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EXPLORING THE EFFECT OF STAKEHOLDER RELATIONSHIP QUALITY ON TECHNOLOGICAL INNOVATION IN OFF-SITE CONSTRUCTION: THE MEDIATING ROLE OF THE KNOWLEDGE SHARING

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Abstract. Off-site construction (OSC) is generally propagated as a sustainable and green construction method in the global construction industry. Over the past few decades, OSC has become famous worldwide for its numerous benefits. Technological innovation can speed up the development of OSC and has attracted a lot of attention from stakeholders who are promoting technological innovation by seeking collaborations. OSC is different from traditional manufacturing, and little effort has been spent on how the stakeholder relationship quality affects technological innovation. This study therefore makes efforts to explore the mechanism of how stakeholder relationship quality influences the OSC technological innovation and to explain the stakeholder relationship quality in terms of communication, trust, and commitment. This paper constructs a multidimensional hypothesis model consisting of five concepts: communication, trust, commitment, knowledge sharing, and technological innovation. A valid sample of 125 was collected through a questionnaire survey in mainland China. The sample data were dealt with and analyzed using partial least squares structural equation modeling (PLS-SEM) to validate the proposed hypothesis model. The results reveal that trust and knowledge sharing affect technological innovation directly. Communication and commitment are not identified to have statistically significant influences on technological innovation in OSC. Communication, trust, and commitment positively contribute to knowledge sharing. Last, knowledge sharing completely and partially mediates between relationship quality and technological innovation. This study explores the impact of stakeholder relationship quality on OSC technological innovation and verifies the mediating role of knowledge sharing. These findings provide valuable theoretical guidance for OSC technological innovation and practical insights for stakeholders to promote technological innovation by enhancing relationship quality and knowledge sharing.

Keywords: off-site construction, stakeholder relationship quality, technological innovation, knowledge sharing, PLS-SEM.

Introduction

The construction industry has been criticized for its low efficiency and productivity, which has forced stakeholders to rethink and revisit the entire project development process (Gibb & Isack, 2003). With the diffusion of OSC, the construction industry worldwide is showing increasing interest in OSC adoption (Hosseini et al., 2018). OSC refers to the process of manufacturing and preassembly of specific amounts of building components, modules, and elements, prior to their shipment and installation on construction sites (Goodier & Gibb, 2007). OSC has several advantages over traditional construction, including faster construction (Heravi et al., 2021), lower resource consumption (Cao et al., 2015), higher quality (Li et al., 2011; Nadim & Goulding, 2010), less construction waste (Wang et al., 2015), and higher sustainability (Monahan & Powell, 2011). Nevertheless, OSC is generally subjected to more barriers and challenges because it has greater requirements for construction technology, management modes, and system integration (Li et al., 2020). Previous research showed that there are gaps between practice and theory in the development of OSC. In particular, technical factors are the most fundamental reason for hindering its development, which should be improved through technical means (Dou et al., 2019; Razkenari et al., 2020; Yuan

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et al., 2021a). Therefore, technological innovation to address those barriers and challenges is the key to the more successful and broader implementation of OSC (Dou et al., 2020; Xue et al., 2018a).

Technological innovation in OSC is different from traditional construction or manufacturing industries. the OSC combines manufacturing and construction processes, including design, off-site production, logistics, and on-site installation, with many stakeholders involved (Wuni et al., 2021), so its innovation environment is more complex. It has been difficult for individual companies to meet the needs of technological innovation with their internal resources and capabilities. Research and development (R&D) tasks such as new products, new technologies, and new methods require stakeholders to cooperate and provide technical and resource support (Shi et al., 2021). Stakeholders are increasingly keen to collaborate to improve efficiency and encourage innovation in OSC (Xue et al., 2018b). The organization form of temporary projects relies not only on formal rules but on inter-organizational relationships and collaboration through informal exchanges and interactions, which are then communicated and interacted within the project environment (Pauget & Wald, 2013). Many scholars have also paid attention to the role of this partnership in OSC technological innovation. However, previous research emphasized the impact of the relationship structural characteristics on OSC technological innovation, such as network size, network density, centrality, and network position (Xue et al., 2018b). Existing knowledge of the possible links between relationship quality and technological innovation remains little and inadequate. Specifically, communication, trust, and commitment are the most common factors to measure relationship quality (Mohr & Spekman, 1994). Some scholars have discussed communication, trust, and commitment as key factors for OSC project success and management performance (Xue et al., 2018a; Tang et al., 2019; Zhang et al., 2022), but how these factors affect OSC technological innovation has not been systematically explored. This research gap could result in ineffective technological innovation practices for OSC.

In addition, stakeholder collaboration in OSC is often accompanied by knowledge sharing. Knowledge sharing has always been the focus of the entire construction industry and is also a critical factor affecting architectural innovation (Shi et al., 2021). OSC is highly integrated into production organizations, it puts forward higher requirements for knowledge sharing (Zhang et al., 2022). The OSC requires the participation of multiple construction companies in the cooperative network, involving a variety of expertise. Without a high level of knowledge sharing, it it isn't easy to achieve the goal of technological innovation, and the role of knowledge sharing in technological innovation cannot be ignored (Rajabion et al., 2019). However, knowledge is a type of private asset that is difficult to spread and share across organizations (Shi et al., 2021). This is especially true in OSC. Existing studies agree that stakeholders' communication, trust, and commitment can break organizational and information barriers to knowledge sharing (Zhang et al., 2022; Cummings & Teng, 2003; Pavitt & Gibb, 2003), knowledge sharing depends on a certain extent on good relationship quality. Based on this perspective, whether knowledge sharing plays a role in the impact path of relationship quality on OSC technological innovation needs further discussion.

However, the findings seem rather unspecific for integrating relationship quality, knowledge sharing, and OSC technological innovation. There is still a lack of empirical exploration regarding the relations and effects of relationship quality and knowledge sharing in improving OSC technological innovation. In particular, an in-depth analysis is required to determine their multilateral relationships from quantitative approaches. To fill this gap, the paper introduced knowledge sharing to explore the proposed problem and constructed a multilevel model with stakeholder relationship quality and OSC technological innovation as the explanatory and explained variables, respectively. The multilevel model addresses the following questions: 1) Does stakeholder relationship quality affect OSC technological innovation? 2) How does the stakeholder relationship quality affect knowledge sharing? 3) What role does knowledge sharing between relationship quality and technological innovation exist? PLS-SEM was used to empirically evaluate the structural relationships of the model using survey data from the construction industry in mainland China. The results provide an in-depth understanding of the influential pathways of stakeholder relationship quality, knowledge sharing, and OSC technology innovation, thusguiding for managers to better construct an appropriate knowledge-sharing platform from the perspective of relationship quality and develop scientific technological innovation strategy. In addition, the research also contributes to the technological innovation knowledge system in the context of OSC. The remainder of the paper is organized as follows. Section 1 reviews the literature and theories related to this research and makes the corresponding hypotheses. Section 2 introduces methodology. Section 3 presents the analysis outcomes of the hypothesized model. Section 4 discusses the results and derives the implications. Final section concludes the paper and discusses possible future research directions.

1. Literature review and research hypothesis

1.1. Stakeholders relationship quality and OSC technological innovation

According to stakeholder theory, a stakeholder is defined as a person or organization that can influence or is influenced by achieving a goal (Mosgaard et al., 2016). The stakeholders in this paper are mainly the companies or organizations that actually participate in the construction of OSC projects, including owners, contractors, component suppliers, design firms, and consulting firms. Previous studies have measured the quality of stakeholder relationships differently. Relationship quality is based on trust and commitment and is used by stakeholders to coordinate activities between their organizations. It emphasizes working together to develop and maintain long-term working relationships that generate trust and commitment through social interaction (Dong et al., 2017). Fynes et al. (2005) argued that relationship quality includes communication, trust, commitment, and relationship climate. Poppo and Zenger (2002) argued that it should include open communication, information sharing, trust, dependence, and cooperation. Mohr and Spekman (1994) identified the main characteristics of a successful partnership as trust, commitment, coordination, quality of communication, participation, and joint conflict resolution. Lin et al. (2020) defined relational governance as emotions, preference exchange, trust, and communication. OSC will affect the production relationships in the traditional construction chain. Stakeholder roles will change, leading to more uncertainty in the construction environment (Li et al., 2016). The stakeholder relationship quality should be considered. According to previous studies, the most commonly used communication, trust, and commitment measure the stakeholder relationship quality in OSC. Based on trust, the paper advocates communication, dialogue, and negotiation to solve problems, reduce the risk caused by uncertainty through effective commitment, provide new momentum for all parties to cooperate, and contribute to achieving the goal. Communication mainly refers to informal communication; frequent and effective communication can promote mutual understanding among members and avoid possible misunderstandings in the process of cooperation, which is regarded as an important relationship norm (Boyle et al., 1992). All cooperative relationships are predicated on trust (Lin et al., 2020). Trust is based on a positive expectation that counterparties will act mutually acceptable manner and act equitably when there is opportunism (Das & Teng, 2001). Competence trust and goodwill trust are two significant types of trust (Guo et al., 2021). Competence trust means that one party expects the other party to perform its duties under the contract. Goodwill trust reduces perceived relationship risk by increasing confidence in the other party's willingness to perform their duties. The commitment referred to in this study is a relational commitment, an essential element of interdependence in resource interactions. This relationship commitment implies a willingness among stakeholders to do their best to maintain the relationship (Farrelly & Quester, 2015). Moliner et al. (2007) consider commitment as a tendency to develop stable relationships to sacrifice short-term benefits to maintain long-term benefits.

Technological innovation is an important type of innovation (Garcia & Calantone, 2002). Technological innovation refers to the company's adoption or development of new or advanced technologies to improve customer value related to existing products and markets (Ernst et al., 2011). In the construction industry, Manley (2008) divided innovation into two categories: technological innovation and organizational innovation. Technological innovation involves a technological approach to process or product innovation. Process innovation improves construction methods, while product innovation is the implementation and adoption of new products or technologies (Manley, 2008). With the accelerated change in construction technology and the increasing complexity of technological innovation, OSC technological innovation is defined as the new application of existing technologies or engineering methods to improve OSC-related activities (Suliman & Rankin, 2021). Establishing high-quality structures, high performance, and collaboration mechanisms among stakeholders can increase innovation in construction technology (Xue et al., 2018b), and it can realize the integration of innovation resources and the synergy of innovation behaviors, thus realizing the technological innovation of "1 + 1 > 2".

Communication between stakeholders is considered to be one of the main factors for successful innovation (Dulaimi et al., 2003). The closer we are, the more frequently we communicate with each other, and the more accurately we can grasp the market acceptance of our innovations. A rich two-way communication format can stimulate and facilitate new innovation activities in companies by providing the external information needed to generate new products (Cruz-González et al., 2015). Trust can strengthen the stickiness and make the cooperation relationship more stable. Thanks to the stability of the cooperation mechanism, stakeholders are more enthusiastic about participating in innovation together (Luo et al., 2015), conducive to speeding up innovation and providing timely and accurate support to each other. Commitment reduces stakeholder conflict and motivates stakeholders to work hard for innovation (Das & Teng, 2001). Based on the above research and analysis, the following hypotheses are proposed in this article:

H1a: Communication among stakeholders positively affects OSC technological innovation;
H1b: Trust among stakeholders positively affects OSC technological innovation;
H1c: Commitment among stakeholders positively affects OSC technological innovation.

1.2. Stakeholders relationship quality and knowledge sharing

Knowledge is the basis of any form of innovation, and knowledge flows throughout the innovation process (Zhang et al., 2021). Knowledge sharing means that the knowledge individuals in the organization transform their personal knowledge into the common knowledge of the organization through various sharing channels and share and use it for all knowledge individuals in the organization, which is one of the most critical processes of knowledge management (Du et al., 2007). From the knowledge level, the stakeholders in the OSC process form an extensive knowledge system, and the stable relationship quality can better facilitate knowledge sharing. Hoa et al. (2020) stated that communication, trust, commitment, etc., facilitate knowledge sharing. A constructive communication atmosphere positively impacts on knowledge output and absorption (Hall, 2001; Hendriks, 1999). Yuan et al. (2009)

showed that trust and commitment play a significant role in knowledge sharing. Trust is crucial for knowledge sharers and acquirers; trusted environments increase individuals' willingness to acquire and share knowledge (Gang & Ravichandran, 2015). Guo et al. (2021) also verified that inter-organizational trust positively affects on information exchange. Commitment helps to increase the willingness to cooperate among stakeholders and reflects the level and depth of cooperation. The collaborative process is accompanied by knowledge-sharing behavior, providing more knowledge-sharing opportunities (Cummings & Teng, 2003). Stakeholders may sacrifice short-term benefits for long-term benefits, maintain closer relationships with each other, generate a positive desire for mutual benefit, and promote knowledge sharing. Based on the above research and analysis, the following hypotheses are proposed in this article:

H2a: Communication among stakeholders positively affects knowledge sharing;
H2b: Trust among stakeholders positively affects knowledge sharing;
H2c: Commitment among stakeholders positively affects knowledge sharing.

1.3. Knowledge sharing and OSC technological innovation

It is difficult for individual organizations to access valuable innovation knowledge (Lawson et al., 2015). In the innovation process, the R&D tasks of new products, technologies, and methods require corresponding technical and resource support among the stakeholders. Differentiated proprietary technologies can quickly become an essential resource for technological innovation. Over time, these organizations achieve innovation by effectively managing internal and external knowledge flows (Zhang et al., 2021). Knowledge sharing among stakeholders refers to the exchange of knowledge and includes integrating and utilizing knowledge, which is then transformed into own knowledge (Ritala et al., 2015). A more extensive knowledge base means a greater possibility of converting knowledge into productivity and facilitating top-down product improvement and technology development. Therefore, knowledge sharing plays a positive role in promoting technological innovation (Ritala et al., 2015; Wang & Hu, 2020; Rajabion et al., 2019). Based on the above research and analysis, the following hypotheses are proposed in this article:

H3: Knowledge sharing positively affects OSC technological innovation.

1.4. The mediating role of the knowledge sharing

Knowledge sharing is considered to have a mediating role in many cases (Raziq et al., 2020; Bagherzadeh et al., 2020). Similarly, this article argues that knowledge sharing mediates the relationship between stakeholder relationship quality and OSC technological innovation. Stakeholders trust each other and communicate well, and this relationship creates important prerequisites for knowledge sharing. Communication, trust, and commitment influence technological innovation through knowledge sharing (Hoa et al., 2020). Stakeholders build a good quality of relationship through communication, trust, and commitment in OSC, leading to more diverse knowledge exposure among stakeholders. With the continuous development of knowledge sharing, stakeholders can complement each other's strengths and support each other, thus promoting technological innovation. In this regard, the following hypothesis is proposed in this article:

H4a: Knowledge sharing mediates between communication and OSC technological innovation;
H4b: Knowledge sharing mediates between trust and OSC technological innovation;
H4c: Knowledge sharing mediates between commitment and OSC technological innovation.

Figure 1 shows the final hypothesized path model based on the literature review above.

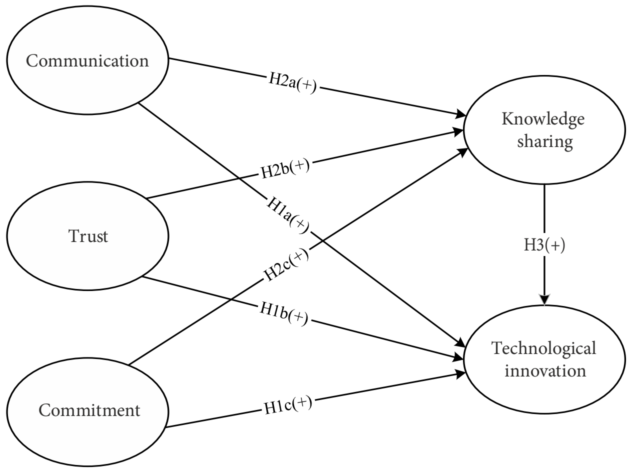

Figure 1. The methodological process

2. Research methodology

The paper designed a research framework to explore the topic of "Exploring the effect of stakeholder relationship on technological innovation in OSC", the research framework is shown in Figure 2. This research is conducted in four phases. In phase 1, the conceptual model and ten hypotheses are formulated. Phase 2 presents a research method, including questionnaires and PLS-SEM. Phase 3 applies the proposed approach to test the ten hypotheses, meanwhile analyzes the results of the measurement and structural models. Phase 4 discusses the results, then presents the theoretical and practical implications.

In Section 2, the paper has constructed the conceptual model. This section will focus on the research methodology. Firstly, a questionnaire was designed based on the research questions; then, questionnaires were distributed to Chinese construction industry practitioners to obtain data from large companies with experience in implementing OSC projects in China, including but not limited to the owner, contractor, component supplier, designer, and

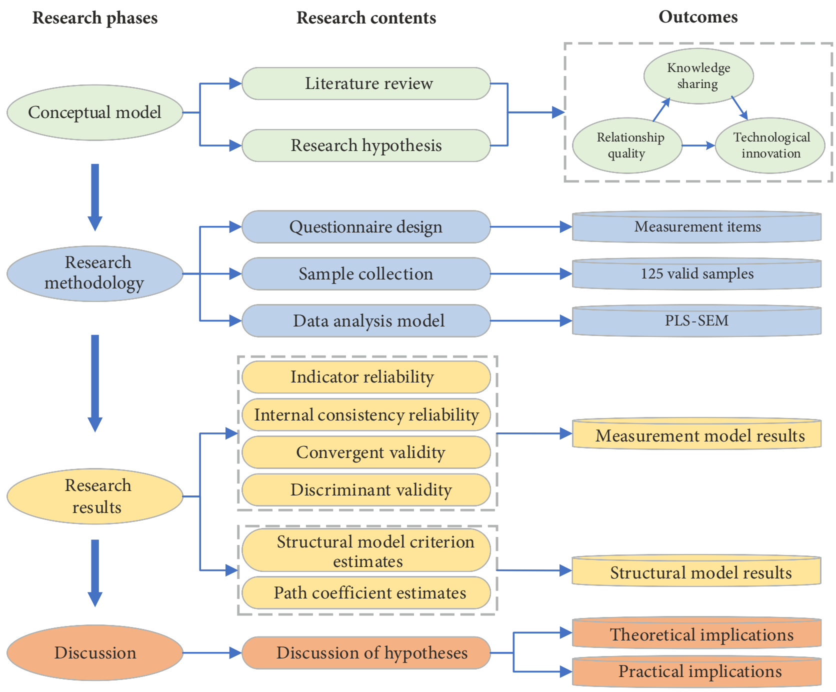

Figure 2. Research framework

consultant. Finally, the data were analyzed and processed using PLS-SEM to determine the influence relationships and pathways between stakeholder relationship quality, knowledge sharing, and technological innovation.

2.1. Questionnaire design

The questionnaire consisted of two parts, the first part introduced the purpose of the study, and five questions were designed to collect information from the respondents. The second part includes 16 measurement items, using a five-point Likert scale (i.e., 1 = strongly disagree, 3 = neutral, and 5 = strongly agree) to ask respondents how much they agree with the description of measurement items. Most of these items were adapted from a review of the existing literature. All of them were adapted to the characteristics of the OSC project to fit the research context and ensure content validity. The measure of communication refers to relevant studies by Lin et al. (2020) and Bstieler and Hemmert (2008). Three items are developed from the dimensions of frequency, timeliness, and effectiveness. The measure of trust refers to relevant studies by Pinto et al. (2009), Park and Lee (2014), and De Clercq et al. (2011). Three items are developed from the dimensions of interest, ethics, and competence. Commitment is measured primarily in terms of performance, relationship importance, and willingness to maintain the relationship. These items are mainly from the relevant research of Kumar et al. (1995) and Hewett et al. (2002), and survey interview results. Four items are used to measure knowledge sharing; Park and Lee (2014), and Shi et al. (2021) believe that the measure of knowledge sharing should cover the OSC construction process, product requirements, technical documentation (Innovation Manual), and innovative idea. Shi et al. (2021) and Hagedoorn and Cloodt (2003) believe that innovation input, output, and diffusion can fully represent technological innovation. Based on the survey and interview results, three questions are developed. The questionnaire was revised to ensure its applicability and comprehensibility. First, semi-structured interviews were conducted successively with five expert scholars with senior research experience in OSC, covering the presentation, content, and clarity of each item, followed by an iterative revision based on their comments. Then, a pilot study was conducted on five well-known companies. The content of the questionnaire was adjusted to ensure that the questionnaire was adequate and that the respondents could easily understand the meaning of the questionnaire items and provide accurate answers. Table 1 provides details of the final measurement items.

2.2. Sample and data collection

The questionnaire was conducted through a combination of online and offline. Respondents were mainly key employees from owners, contractors, component suppliers, design firms, and consulting firms operating in China, such as project managers or specialists with a comprehensive understanding of the company. These companies have been involved in the production, construction, consulting, and design of components for at least three or more OSC projects. The research team included five members from two universities and was supported by the Ministry of Housing and Urban-Rural Development of China (MOHURD) in distributing the questionnaire. Firstly, a link to the electronic questionnaire was sent to the respondents.

Table 1. Constructs and measurement items

Construct	Measurement items	References
Communication (CO_n)	CO_n1: Our communication with our main partners is frequent	Lin et al. (2020), Bstieler and Hemmert (2008)
	CO_n2: Our communication with our main partners is timely	
	CO_n3: The information exchanged between us, and our main partners are accurate	
Trust (Tr)	Tr1: We believe that our main partners will not pursue their own interests at the expense of ours	Pinto et al. (2009), Park and Lee (2014), De Clercq et al. (2011)
	Tr2: We believe that our principal partners have always adhered to high ethical principles	
	Tr3: We believe that the main partners are capable of achieving the desired results	
Commitment (CO_t)	CO_t1: We and our main partners have made and kept commitments to their respective responsibilities	Kumar et al. (1995), Hewett et al. (2002) and interview
	CO_t2: We attach great importance to our relations with our main partners	
	CO_t3: We hope to maintain long-term cooperative relations with our main partners	
Knowledge sharing (KS)	KS1: We often share our knowledge and experience in the OSC with our main partners	Park and Lee (2014), Shi et al. (2021) and interview
	KS2: We often share knowledge and experience of components, parts, modules, and other product requirements with our main partners	
	KS3: We often share innovation reports, manuals and technical documents with our main partners	
	KS4: We often share new ideas of innovation with our main partners	
Technological innovation (TI)	TI1: We have invested a lot of capital and manpower support in OSC technological innovation	Shi et al. (2021), Hagedoorn and Cloodt (2003) and interview
	TI2: We have many patents, standards and advanced processes related to OSC technology	
	TI3: Our patents, standards and advanced technology and other technological innovations are widely used by peers	

Then, for those respondents who did not complete the questionnaire, we followed up with further communication with them, either by phone or online, to explain the purpose of our study and to seek their cooperation in data collection. The questionnaire was conducted in mainland China from October 2021 to November 2021.

Through the above process, 147 of 260 questionnaires were returned, and 125 valid questionnaires after screening. The effective response rate was 48.1%, which is acceptable compared with the effective response rates (45.5% and 46.8%, respectively) in previous studies of project management (Zhang et al., 2019; Yuan et al., 2021b). The screening work follows the following two main principles:1) using response time as a screening method, respondents must take a certain amount of time to answer the questions accurately (DeSimone et al., 2015). Although differences in item length and reading speed made it difficult to determine cutoff scores, respondents were unlikely to answer questions faster than 2 seconds per item (Huang et al., 2012). 2) the use of long strings as a filtering method depends on the assumption that long successions of identical answers may indicate poor data quality (DeSimone et al., 2015). Based on the above two principles, we removed the samples with less than 40 s answer time and the examples with the same answer for all questions. The questionnaire screening process mentioned above reduced the sample size but ensured the quality of the sample.

Table 2 lists respondents' demographic information. The respondents came from 147 companies across seven geographical regions in China. About 89.6% of respondents obtained a bachelor's degree or above, and about 68% of respondents had more than five years' experience in the construction industry. Therefore, respondents are knowledgeable and experienced professionals who are more familiar with the realities of the company and project and can answer questions effectively. Enterprises with early exposure to OSC projects were mainly selected as key survey respondents to ensure the typicality and reliability of industry survey data and avoid bias of single data sources. These include Country Garden, Vanke, China State Construction Engineering System, China grand enterprises, etc. Among 147 respondents, 24% come from owners, 32.8% from contractors, 13.6% from component suppliers, 11.2% from design firms, 12% from consulting firms, and 6.4% from other related companies. These enterprises cover the entire business of the OSC.

2.3. PLS-SEM data analysis method

The empirical data collected from the questionnaire survey were analyzed using structural equation modeling (SEM) to test the research hypotheses. The investigation of the interaction between stakeholder relationship quality, knowledge sharing, and OSC technological innovation

Table 2. Demographic information of respondents

Categories	Type description	Number of respondents	Percentage (%)
Organization	Owner	30	24
	Contractor	41	32.8
	Component supplier	17	13.6
	Design firm	14	11.2
	Consulting firm	15	12
	Others	8	6.4
Education	Junior college and below	13	10.4
	Bachelor degree	69	55.2
	Master degree	39	31.2
	Doctor degree	4	3.2
Years of experience in the construction industry	≤ 5	40	32
	5~10	34	27.2
	10~20	30	24
	> 20	31	24.8
Years of experience in the construction industry	≤ 5	88	70.4
	5~10	18	14.4
	10~20	16	12.8
	> 20	3	2.4
Region	Northeastern China	11	8.8
	East China	75	60
	The central of China	5	4
	North China	20	16
	Southern China	8	6.4
	Northwestern China	3	2.4
	Southwest China	3	2.4

was a multifactor analysis problem, and SEM was often used for such issues (Hair et al., 2012). Compared with other analysis methods such as grey clustering analysis and social network analysis, SEM integrates the characteristics of factor analysis and path analysis and has the following advantages (Ali et al., 2018): 1) multiple dependent variables were processed simultaneously, 2) a specific measurement error was allowed and 3) relationships between latent variables could be found. This study involves the relationship between multiple causes and multiple results, and a large number of potential variables are challenging to predict directly. In addition, there may be multicollinearity between variables. The data used to measure variables are often collected by questionnaire survey. This subjective method will inevitably lead to data errors. Fortunately, SEM can deal with these problems well and has a good fit with this study.

There are two main types of SEM commonly used: covariance-based CB-SEM techniques and variance-based PLS-SEM techniques. The reason for using PLS-SEM in this study is as follows (Hair et al., 2012): 1) CB-SEM is suitable for theory testing and confirmatory modeling, while PLS-SEM is more ideal for theory development and prediction. This study focuses on exploring and predicting the impact of stakeholder relationship quality on OSC technological innovation, which is an exploratory study, and it is more reasonable to use PLS-SEM. 2) CB-SEM is used with strict requirements on data distribution and sample size, while PLS-SEM requires relatively more minor sample size and does not require normally distributed data. In this study, the data samples obtained using the improbability convenience sampling method were suitable for analysis by using PLS-SEM. 3) When used for complex models with many structures, PLS-SEM shows more robust estimates than CB-SEM, which will help analyze the proposed integrated model. Although PLS-SEM is suitable for small sample analysis, there are minimum requirements for sample size: (1) 10 times the maximum number of indicators used to measure one construct in the measurement (outer) model or (2) 10 times the maximum number of paths relationships directed at a latent construct in the structural (inner) model (Barclay et al., 1995). According to this rule, the minimum number of samples to be satisfied in this study is 40 (i.e., 4 × 10 = 40), and we collected 125 valid samples, which fully meets the requirement. Smart PLS 3.0 was used to process the data to evaluate the measurement and structural models.

Table 3 lists all criteria and rules of thumb for evaluating the measurement model and structural model. Since all the indicators in this study are reflective, the 1) indicator reliability, 2) internal consistency reliability, 3) convergent validity, and 4) discriminant validity of the measurement models need to be assessed (Hair et al., 2012). After passing the measurement model test, five criteria are needed to evaluate the structural model: (1) coefficient of determination (R^2), (2) predictive relevance (Q^2), (3) path coefficient, (4) effect size (f^2) and (5) goodness of fit (*GoF*).

3. Results and analysis

3.1. Measurement model results

First, indicator reliability is reported. Generally, indicators with loadings between 0.40 and 0.70 should only be considered for removal from the scale if deleting this indicator leads to an increase in composite reliability above the suggested threshold value. Another consideration in deleting indicators is how their removal affects validity. Weaker indicators are sometimes retained based on their contribution to content validity (Hair et al., 2011). Table 4 shows that only the outer loading of indicator CO_n1 (0.627) did not reach 0.7, but this indicator has a large contribution to content validity and should be retained. Other indicators' outer loadings were all higher than 0.7 and significant at the 0.001 level. Each construct' CA, CR, and AVE all meet the requirements, indicating that the measurement model has good internal consistency reliability and convergent validity (Table 4). Finally, the Fornell-Larcker criterion, cross-loadings, and HTMT, three criterions all meet the requirements (Table 5), indicating that the measurement model has good discriminant validity.

Table 3. Criteria and rules of thumb when using PLS-SEM

Model evaluation type	Criterion	Recommendations / rules of thumb	References
Measurement (outer) model evaluation	***Indicator reliability***		
	Reflective indicator loadings	Values should be significant at the 5% level and exceed 0.7; in exploratory studies, loadings of 0.40 are acceptable	Hulland (1999)
	Internal consistency reliability		
	Cronbach's alpha (CA)	CA ≥ 0.7, in exploratory research 0.60 is considered acceptable	Bagozzi and Yi (1988)
	Composite reliability (CR)	CA ≥ 0.7, in exploratory research 0.60 is considered acceptable	Bagozzi and Yi (1988)
	Convergent validity		
	Aver age variance extracted (AVE)	AVE ≥ 0.5	Fornell and Larcker (1981)
	Discriminant validity		
	Fornell–Larcker criterion	Each construct's AVE should be higher than its squared correlation with any other construct	Fornell and Larcker (1981)
	Cross-loadings	Each indicator should load highest on the construct it is intended to measure	Chin (1998)
	Heterotrait-monotrait (HTMT)	HTMT < 0.85	Henseler et al. (2015)
Structural (inner) model evaluation	Coefficient of determination (R^2)	0.26, 0.13 and 0.02 are considered substantial, moderate and weak.	Cohen (1988)
	Predictive relevance (Q^2)	$Q^2 > 0$ is indicative of predictive relevance	Chin (1998)
	Path coefficient estimates	Path coefficients among the latent variables should be checked according to their algebraic sign, magnitude, and significance	Urbach and Ahlemann (2010)
	Effect size (f^2)	0.02, 0.15, 0.35 for weak, moderate, strong effects	Cohen (1988)
	Goodness of fit (*GoF*)	0.1, 0.25, 0.36 for weak, moderate, and substantial *GoF*	Wetzels et al. (2009)

Table 4. Reliability and convergent validity

Construct	Indicator	Outer loadings	CA	CR	AVE
CO_n	CO_n1	0.627	0.626	0.784	0.550
	CO_n2	0.799			
	CO_n3	0.787			
Tr	Tr1	0.899	0.772	0.869	0.691
	Tr2	0.875			
	Tr3	0.707			
CO_t	CO_t1	0.850	0.736	0.849	0.652
	CO_t2	0.814			
	CO_t3	0.757			
KS	KS1	0.772	0.775	0.856	0.598
	KS2	0.815			
	KS3	0.716			
	KS4	0.785			
TI	TI1	0.794	0.800	0.882	0.714
	TI2	0.864			
	TI3	0.875			

Table 5. Discriminant validity

Fornell-Larcker criterion					
Construct	CO_n	Tr	CO_t	KS	TI
CO_n	**0.742**				
Tr	0.359	**0.832**			
CO_t	0.450	0.335	**0.808**		
KS	0.440	0.488	0.444	**0.773**	
TI	0.352	0.502	0.351	0.590	**0.845**
Cross Loadings					
Construct	CO_n	Tr	CO_t	KS	TI
CO_n1	**0.627**	0.115	0.323	0.183	0.065
CO_n2	**0.799**	0.325	0.384	0.325	0.322
CO_n3	**0.787**	0.288	0.317	0.405	0.298
Tr1	0.312	**0.899**	0.326	0.436	0.430
Tr2	0.318	**0.875**	0.210	0.456	0.435
Tr3	0.263	**0.707**	0.311	0.311	0.387
CO_t1	0.422	0.300	**0.850**	0.370	0.394
CO_t2	0.351	0.208	**0.814**	0.379	0.201
CO_t3	0.303	0.300	**0.757**	0.326	0.226
KS1	0.369	0.324	0.384	**0.772**	0.430
KS2	0.336	0.316	0.375	**0.815**	0.428
KS3	0.264	0.488	0.324	**0.716**	0.457
KS4	0.391	0.369	0.291	**0.785**	0.501
TI1	0.321	0.355	0.262	0.429	**0.794**
TI2	0.332	0.422	0.350	0.542	**0.864**
TI3	0.246	0.487	0.273	0.515	**0.875**
Heterotrait-Monotrait Ratio (HTMT)					
Construct	CO_n	Tr	CO_t	KS	TI
CO_n					
Tr	0.464				
CO_t	0.656	0.450			
KS	0.579	0.622	0.589		
TI	0.431	0.637	0.438	0.742	

3.2. Structural model results

In this section, the paper would like to report five criteria: 1) KS's and TI's R^2 values were 0.361 and 0.414, respectively, indicating a high level of the explanatory power of the structural model. 2) KS's and TI's Q^2 values were 0.202 and 0.274, 0.202 and 0.274, respectively. Respectively, ensuring good predictive relevance of the structural model. 3) The f^2 value of H1b, H2a, H2b, H2c and H3 were 0.054, 0.143, 0.066, 0.086 and 0.187, these exogenous variables had at least small effects on endogenous variable, but H1a (0.003) and H1b (0.004) did not perform well. 4) $GoF = \sqrt{\overline{AVE} \times \overline{R^2}}$, so the GoF value is 0.498, showing the complete model performs very well. 5) The results of hypotheses testing were summarized in Table 6, Table 7, and Figure 3. Among them, only trust in relationship quality has a significant positive effect on technological innovation (H2b: Pc = 0.263, p < 0.05). Communication and commitment do not affect technological innovation, therefore only hypothesis H1b is supported and H1a, and H1c are not supported. However, communication, trust and commitment all had significant positive effects on knowledge sharing (H2a: Pc = 0.215, p < 0.01; H2b: Pc = 0.322, p < 0.001; H2c: Pc = 0.236, p < 0.01), H1a, H1b and H1c are supported. Knowledge sharing had a positive and significant impact on technological innovation (H3: Pc = 0.414, p < 0.05), and H3 was also supported.

Then, the paper explored the mediating role of knowledge sharing. Although communication and commitment do not have a direct effect on technological innovation, both can indirectly influence technological innovation through knowledge sharing, in which knowledge sharing plays a direct mediating role (H4a: Pc = 0.089, p < 0.05; H4c: Pc = 0.098, p < 0.05), H4a and H4c are supported.

Table 6. Path analysis results of the structural model

Path	Path coefficient	T-value	Inference
H1a:CO_n -> TI	0.050	0.621	Rejected
Hb:Tr -> TI	0.263	2.351*	Supported
H1c:CO_t -> TI	0.057	0.750	Rejected
H2a:CO_n -> KS	0.215	2.359**	Supported
H2b:Tr -> KS	0.332	4.001***	Supported
H2c:CO_t -> KS	0.236	3.466**	Supported
H3:KS -> TI	0.414	3.179*	Supported

Notes: *p < 0.05; **p < 0.01; and ***p < 0.001.

Table 7. The indirect effect of the knowledge sharing

Path	Path coefficient	T-value	Inference
H4a:CO_n -> KS -> TI	0.089	2.055*	Supported
H4b:Tr -> KS -> TI	0.137	2.613**	Supported
H4c:CO_t -> KS -> TI	0.098	2.038*	Supported

Notes: *p < 0.05; **p < 0.01; and ***p < 0.001.

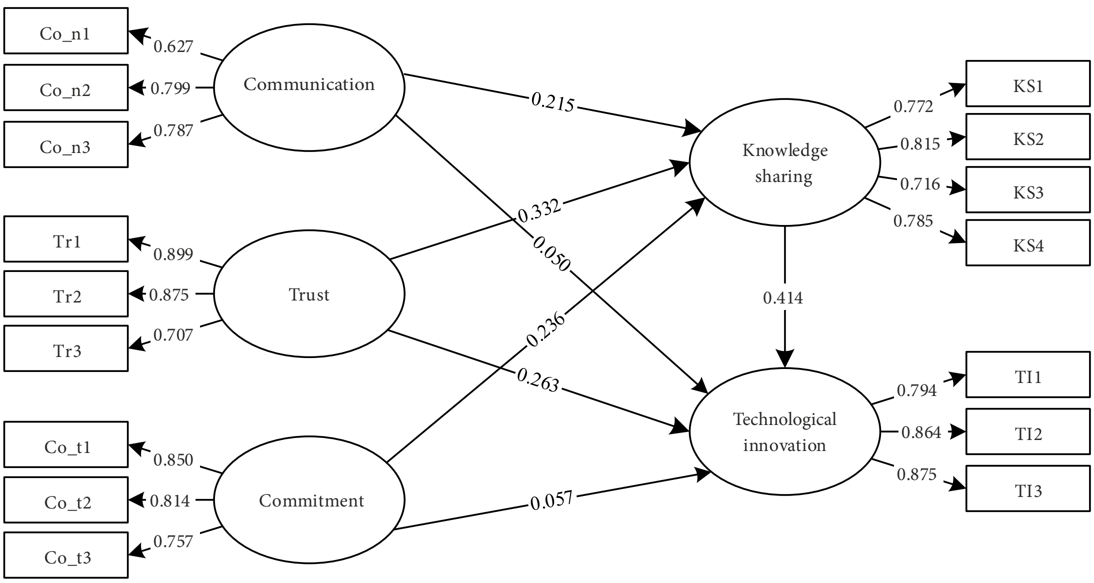

Figure 3. Results of the structural model

And trust can affect technological innovation directly and indirectly through knowledge sharing, which suggests a partial mediating role of knowledge sharing between trust and technological innovation (H4b: Pc = 0.137, $p < 0.01$), and similarly, H4b is supported.

4. Discussion and implications

This exploratory study focuses on the influence paths between relationship quality, knowledge sharing, and technological innovation in OSC. Through structural model estimation, eight hypotheses were supported, and two hypotheses were rejected. Then, this paper discusses the result and implications in this section.

4.1. Discussion of hypotheses

4.1.1. Effect of stakeholder relationship quality on technological innovation

Communication, trust, and commitment are the three constructs that measure relationship quality. Surprisingly, there was no significant effect of communication on OSC technological innovation (H1a), which seems to be somewhat inconsistent with previous studies (Dulaimi et al., 2003; Cruz-González et al., 2015). However, it is essential to mention that most of the previous studies were based on traditional construction or manufacturing, while for OSC, it is a construction method that combines manufacturing and construction with a complex construction process. In OSC, construction processes are geographically and organizationally fragmented as some of the works (e.g., manufacturing and preassembly of some building components, modules, and elements) have moved to the factory. This production mode put forward higher requirements for cross-organizational communication. Specifically, the absorption of architectural innovation requires the participation of various stakeholders, but stakeholders such as owners, construction companies, design units, suppliers, and consultants have minimal knowledge of OSC, and knowledge barriers can quickly appear in the process of cooperation (Xue et al., 2018b). Therefore, this advanced mode of production makes stakeholders tired of effective communication in the process of collaborative innovation, but more inclined to profit from information asymmetry, which leads to conflicts of interest. Excessive conflicts of interest make the communication process often accompanied by bickering, resulting in a lot of information redundancy. Such communication tends to be profit-oriented and has little impact on technological innovation. Secondly, in the field investigation, it was found that advanced communication tools such as email, telephone, and Internet were frequently used, which significantly improved the communication efficiency between organizations. However, it is important to emphasize that information is transmitted between two or more stakeholders. Due to differences in expertise and geographical location among different stakeholders, the recipients may exaggerate or distort the information when transmitting it to other participants, resulting in repeated or even invalid tasks. Face-to-face communication, such as live meetings and oral presentations, was also considered important because it was better to resolve disagreements, track mission goals and create knowledge. Unfortunately, OSC projects are more about online communication in practice. A lot of ineffective communication does not effectively promote technological innovation.

Expectedly, trust does positively contribute to technological innovation (H1b), as in previous studies (Luo et al., 2015). In construction, the importance of trust cannot be overemphasized (Lu et al., 2021). Construction projects often involve many uncertainties and risks. Therefore trust is necessary among stakeholders to foster rapport that "bridges gaps, build beliefs, and synergizes strengths" (Wong et al., 2008). With the development of OSC technology, trust is playing an increasingly important role in project management (Zhang et al., 2022). Housing industrialization alliance and prefabricated building alliance based on trust and cooperation have emerged in China. The participants in these alliances must maintain a high degree of trust to enhance their stability. Meanwhile, trust can help relevant enterprises to attract more potential partners with high technology and high quality to promote OSC technological innovation. In addition, trust makes collaboration among stakeholders more open. Relevant enterprises are more likely to be inspired and influenced by external information. In a trust-based environment, new technological achievements launched by appropriate enterprises are more likely to be adopted by partners to promote OSC technological innovation.

However, there was no significant direct effect of commitment on technological innovation. While this is contrary to hypothesis (H1c), it is also easy to understand from two aspects. First, OSC is in the initial stage of development. Most OSC activities are pilot projects, and the stakeholders are temporary organizations with insufficient project experience. While they establish a broadly shared vision in the OSC, this commitment does not have a specific basis for cooperation. Therefore, in the process of project construction, although stakeholders are willing to make commitments, they tend to have opportunistic behaviors due to unilateral interests, which can easily destroy the long-term committed relationship. In the survey interview, some project managers also indicated that it is no cost to break this committed relationship. The short-term commitment did not have a significant impact on OSC technology innovation. Second, due to the complexity of the OSC process and the diversity of stakeholders, relationship commitments at this stage bring more reusable resources or cooperation models rather than innovative knowledge. Therefore, commitment can effectively promote the successful implementation of the project but can not be directly transformed into the production power of technological innovation.

4.1.2. Effect of stakeholder relationship quality on knowledge sharing

In exploring the effect of relationship quality on knowledge sharing, it was found that communication, trust, and commitment, as three constructs measuring relationship quality, all contribute significantly to knowledge sharing, consistent with hypotheses H2a, H2b, and H2c. There is no doubt that relationship quality plays a vital role in the knowledge-sharing process (Yli-Renko et al., 2002), and all three of them provide a good environment and atmosphere for knowledge sharing. The OSC is more decentralized, complex, and interdependent than traditional projects, requiring effective coordination between stakeholders of both on-site and off-site work (Wuni & Shen, 2020a). As a transformative technology in the construction industry, OSC is often accompanied by technological uncertainty, and the lack of knowledge and experience makes users have to seek technology and knowledge support across interfaces. Higher relationship quality can make the knowledge receiver believe that the knowledge sender is sincere in transferring knowledge and then deepen the understanding of shared knowledge (Shi et al., 2021). Specifically, proper communication between stakeholders is the premise of knowledge sharing. Online and offline communication enables stakeholders to clarify the mission and objectives of project implementation, gain a deeper understanding of each other's resources and capabilities, and facilitate the diffusion of knowledge. Trust and commitment are conducive to improving OSC stakeholders' expectations of future cooperative relationships, enhancing their confidence in obtaining more opportunities and benefits through stable trading relationships, and strengthening stakeholders' willingness to share knowledge. In general, high relationship quality can effectively break down inter-organizational barriers in knowledge diffusion and provide an excellent external environment for knowledge sharing.

4.1.3. The mediating role of the knowledge sharing

It is further verified that knowledge sharing has a solid contribution to technological innovation (H3), and even in the construction field, adequate knowledge sharing among stakeholders is likewise considered to improve innovation performance (Shi et al., 2021). In OSC technological innovation, stakeholders share new resources and technologies by communicating to complement the internal resources involved, creating advantages for innovation (Xue et al., 2018b). On the one hand, a single organization cannot grasp all the knowledge about the construction process and product innovation. By sharing different technical expertise and experience, each stakeholder can effectively break the knowledge barrier and expand the knowledge stock. The more the knowledge stock, the more it is conducive to top-down product improvement and technology development (Wu, 2012). On the other hand, stakeholders can create new knowledge and ideas based on existing knowledge through knowledge sharing. This helps organizations to increase their investment in technological innovation and promote the output and diffusion of technological innovation products.

The mediating role of knowledge sharing was verified through path analysis, revealing that knowledge sharing is a valuable tool to improve the technological innovation of OSC. Knowledge sharing can be viewed as a partial mediator between trust and OSC technological innovation, with a mediation effect of 0.137. First, trust facilitates the transfer of complex and uncoded knowledge and enhances the mining of knowledge depth. Secondly, trust is conducive to the diffusion of rich and novel knowledge and enhances the search for knowledge breadth. Finally, trust-based stakeholders are bound to improve openness at organizational boundaries. The open organizational relationship enhances the transference intention of the knowledge sender and the knowledge absorption ability of the recipient. To sum up, the trust provides a good environment for transferring complex and uncoded knowledge. Besides, communication and commitment can indirectly affect OSC's technological innovation through knowledge sharing. Both can effectively break the barriers of information flow and provide knowledge reserve for technological innovation by accelerating the absorption, transformation, and integration of knowledge.

In general, the ability to share resources and complement each other among stakeholders fosters more incredible innovation (Wuni & Shen, 2020b). But, much diverse knowledge is distributed throughout the construction supply chain network, and knowledge is often "sticky" and difficult to disseminate (Wang & Hu, 2020). A good communication atmosphere, a trusting environment, and relationship commitment can create good external conditions for knowledge sharing and technological innovation among stakeholders. The relationship quality between these stakeholders is enhanced through effective communication, mutual trust, and relationship commitment, which helps to achieve an excellent knowledge-sharing network, thus eliminating information asymmetry, forming a shared vision, and making OSC technological innovation easier.

4.2. Theoretical implications

This study reveals the internal mechanism and influence path of stakeholder relationship quality, knowledge sharing and technological innovation in OSC, and makes theoretical contributions to the body of knowledge from three aspects. (1) This study enhances an understanding of stakeholders' relationship quality. This advances research from relationship structure characteristics in OSC technology innovation cooperation to relationship quality, using three critical dimensions of communication, trust, and commitment to measure relationship quality (Mohr & Spekman, 1994). By providing evidence of the relationship between communication, trust, and commitment and OSC technology innovation, we find that trust has a significant positive effect on technological innovation. In constrast, communication and commitment have negligible effects. Such complex findings differ from manufacturing and traditional construction contexts because OSC has a more complex and dynamic technological innovation environment. Therefore, this study provides a more targeted theoretical basis for managers to establish communication mechanisms, trust mechanisms, and committed relationships in the process of technological innovation. (2) This study further uncovers the mediating role of knowledge sharing, providing an integrative view of how relationship quality influences OSC technological innovation. In addition to confirming the vital role of knowledge sharing in OSC technological innovation, this study evaluates the functional mechanism of relationship quality from the perspective of knowledge sharing. Specifically, the impact of stakeholder relationship quality on OSC technological innovation will be transmitted through knowledge sharing. In particular, communication and commitment cannot be the direct driving force of technological innovation but help create a good external environment, thus indirectly affecting technological innovation. (3) The research results complement and improve the theory of OSC technological innovation integrate and expand the research on the application of stakeholder management, knowledge management, and innovation management in OSC.

4.3. Practical implications

The study results also provide some practical implications for technological innovation in OSC. First, stakeholders should not rely too much on online communication such as email and telephone. Project managers should improve their communication skills and hold regular face-to-face meetings. The establishment of a scientific communication mechanism is helpful to breaking the one-way knowledge transfer from point to point and forming an interactive knowledge-sharing network. In addition, enterprises should use advanced information technology such as BIM, mobile enabling technology (RFID, GPS), and application services (AR/VR, cloud computing) to promote the real-time acquisition and sharing of information among different stakeholders. For example, Li et al. (2017) combined BIM and RFID to develop a real-time collaboration platform for knowledge exchange, information sharing, and proactive monitoring of the OSC supply chain in Hong Kong. Second, at the initial stage of OSC project cooperation, there may be a lot of mutual suspicion and temptation among stakeholders, leading to an increase in opportunistic behavior. At this stage, the trust mechanism and commitment relationship between stakeholders are relatively fragile, and the relationship quality is easily destroyed. Therefore, project managers should regulate contract elements, set up incentives and penalties to increase the cost of opportunistic behavior, and restrain the behavior of stakeholders. With the deepening of cooperation, the continuous interaction between stakeholders will continuously enhance trust and improve the stability and durability of relationship commitment. Third, enterprises should actively participate in the experience exchange meeting of the OSC industry technology innovation Alliance. Meanwhile, they should establish a technical training system and increase talent introduction to improve the cumulative effect generated by knowledge and professional skills. In addition, core stakeholders can take the lead in establishing OSC demonstration and practice bases to promote the rapid absorption and transformation of innovative knowledge.

Conclusions

Currently, OSC is a widely accepted alternative to traditional on-site construction. Technological innovation is attracting the attention of stakeholders as one of the key factors influencing the development of OSC. To better facilitate the achievement of OSC technological innovation goals, we propose ten hypotheses to explore the influence of stakeholder relationship quality (communication, trust, commitment), knowledge sharing and technological innovation, and the mediating role of knowledge sharing. PLS-SEM was used to analyze the survey data collected in the Chinese construction industry. The findings indicated that: 1) trust and knowledge sharing directly affect technological innovation. At the same time, communication and commitment are not identified to have statistically significant influences on technological innovation in OSC. 2) Communication, trust, and commitment positively contribute to knowledge sharing. 3) The three indirect paths of "CO_n -> KS -> TI", "Tr -> KS -> TI" and "CO_t -> KS -> TI" are significant. In other words, knowledge sharing has a fully or partially mediating role between relationship quality (communication, trust, commitment) and technological innovation.

The study reveals the influence mechanism between stakeholder relationship quality and OSC technological innovation and the intrinsic role of knowledge sharing. The findings will help motivate stakeholders to promote knowledge sharing through improving relationship quality, thus further achieving the technological innovation goal of OSC. It will provide some theoretical basis and practical guidance for the sustainable development of the construction industry. Future research can add more variables to expand this study and further complement the OSC technology innovation body of knowledge.

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Author contributions

Shengbin MA conducted the global study and completed the paper in English; Zhongfu LI participated in the data collection and processing and revised important knowledge content critically; Long LI controlled the overall thinking of the study, and made an excellent contribution to the details; Mengqi YUAN gave guidance in software application; Xianfei YIN gave some good suggestions and made a comprehensive English revision.

Disclosure statement

The authors declare no conflicts of interest.

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