

Path analysis was employed to test the hypotheses and analyze the mediating effects of latent variables. We used the bootstrap method due to its high statistical power and accurate confidence intervals [71], conducting 5000 bootstrap sampling iterations and a mediation effect test at the 95% level. The mediation effect was considered to be proven if the upper and lower confidence intervals of the bias-corrected test did not contain zero and were significant [72].

5. Research Results

5.1. Data Inspection

SPSS 25.0 software was used to analyze the 281 questionnaires for normal distribution, homology bias, and non-response bias to test the validity of the data. The normal distribution test results show that the absolute value of the skewness of the sample data is not greater than 3, and the absolute value of the kurtosis is not greater than 10 [73]. Thus, the overall data of the sample conforms to the overall distribution. In the homology bias test [74], the Harman method was employed for non-rotation factor testing. The four factors extracted from 281 questionnaires explain 66.725% of the total variance. The variance of the first factor is 22.225%, accounting for 33.308% of the total variance of the factors, which meets the eligibility criteria of less than 50%. This result indicates that the common source bias in this study is not serious and within the acceptable range. In the non-response bias test, the chi-square test [75] results of early and late respondents in the sample show that there is no significant difference in working years and BIM participation ($p > 0.05$), excluding the possibility of non-response bias and indicating that the sampling method is reasonable. In summary, the above data test results show that the questionnaire data is effective. Please see the Supplementary Materials for further details on the data inspection process.

5.2. Descriptive Statistical Analysis of Data

The descriptive statistical analysis mainly focused on the background survey of respondents. It included the unit type, professional title, working years, and the number of BIM projects. As shown in Figure 4, the construction unit respondents account for 34.52%, those of universities and research institutions account for 22.42%, and those of the design unit account for 20.28%. The proportion of the three units is high, indicating that they are more influenced by information transmission in the construction supply chain. As shown in Table 3, 67.62% of the respondents participate in the BIM project experience, the proportion of respondents with intermediate and senior titles is more than 50%, and 68.68% of the respondents have more than three years of employment in related industries, indicating that the respondents have certain professional experience, knowledge levels, and abilities. Questionnaire data collection was mainly concentrated by domestic construction industry workers, and the questionnaire collection and distribution process was described in detail in Section 3.2.

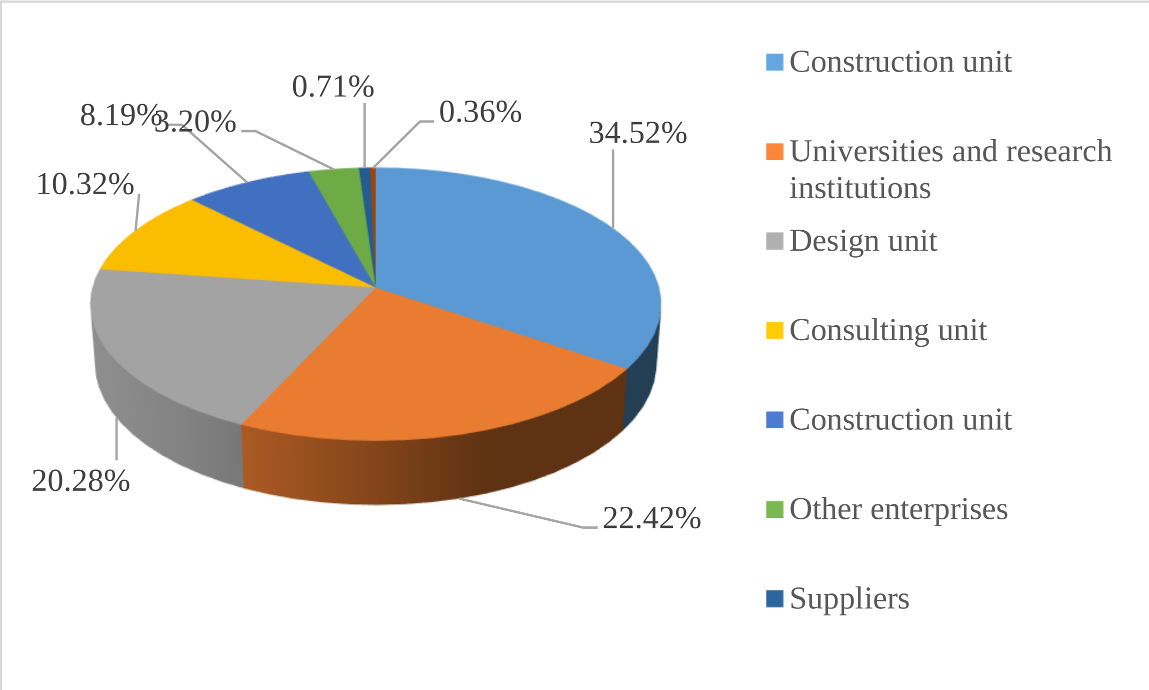


Figure 4. Respondent's unit type and number of personnel.

Table 3. Basic information of respondents.

Information	Quantity	Proportion
Job title		
Primary	57	20.28%
Intermediate	103	36.65%
Advanced	44	15.66%
Other	77	27.40%
Years of experience in the construction industry		
3 years and below	88	31.32%
3–5 years	46	16.37%
5–8 years	48	17.08%
8 years and above	99	35.23%
Number of BIM projects participated		
Never participated	91	32.38%
1–2	96	34.16%
3–5	36	12.81%
6–10	17	6.05%
10 or more	41	14.59%

5.3. Reliability and Validity Tests

The analysis results of the reliability and validity tests are shown in Table 4. The factor loading of the observed variables is between 0.65 and 0.87. The Cronbach's α values of the latent variables are all greater than 0.7, indicating that the reliability of the sample data is strong. Additionally, the CR values are all greater than 0.7, and the AVE values are all greater than 0.5, indicating that the sample data is highly accurate. Therefore, the reliability test and validity test of the sample data meet the requirements.

Table 4. Reliability and validity.

Facet	Code	Cronbach's Alpha	Factor Loading	CR	AVE
Information collaboration (IC)	IC1	0.883	0.82	0.884	0.560
	IC2		0.80		
	IC3		0.69		
	IC4		0.75		
	IC5		0.74		
	IC6		0.68		
Stakeholders (SH)	SH1	0.756	0.77	0.761	0.515
	SH2		0.69		
	SH3		0.69		
External Stability Mechanism (ESM)	ESM1	0.873	0.87	0.877	0.643
	ESM2		0.87		
	ESM3		0.79		
	ESM4		0.66		
Information technology (IT)	IT1	0.806	0.73	0.817	0.529
	IT2		0.81		
	IT3		0.71		
	IT4		0.65		

Note: IC1 = Timely update of information transmission; IC2 = The quality of information; IC3 = using easily of software; IC4 = Information visualization; IC5 = Information sharing; IC6 = Development and application of information technology; SH1 = Early (pre-planning stage) engagement and collaboration among project stakeholders; SH2 = Cooperation among project stakeholders; SH3 = Trust among project stakeholders; ESM1 = Risk management mechanism; ESM2 = Supervision mechanism; ESM3 = Restrictive mechanism; ESM4 = Perfect legal provisions system; IT1 = Information interoperability between different software; IT2 = Collaborative management platform; IT3 = Building BIM database; IT4 = Compatibility of information transmission.

5.4. Model Fitting Test

The results in Table 5 show that the fitting indexes of the constructed prediction model are all within an acceptable range and are highly consistent with the actual situation. Therefore, the fitting effect of the established structural model is the best.

Table 5. Fitting index table.

Fitting Index	Model Score	Compliance
X2/df	1.990	acceptable
GFI	0.918	acceptable
RMSEA	0.059	acceptable
NFI	0.914	acceptable
AGFI	0.890	acceptable
CFI	0.955	acceptable

Note: X2/df = Chi-square/Degree of freedom; GFI = Goodness-of-fit index; RMSEA = Root mean square error of approximation; NFI=Norm fitting index; AGFI = Adjusting goodness of fit index; CFI = Comparative fit index.

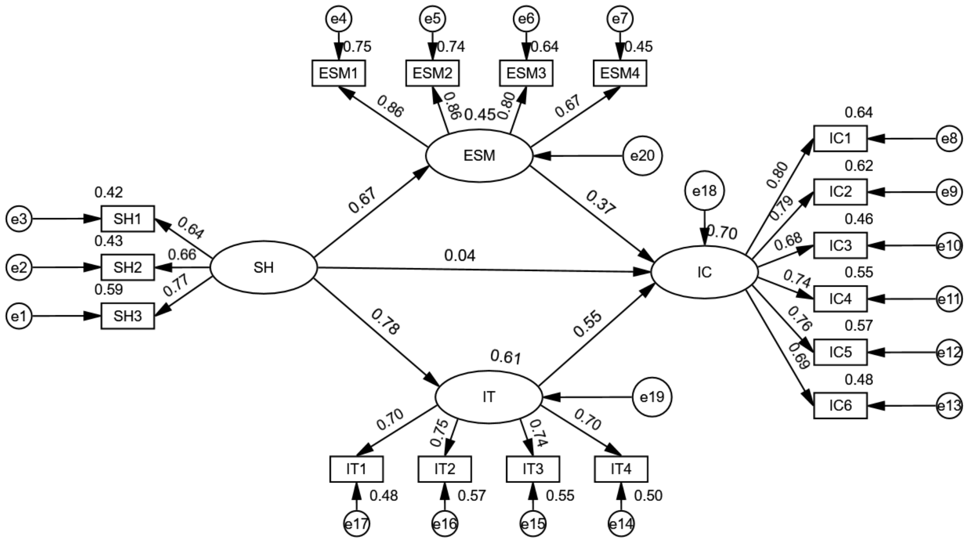
5.5. Hypothesis Testing

As shown in Table 6, the p-value of hypothesis H3 is greater than 0.05, indicating that Hypothesis H3 is not supported; the p-values of hypotheses H1, H2, H4, and H5 are all less than 0.05, indicating that the hypotheses are supported. The optimal structural equation model is shown in Figure 5, illustrating the internal influence mechanism among stakeholders, external stability mechanisms, information technology, and information collaboration. The figure also describes the inclusion relationship between the above four latent variables and the corresponding observed variables in detail.

Table 6. Summary of regression weights and hypothesis testing results for structural models.

Hypothesis	Path	Estimate	S.E.	C.R.	*p*	Result
H1	SH→ESM	0.627	0.068	9.220	***	support
H2	SH→IT	0.663	0.073	9.023	***	support
H3	SH→IC	0.032	0.109	0.292	0.770	not support
H4	ESM→IC	0.347	0.068	5.133	***	support
H5	IT→IC	0.567	0.114	4.984	***	support

Note: *** means $p < 0.001$; IC = Information collaboration; SH = Stakeholders; ESM = External Stability Mechanism; IT = Information technology.



Note:
IC = Information collaboration;
SH = Stakeholders;
ESM = External Stability Mechanism;
IT = Information technology;
IC1 = Timely update of information transmission;
IC2 = The quality of information;
IC3 = using easily of software;
IC4 = Information visualization;
IC5 = Information sharing;
IC6 = Development and application of information technology;
SH1 = Early (pre-planning stage) engagement and collaboration among project stakeholders;
SH2 = Cooperation among project stakeholders;
SH3 = Trust among project stakeholders;
ESE1 = Risk management mechanism;
ESE2 = Supervision mechanism;
ESE3 = Restrictive mechanism;
ESE4 = Perfect legal provisions system;
IT1 = Information interoperability between different software;
IT2 = Collaborative management platform;
IT3 = Building BIM database;
IT4 = Compatibility of information transmission.

Figure 5. Structural equation model.

5.6. Mediating Effect Test

As shown in Table 7, the confidence intervals of the three paths of the mediating effect do not contain 0, and the *p* values are all less than 0.05. At the same time, the direct effect confidence interval between stakeholders and information collaboration contains 0 and is not significant, indicating that an external stable environment and information technology play a complete intermediary role between stakeholders and information collaboration.

Table 7. Mediation effect test results table.

	Path	Estimate	Confidence Interval Lower	Confidence Interval Upper	*p*
Direct effect	SH→IC	0.032	-0.298	0.431	0.857
Mediation effect	SH→ESM→IC	0.218	0.106	0.396	0.002
	SH→IT→IC	0.376	0.162	0.693	0.002

Note: IC = Information collaboration; SH = Stakeholders; ESM = External Stability Mechanism; IT = Information technology.

6. Discussion

The purpose of this paper is to reveal the internal influence mechanism of information collaboration factors by studying the factors affecting information collaboration in the construction supply chain so as to improve project management efficiency. The results of the hypothesis test and mediating effect test analysis show that the hypotheses H1, H2, H4, and H5 are established. However, while stakeholders have a positive impact on information technology, their influence is not significant, meaning that hypothesis H3 is disproved. We analyze the reasons for these results by comparing our findings with previous studies, as discussed below.

6.1. Similar Results to Previous Research

(1) Hypothesis H1 is established, indicating that stakeholders have a significant influence on the external stability mechanism. Based on the interest demands of stakeholders, a coordination mechanism based on the full participation of the government can more effectively protect the interests of all parties and guide all stakeholders to build a strong construction market [46]. Therefore, this study further validates previous views. (2) Hypothesis H2 is established, indicating that stakeholders have a significant influence on information technology. Early stakeholder involvement in the project facilitates the implementation of BIM technology [37]. Its successful implementation requires stakeholders to participate in the project as early as possible and exchange information on a single data-sharing platform [54]. Therefore, this finding is consistent with previous studies. (3) Hypothesis H4 is established, which indicates that the external stabilization mechanism has a significant effect on information collaboration in the construction supply chain. An information supply chain mediated by supervision, restraint, and management mechanisms of relevant departments can provide resources for stakeholders, improve the quality of information transmission, and solve the problems of information lag and information distortion [54]. The realization of information coordination requires a cooperation mechanism to ensure the stability of cooperation [14]. Under the background of the rapid development of information technology, the information-sharing behavior of the construction supply chain needs to establish a stable external environment for the system, which is also verified by the findings of previous studies. (4) Hypothesis H5 is established, indicating that information technology has a significant impact on information collaboration. Information technology plays a central role in the supply chain [8]. Technology is considered a key enabler for integrating processes and managing information under the increasing demand for information sharing and communication [76]. Configuring an information collaboration platform can ensure the transparency, traceability, and accuracy of information in the supply chain [77], which is also supported by the results of previous studies.

To summarize, high-quality cooperation among stakeholders is conducive to the establishment of a high-quality external stability mechanism, which can solve the problems existing among stakeholders. The active participation of stakeholders can help break barriers to the implementation of information technology, while an external stability mechanism will provide a strong guarantee for construction supply chain information collaboration and promote efficiency in construction supply chain project management. Finally, the use of information technology in the construction supply chain accelerates the flow of information, thereby enhancing its efficiency.

6.2. Different Results to Previous Research

Hypothesis H3 is not established, which indicates that the effect of stakeholders on information collaboration in the construction supply chain is not significant. The cooperation and trust between stakeholders will indeed enhance the effect of information synergy [52]. The degree of information sharing will be affected by mistrust and bad cooperation between participants [50], and poor communication among stakeholders will lead to information lag [78]. A lack of trust among stakeholders also affects the flow of data and the quality of information [79]. However, the lack of information technology tools for information sharing among stakeholders will reduce the quality of information collaboration [42]. At the same time, the lack of corresponding external stable environment constraints between stakeholders will also result in poor information synergy [51]. Therefore, stakeholders have an indirect influence on information collaboration, mainly through information technology tools and external stabilization mechanisms. This finding also verifies that information technology and external stability mechanisms operate as an intermediary between stakeholders and information collaboration. Trust and information sharing among stakeholders are cyclical [80,81], whereby the trust level of participants depends largely on the level of information sharing and asset investment [81]. Effective information organization and coordination promote the sustainable development of information exchange among participants. Therefore, it cannot be considered simply that stakeholders will have a significant impact on information collaboration, as the two affect each other.

To summarize, the mediating effect test proves that there is a potential relationship between the structural equation model constructed in this paper and that information technology and external stability mechanisms play a complete mediating effect between stakeholders and external stability mechanisms. Stakeholders must use information technology tools to process building data information to ensure the quality and compatibility of information so as to achieve the purpose of smooth circulation of information in construction projects. Due to the large number of stakeholders, the lack of an external stability mechanism will diminish supply chain information collaboration efficiency [54]. Therefore, information technology and external stabilization mechanisms play an important role between stakeholders and information collaboration.

7. Research Conclusions

This paper systematically studied the stakeholders, information technology, external stability mechanism, and information collaboration according to previous research findings, questionnaire surveys, and the structural equation model. We aimed to improve the efficiency of project management by revealing the information collaboration mechanism of the construction supply chain. The results showed that stakeholders, information technology, and external stability mechanism had a positive impact on information collaboration, and the impact of stakeholders on information collaboration was not significant. Additionally, information technology and external stability mechanisms played a complete intermediary role in the supply chain. The innovation of this paper was to quantify the influence degree of each influencing factor on information collaboration and analyze the potential relationship through the mediating effect. Thus, the conclusions of the study are of great significance both theoretically and in practice.

7.1. Theoretical Contribution

(1) This study sought to address the construction supply chain information collaborative research gap. Logistics and capital flow in the construction supply chain are dependent on information flow. Previous research on information collaboration in the construction supply chain is limited, and the theory on supply chain information collaboration is insufficient. The general literature has asserted that stakeholders, information technology, and the external stability environment have a direct positive impact on information collaboration. However, the relationship between the various factors has not been quantified, and it is difficult to directly measure the impact of various factors on each other. Therefore, this study establishes a structural equation model of the information collaboration factors affecting the construction supply chain. Taking stakeholders, information technology, and external stability mechanisms in the construction supply chain as influencing factors, it analyzes their impact on information collaboration and quantifies the relationship between various factors. As a result, this study provides a more comprehensive and systematic analysis than previous studies on the impact of information collaboration. It also fills the gaps in the research of construction supply chain information collaboration and supplements the theoretical research of construction supply chain information collaboration.

(2) The research scope of information collaboration in construction project collaborative management was expanded. Large-scale construction projects have the characteristics of complexity and diversification, which generate a large number of complex multi-source heterogeneous data. Information collaboration will affect the overall construction efficiency of a project. Previous studies have focused on technical issues, with an emphasis on the development of tools to promote supply chain information flow. There is a lack of systematic research on management issues, especially the obstacles that affect information collaboration in the collaborative management of construction projects. Additionally, the internal mechanism between influencing factors and information collaboration has not been revealed from the perspective of the construction supply chain. Based on the structural equation model, we carry out hypothesis and mediating effect tests to judge the internal mechanism of information collaboration influencing factors. Compared with previous studies, the influencing factors of construction project information collaboration are analyzed more systematically in this work, and a potential path of information collaboration is identified. Therefore, the research scope of construction project collaborative management on information collaboration is expanded.

7.2. Practical Significance

Based on the results of the hypothesis and intermediary testing, we put forward the following suggestions to improve the efficiency of information collaborative management in the construction supply chain.

(1) Strengthen construction supply chain management through high-quality cooperation among stakeholders. When stakeholders participate in construction at the early stage of a project, they can understand the details and operation mechanism of the project supply chain and remove obstacles restricting the implementation of technical tools. This will also enhance trust among stakeholders and ensure high-quality cooperation between them. Therefore, supply chain management should be strengthened to improve the operation efficiency of the supply chain.

(2) The goal of construction supply chain management can be achieved by improving the level of information technology. Information technology is the information hub in the supply chain. The interoperability between information technology tools and the compatibility of information transmission will both ensure the integrity and accuracy of information and realize safe and transparent information sharing, thus obtaining information collaboration. Therefore, improving the level of information technology adoption and enhancing its development can achieve the difficult goal of construction supply chain management and achieve efficient collaboration.

(3) Improve the stability mechanism to ensure a stable environment for the operation of the building supply chain. A large amount of building information is generated in the process of project construction. In the process of information transmission, relevant laws and regulations need to be formulated to ensure its quality and safety. At the same time, relevant departments require supervision, management, and other mechanisms to provide a stable and healthy environment for construction supply chain operation so as to promote project integration.

7.3. Limitations and Future Research Directions

We acknowledge the following limitations of this study: (1) The sample data are mainly collected in China, and future research should expand the research objects to include practitioners and researchers in different regions of China as well as foreign practitioners and researchers. (2) Although the structural equation model is an empirical study, the research results are based on the survey data, and further engineering cases are needed to demonstrate the research results of this paper. For example, by taking the actual engineering case as the data source, based on the perspective of configuration, the FSQCA method should be used to study the adoption of construction supply chain information collaboration to supplement and demonstrate the results of this study in actual practice.

Supplementary Materials: The following supporting information can be downloaded at: Chinese questionnaire link: https://www.wjx.cn/vj/waUUwNB.aspx; English questionnaire link: https://www.wjx.cn/vm/Pc1c56o.aspx.

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