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Effects between Information Sharing and Knowledge Formation and Their Impact on Complex Infrastructure Projects' Performance

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Abstract: Adopting knowledge management theories from an inter-organizational perspective, this study aims to uncover the relationships among information sharing (IS), knowledge organization (KO), and knowledge integration (KI) through knowledge formation (KF) for improving complex infrastructure project performance. Two hundred and thirty-four valid questionnaires were collected from organizations involved in complex infrastructure projects, and their responses were evaluated using partial least-squares structural equation modeling. The findings show that IS has a significant effect on the improvement of project performance and manifests as multiple mediation roles through KO, KI and KF, not via the direct effect of IS on KI and that of KO on KF. Inter-organizational trust also plays a new and positive moderating role in the relationship between KO and KI, not in the relationship between IS and KO. This study not only provides insights on the practice of knowledge management for improving complex infrastructure project performance, but it also discovers new pathways of knowledge management and relational governance through project-specific knowledge formation.

Keywords: information sharing; knowledge management; knowledge formation; complex infrastructure project performance

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1. Introduction

Complex infrastructure projects are known for cost overruns, schedule delays, complicated work processes, and fragmented work practices [1]. The high interdependencies exhibited in infrastructure projects can leave essential infrastructure projects' functions susceptible to failure [2]. With the advent of the knowledge economy, project-based organizations have realized the significance of advancing knowledge management to increase competitiveness and sustainable performance [3]. From a knowledge management perspective, the emergence of new knowledge in complex infrastructure projects is the essence of innovation [4]. New knowledge is developed through knowledge formation (KF) (also known as knowledge creation) which encompasses specialized knowledge that is the result of collective knowledge, such as new ideas, innovative solutions, new processes, and new procedures, shared by multi-disciplinary teams in complex projects [5].

Complex infrastructure projects depend on the specialist knowledge from inter-disciplinary experts throughout a project's life cycle [6]. It is imperative to ensure that the knowledge flow across the multi-disciplinary teams is well managed to improve project performance. Existing studies have demonstrated that information sharing (IS) and knowledge formation (KF) create value for complex projects and improve project performance [7,8]. From a project-level perspective, knowledge management should comprise procedures that aim to create, deploy, and disseminate micro knowledge for project operation based on the macro knowledge of stakeholders at all levels of organizations with the purpose of increasing the abilities of stakeholders' participation directly or indirectly for effective project implementation or to improve their opportunities for affecting project operation [9]. Knowledge management includes all processes from knowledge acquisition to knowledge application to achieve a positive outcome. An existing study reveals that the lack of systematization or knowledge identification practices has made organizations lose their innovative position and restrained their absorptive capacity in identifying necessary knowledge in project management [10]. For complex infrastructure projects, it is essential to identify knowledge management processes so that project stakeholders can identify ways to create new knowledge for improving project performance. However, no prior study has conducted an in-depth analysis to examine how information sharing and knowledge formation can be used to improve complex infrastructure project performance.

This study posits that information sharing can improve project performance through KF and this relationship is mediated by knowledge organization (KO) and knowledge integration (KI). KO refers to the use of clear rules to codify and manage the processing and production of knowledge through knowledge acquisition and storage [11] whereas KI is knowledge synthesis that involves various types of expert knowledge from an individual to collective level [12]. In a complex infrastructure project setting, KO is an important project management area that allows organizations involved in the same project to capture, store, retrieve, and distribute knowledge for conveying useful information to project team members through formalized processes [13,14]. However, KO does not facilitate KF in developing new knowledge; KF can be achieved by integrating the heterogeneous knowledge and experience of multiple stakeholders through KI [15]. The KI process entails the identification of valuable knowledge and the conversion of raw data and information into KF [16,17]. Prior studies show that the ability to integrate specialized knowledge from interdisciplinary team members effectively is key in determining project performance [18]. Project planning, organizing, leading, and controlling can improve a construction project's success via KI [12]. However, how KI influences complex infrastructure project performance remains unclear. Whether KF is caused by KO and/or KI remains an unanswered question too. Additionally, this study also proposes that inter-organizational trust (GT) plays an important moderating role in the relationship between KO and KI. When knowledge is organized, project stakeholders from various organizations could identify the solutions that they need to resolve complex problems or create value for enhancing project performance.

To improve complex infrastructure project performance, this study aims to uncover the relationships among IS, KO, and KI through KF. Empirical data were collected from cross-organizational complex infrastructure projects using the questionnaire survey method, and the relationships among constructs were analyzed through partial least-squares structural equation modeling (PLS-SEM). The rest of this paper is structured as follows. Section 2 describes the theoretical foundation of complex infrastructure project KO, KI, and KF. Section 3 discusses the research hypotheses. Section 4 describes the measurements and research methodologies, and Section 5 presents the data analysis and research findings. Section 6 discusses the research contributions, implications, and limitations.

2. Theoretical Background

2.1. Information and Knowledge in Complex Infrastructure Projects

In complex infrastructure projects, information primarily refers to the data generated and shared by various stakeholders. This information is voluminous and highly fragmented, which leads to inefficiencies in information retrieval by project stakeholders [19]. Information flow aids in describing the required work, supporting decision making, analyzing progress, sharing information with other participants, and recording claims for future reference [20]. This is the premise behind managing information flow, which is extremely important for ensuring project success [21,22].

The term knowledge indicates the appropriate collection of information [23]. In this study, knowledge implies inter-organizational practices, rules, and experiences acquired via information spillover [24]. Complex infrastructure projects are highly knowledge-intensive because of their complexity in terms of cost, planning, technology, and forms of collaboration [25]. Another key reason is that complex infrastructure projects are outside "business as usual" and often are unique in one or more ways. The knowledge required for implementing project tasks is spread across many participants. Thus, IS, KO, and KI are important to create new knowledge for complex infrastructure projects, particularly for complex projects, to resolve complex problems [26].

2.2. IS, KO, KI and KF in Complex Infrastructure Projects

IS, KO, KI, and KF are particularly important in knowledge management for facilitating KF [5,27]. For instance, extant studies show that IS can improve project performance in large organizations [28,29] after the requisite information has been obtained. KO is an important element to hold knowledge management components together [30]. Here, KO refers to the use of clear rules to codify and manage the processing and production of knowledge through knowledge acquisition and storage [11]. This is followed by KI, which is a crucial step in the path to achieving KF. Problems in complex infrastructure projects can be classified into complicated and complex problems [31,32]. Complicated problems can be decomposed into many challenging and clearly bound problems which could be resolved through KI methods such as value engineering, big room, smart sheet, and last planner systems [7].

KF is an emerging method to solve problems, via new technology, new methods, new procedures, and new processes, by organizing and learning about knowledge uncertainty [5]. Different types of project-related problems require corresponding KF which is based on the problem complexity and novelty [32]. However, KF cannot be achieved if relevant information is not collected and organized for KI. Learning needs to be formalized to understand how various methods apply in a real-life project, what the reasoning is, and how they impact the project [7]. The process of learning formalization requires proper knowledge acquisition and storage for utilization. The learning process also involves reflection and knowledge assimilation [33] which accentuate the importance of KI. KI uses tools, methods, and techniques to support, facilitate and promote different types of learning, and thereby support the transfer among stakeholders to develop KF [34]. Therefore, from a project perspective, KF is created through organizing learning and shared knowledge, which can be understood as a core organizational competence to improve the performance of complex infrastructure projects. KO, which is in the domain of organizing knowledge, and KI—a process of integrating knowledge for learning—are two elements that play crucial roles in the development process of KF.

3. Research Hypotheses

3.1. IS and Project Performance

In complex infrastructure projects, the amount of information increases exponentially, complicating information management [35]. IS is described as the central process in which stakeholders share and use available informational resources [36,37]. It is conducted by stakeholders in accordance with contract requirements to provide and share existing documents and information. In practice, project owners establish rules and processes to promote the flow of information among stakeholders [38]. Since complex infrastructure projects consist of various independent tasks, IS can better promote the understanding of and interaction among the tasks, thereby reducing errors and improving project performance. Furthermore, through an existing meta-analysis, it is identified that IS positively promotes cohesion, KI, decision satisfaction, and project performance [36]. Meanwhile, when information is authenticated as knowledge by project members, it reduces coordination costs among members, shortens project cycles, and improves the efficiency of task completion [39].

H1. *IS positively influences project performance.*

3.2. Mediating Role of KO in the IS-KI Relationship

In complex infrastructure projects, besides explicit knowledge exchanges, project members gain insights into others' ideas and information through face-to-face interactions during the collaborative process, which contributes toward tacit knowledge acquisition [40]. A cooperative culture of IS promotes communication and exchange among all participants and encourages them to contribute relevant knowledge to meet the needs of KI [41]. Complex problem solving requires KI of multiple resources, including information and knowledge, which are obtained from within and outside organizations that are involved in the projects. KI combines existing knowledge to achieve KF [42]. To connect different types of knowledge, the KI community must have a common knowledge base [43]. In this case, inter-organizational IS could promote effective communication and facilitate the sharing of experience and learnings, thereby significantly improving project performance [41,44]. In complex infrastructure projects, KO is delegated depending on the needs of various stakeholders. In other words, according to the task requirements of various stakeholders, pre-given knowledge is recombined and internalized into useful knowledge through IS, knowledge acquisition, and storage [45,46]. Therefore, the authors posit that:

H2. *KO mediates the relationship between IS and KI.*

3.3. Mediating Role of KI in the KO-KF Relationship

From the perspective of complex projects, the knowledge of different stakeholders constitutes the project network's knowledge [47]. Members of organizations involved in the project can facilitate knowledge creation by sharing personal experiences and integrating knowledge from various sources [48]. Therefore, KO provides different types of knowledge sources and promotes KI, which leads to KF in complex infrastructure projects [49]. KF is inherent to collective problem solving under time and cost constraints and leads to the development of new knowledge, such as new ideas, innovative solutions, new processes, and new procedures [5,50]. KI and KF are both indispensable for the study of cross-organizational complex infrastructure projects [51]. This is because complex infrastructure projects are gradually completed through the division of tasks and organizational restructuring. Frequent communication between project members integrates distributed and heterogeneous knowledge sources to facilitate knowledge creation [52]. In other words, KI can be viewed as a platform or tool to identify heterogeneous knowledge and transform it into knowledge for achieving goals [53].

H3. *KI mediates the relationship between KO and KF.*

3.4. KF and Project Performance

Continuous KF responds to knowledge uncertainty in complex infrastructure projects [54]. It is impossible to obtain specific knowledge at the project planning stage; however, an emergent knowledge solution addresses the challenges of delivering a project [55]. By exchanging existing information and knowledge, participants integrate distributed and heterogeneous knowledge sources [56]. Project execution is seldom a process of implementation; rather, it is a journey of knowledge creation [57]. Based on emergent KF, problem solving is highlighted as a productive process of innovating solutions and is intrinsic to complex infrastructure projects as an organizational practice. In complex infrastructure projects, via KF, new methods, new technologies, and new processes are developed to solve technical and managerial problems; this new knowledge is crucial for improving project performance [58–60].

H4. *KF positively influences project performance.*

H5. *KO, KI, and KF play multiple mediating roles between IS and project performance.*

3.5. Moderation Effect of Inter-Organizational Trust

Inter-organizational trust is the foundation of relational governance; it refers to the positive expectations of one member about the behavior of other members [61]. Since project members come from different companies, they are driven to maximize the interests of their own organization [62]. Inter-organizational trust mitigates the precautionary mentality of project stakeholders, thus addressing potential issues such as the information asymmetry that may occur in the process of IS [63]. In this case, project stakeholders monitor their opportunistic behavior, engage in bilateral problem solving, and commit to the achievement of shared objectives [64].

In the KO process, the interaction among stakeholders is based mainly on rules and processes; there is negligible focus on the promotion of tacit knowledge exchange and collaborative innovation, which rely on inter-organizational trust. However, KI involves multiple stakeholders and heterogeneous knowledge, which are influenced significantly by the relational governance mechanism. Inter-organizational trust could be regarded as an important informal cooperative mechanism that promotes multidimensional KI [65]. Trust improves the quality of relationships, motivates project members to engage in knowledge sharing, and simplifies knowledge transfer between members [66]. Inter-organizational trust can help one stakeholder predict and understand the behavior of others, thereby improving KI capabilities based on coordination [67]. Therefore, inter-organizational trust reflects the breadth and depth of relationships among stakeholders.

H6. *Inter-organizational trust does not moderate the influence of IS on KO.*

H7. *Inter-organizational trust positively moderates the positive influence of KO on KI.*

4. Research Methodology

4.1. Sample and Procedures

Data were collected in cooperation with the Jiangsu Provincial Department of Transportation; under its jurisdiction, 54 municipal districts were asked to collect data on recently completed projects that exceeded RMB 1 billion. A questionnaire was developed based on the literature, and some items were modified to fit the Chinese context. The questionnaire was distributed to owners or contractors who were involved in and aware of the details of the investigated project. The respondents were asked to fill the items of the questionnaire based on the specific project mentioned in the project name and specific bidder section. The support and cooperation of local authorities helped ensure the quality of the research data. A total of 313 questionnaires were returned. After removing all incomplete responses, 234 valid questionnaires from 21 owners, 152 contractors, and 61 others (including external designers and consultants) were used for data analysis, representing 8.9%, 65%, and 26.1% of the sample, respectively.

Most infrastructure projects were road construction projects (57.3%); the rest included bridges (13.7%), railways (18.4%), and other mixed-development projects (10.6%). The projects were complex in nature as they required continuous change in terms of progress and activity owing to uncertainties [68]. They also consisted of numerous diverse interconnected components, and they were highly dependent [69]. Most respondents were project engineers (47.8%); project leaders accounted for 2.6% of the sample, and the department heads of the project management office accounted for 38.9%. Table 1 shows the details of the survey participants and projects.

Common method bias refers to the artificial covariation between the independent and dependent variables caused by the same data source; this bias is prevalent in psychological and behavioral science research based on questionnaire surveys. It is a systematic error that seriously confuses the research results [70]. Procedural and statistical methods can be used to control the common method bias [71]. Data were collected in two stages with an interval of one month between the stages, which was expected to reduce the likelihood of potential sources of leading common method variance [72]. The respondents were required to fill in the basic information of the project and IS, KO, KI, and KF in the first stage. One month later, the transportation authorities required the related respondents to fill out the remaining information on the project performance. Furthermore, some experts were asked to fill out the questionnaires in advance, and the questionnaires were edited several times to remove ambiguous, unfamiliar terms and vague concepts.

Table 1. Basic information on respondents and projects.

Item	Indicators	Frequency	Percentage (%)
Project organization	Owners	21	8.9
	Contractors	152	65
	Others	61	26.1
Age	Under 30 years	125	53.4
	30–40 years	70	30
	40–50 years	31	13.2
	50–60 years	8	3.4
	Above 60 years	0	0
Years of work	Under 5 years	104	44.4
	5–10 years	63	27
	10–15 years	29	12.4
	15–20	25	10.7
	above 20 years	13	5.5
Position	Company directors	6	2.6
	Project managers	15	6.4
	Department heads	91	38.9
	Project engineers	112	47.8
	Others	10	4.3
Project category	Bridge	32	13.7
	highway/road	134	57.3
	Railway	43	18.4
	other mixed-development projects	25	10.6

4.2. Measurement

The respondents answered each questionnaire item using a 5-point Likert scale, where "1" stands for strongly disagree and "5" stands for strongly agree. All the constructs were assessed using reflective measurements. Table 2 shows the measurement items and their relevant references.

4.2.1. IS

IS provides more scientific information to support decision making in project management [73]. Information can be developed through consistent discussions among project team members from different firms, such as at team meetings [18]. Team members are willing to share information when they trust their team, which is influenced by the frequency of communication, shared project value, and perceived expertise of team members [74]. This construct measures the degree of data sharing and the articulation and presentation of explicit knowledge in the form of text, graphics, words, or other symbolic forms among project stakeholders [75].

4.2.2. KO

In the context of a project, knowledge management is defined as "processes that aim to generate, utilize, and distribute the micro-knowledge necessary for project execution and processes that are performed on the macro-knowledge of people at all organizational levels and that aim to increase the capabilities of direct or indirect participation of people in effective project execution or to increase their possibilities for influencing project execution." [9]. As compared to knowledge management, KO is more concerned with knowledge-organizing processes and systems [14]. In this study, the focus is on an inter-organizational setting in which inter-organizational trust is hypothesized as the moderator between KO and KI. KO involves a formal process to acquire and store knowledge for converting tacit knowledge into explicit knowledge [76].

4.2.3. KI

KI is a collaborative process of combining knowledge by interdisciplinary team members [77,78]. It is concerned with the selection mechanism for managing complementary knowledge in an economizing manner [27]. This construct involves the interaction and integration of distributed and heterogeneous knowledge sources.

4.2.4. KF

KF is the transformation of a piece of specialized knowledge [79], which is the result of conceiving, articulating, designing, operating, and bringing into existence [80]. In this study, it does not only encompass the specialized knowledge created, but it is also used to define solutions in complex infrastructure projects [5,50]. It requires cooperation among team members from cross-organizations, particularly the inputs of team members from different disciplines, to contribute and collaborate for creating knowledge [81]. Based on the explanations above, KF refers to the use of emergent new solutions, such as new ideas, innovative solutions, new processes, and new procedures for problem solving by inter-organizations in complex infrastructure projects [5,50].

4.2.5. Inter-Organizational Trust

Inter-organizational trust contributes toward promoting mutual collaboration and common goals [82]; it consists of calculus-based trust, relational-based trust, and institution-based trust [61].

4.2.6. Project Performance

Project performance is typically termed as project success to define what a project achieves by way of satisfying the owner and creating business value for the firm and project stakeholders [83].

Table 2. Measurement Items.

Construct and Item	References
Information sharing (IS) IS1: We shared technical documents and project information with other stakeholders. IS2: We shared information from discussions with other stakeholders. IS3: We had a culture of information sharing.	[52]
Knowledge formation (KF) KF1: This project has facilitated several technological innovations. KF2: This project has developed new work procedures, methods, or improved pre-given methods. KF3: A set of best practices have been innovated and applied to this project	[4,5,84]
Knowledge integration (KI) KI1: We adopted an integrated approach to promote knowledge creation ability. KI2: We formed an effective synergy mechanism and integration platform with other stakeholders. KI3: We effectively integrated the different sources of knowledge.	[85]
Knowledge organization (KO) KO1: We had formal processes and methods to gain required knowledge. KO2: We have fully understood the expertise, capabilities, and knowledge of other partners.	[86]
KO3: We often reflected on work mistakes, summed up experiences, and improved work methods along with other stakeholders KO4: We had a good document management system that allowed us to save and use knowledge. KO5 We regularly stored and updated knowledge obtained from our projects.	[87]

Table 2. *Cont.*

Construct and Item	References
KO6: We classified and managed different types of knowledge from different sources. KO7: We could quickly find and access the relevant stored knowledge.	
Inter-organizational trust (GT) GT1: This project owner executed fair contracts and agreements with us. GT2: We believed that other stakeholders considered our interests when making a major decision. GT3: We believed that other stakeholders were honest and would fulfill their promises. GT4: We believed that other stakeholders had the capacity to meet the technological and management requirements of the project.	[61,88]
Project performance (PP) PP1: The project made good progress and was completed within the schedule. PP2: The project was completed within the budget owing to effective cost-control. PP3: The response to changes in the project was timely. PP4: The stakeholders had fulfilled their commitments and the final results were in line with the expected results. PP5: Project stakeholders were likely to cooperate again with projects or other businesses.	[84,89]

4.3. Data Analytical Procedures

The SEM method can be classified into covariance-based SEM (CB-SEM) and variance-based SEM such as the partial PLS-SEM. PLS is an efficient modeling method that is comparable to CB-SEM [90] when the scenarios fulfill the soft distributional assumption, possess high model complexity, have a small sample size, are exploratory in nature, and require parameter estimation accuracy [91]. Based on the dataset and model properties in this study, PLS-SEM was selected for analytical purposes. The hypothetical model was first assessed for its validity and the reliability of the measurement model, and subsequently, the structural model was examined for direct and indirect interaction relationships.

5. Data Analysis and Findings

5.1. Common Method Bias

Common method bias was considered for the construct and method factor. This is a rigorous statistical analysis [71,92]. Table 3 shows that 0.727 is the average substantive variance and 0.020 is the average common-method-based variance, resulting in a ratio of 36.4:1. The table further shows the different path coefficients of the structural model; most method factor loadings are insignificant. Based on the insignificance of the method variance, the results indicate that common bias is not a critical issue in this study.

Table 3. Common method bias analysis.

Path	Substantive Factor Loading (R1)	$R1^2$	Path	Method Factor Loading (R2)	$R2^2$
IS -> IS1	0.957 ***	0.915	METHOD -> IS1	−0.059	0.004
IS -> IS2	0.997 ***	0.995	METHOD -> IS2	−0.162 *	0.026
IS -> IS3	0.708 ***	0.502	METHOD -> IS3	0.211 ***	0.045
KF -> KF1	0.874 ***	0.764	METHOD -> KF1	−0.056	0.003
KF -> KF2	0.806 ***	0.649	METHOD -> KF2	0.069	0.005
KF -> KF3	0.874 ***	0.764	METHOD -> KF3	−0.017	0.000
KI -> KI1	0.884 ***	0.781	METHOD -> KI1	0.029	0.001
KI -> KI2	1.078 ***	1.163	METHOD -> KI2	−0.223 **	0.050
KI -> KI3	0.710 ***	0.504	METHOD -> KI3	0.189 *	0.036
KO -> KO1	1.017 ***	1.034	METHOD -> KO1	−0.267 *	0.071

Table 3. *Cont.*

Path	Substantive Factor Loading (R1)	$R1^2$	Path	Method Factor Loading (R2)	$R2^2$
KO -> KO2	0.773 ***	0.598	METHOD -> KO2	0.001	0.000
KO -> KO3	0.911 ***	0.829	METHOD -> KO3	−0.121	0.015
KO -> KO4	0.645 ***	0.416	METHOD -> KO4	0.221 *	0.049
KO -> KO5	0.815 ***	0.664	METHOD -> KO5	0.034	0.001
KO -> KO6	0.884 ***	0.782	METHOD -> KO6	−0.024	0.001
KO -> KO7	0.710 ***	0.504	METHOD -> KO7	0.117	0.014
GT -> GT1	0.678 ***	0.459	METHOD -> GT1	0.189 *	0.036
GT -> GT2	0.996 ***	0.993	METHOD -> GT2	−0.153 *	0.023
GT -> GT3	0.987 ***	0.974	METHOD -> GT3	−0.184	0.034
GT -> GT4	0.779 ***	0.607	METHOD -> GT4	0.127	0.016
PP -> PP1	0.602 ***	0.362	METHOD -> PP1	0.218 *	0.047
PP -> PP2	0.936 ***	0.876	METHOD -> PP2	−0.183 **	0.034
PP -> PP3	0.854 ***	0.729	METHOD -> PP3	−0.016	0.000
PP -> PP4	0.778 ***	0.606	METHOD -> PP4	0.003	0.000
PP -> PP5	0.839 ***	0.705	METHOD -> PP5	−0.017	0.000
Average		0.727	Average		0.020

Note: *, **, and *** indicate a significance level of $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively; GT = Inter-organizational trust; IS = Information sharing; KO = Knowledge organization; KF = Knowledge formation; KI = Knowledge integration; PP = Project performance.

5.2. Evaluation of the Measurement Model

Since tests of convergent validity and discriminant validity are required in most measurement models [93,94], we conducted the following tests.

5.2.1. Convergent Validity

The first convergent validity test is based on individual item reliability, which is examined by checking outer loadings [95]. Under normal circumstances, the minimum outer loading of an item should be 0.7. Individual item reliability is significantly robust as all factor loadings were above the threshold value. Second, average variances extracted (AVEs) were tested to assess the convergent validity of the measurement models at the construct level, using 0.5 as the threshold value. Next, Cronbach's alpha (α) was examined together with composite reliabilities (CR) to assess internal construct consistency, where the threshold value should be above 0.70.

The results of convergent validity are shown in Table 4. The model possesses sufficient convergent validity based on the results of AVE, CR, and α for IS, KF, KO, KI, inter-organizational trust, and project performance.

Table 4. Factor loadings, AVE, CR, and Cronbach's alpha of indicators.

Construct and Item	Outer Loadings	AVE	CR	Cronbach's Alpha
Information sharing (IS)		0.782	0.915	0.861
IS1	0.908			
IS2	0.860			
IS3	0.885			
Knowledge formation (KF)		0.722	0.886	0.809
KF1	0.823			
KF2	0.869			
KF3	0.856			
Knowledge integration (KI)		0.800	0.923	0.875
KI1	0.913			
KI2	0.885			
KI3	0.884			

Table 4. *Cont.*

Construct and Item	Outer Loadings	AVE	CR	Cronbach's Alpha
Knowledge organization (KO)		0.669	0.934	0.917
KO1	0.772			
KO2	0.775			
KO3	0.798			
KO4	0.848			
KO5	0.848			
KO6	0.862			
KO7	0.819			
Inter-organizational trust (GT)		0.732	0.916	0.878
GT1	0.850			
GT2	0.862			
GT3	0.816			
GT4	0.894			
Project performance (PP)		0.644	0.900	0.862
PP1	0.769			
PP2	0.782			
PP3	0.836			
PP4	0.834			
PP5	0.790			

5.2.2. Discriminant Validity

The Fornell–Larcker analysis is a relatively conservative test for discriminant validity [96]. The AVE's square root was above the correlation values as shown in Table 5, indicating that the constructs exhibit significant discriminant validity [97].

Table 5. Variable correlations.

	GT	IS	KF	KI	KM	PP
GT	**0.803**					
IS	0.781	**0.884**				
KF	0.576	0.390	**0.767**			
KI	0.861	0.713	0.674	**0.838**		
KO	0.886	0.829	0.565	0.843	**0.784**	
PP	0.792	0.576	0.763	0.604	0.619	**0.745**

Note: GT = Inter-organizational trust; IS = Information sharing; KI = Knowledge integration; KO = Knowledge organization; KF = Knowledge formation; PP = Project performance.

5.2.3. Predictive Relevance

Stone–Geisser's Q-square test was conducted using the blindfolding procedure to show Q-square results under cross-validated redundancy [98,99]. Table 6 shows that the results are above 0, indicating good predictive relevance of the hypothetical model.

Table 6. CV-redundancy, communality, and R-squared values.

	CV-Redundancy	Communality	R^2
IS	-	0.676	-
KF	0.228	0.589	0.454
KI	0.498	0.702	0.859
KO	0.446	0.615	0.840
PP	0.305	0.555	0.685
Average		**0.627**	**0.710**

Note: IS = Information sharing; KF = Knowledge formation; KI = Knowledge integration; KO = Knowledge organization; KF = knowledge formation; PP = Project performance.

5.2.4. Goodness of Fit

Goodness of fit (GoF) is an indicator that calculates the predictive power of both measurement and structural models, with 0.1, 0.25, and 0.36 representing critical values for weak, moderate, and strong fitness, respectively. This indicator is derived from average communality and R-squared (R2) as GoF $= \sqrt{((\overline{\text{Com}}) * (\overline{\text{R}^2}))}$. The calculated fitness of this model is 0.627 as shown in Table 5, implying a good overall fit.

5.2.5. R-Squared

The R-squared value indicates the amount of variance in the outcome variable [94]. The measured coefficient values in the PLS model are divided into high (0.67), medium (0.33), and low (0.19) [100]. Table 6 shows that all R-squared values are above 0.33, which means that the predictors can effectively reflect the results of relevant information. In other words, the predictors are effective.

5.3. Structural Model

A structural model should be validated according to the functions of the PLS algorithm and bootstrapping [94]. The standardized path coefficient, β, is calculated based on the PLS algorithm, while the t-value is obtained after bootstrapping for 5000 iterations [93].

5.3.1. Path Coefficient Tests

Table 7 and Figure 1 show positive relationships between IS and KO (β = 0.388, $p < 0.01$), IS and project performance (β = 0.320, $p < 0.01$), KF and project performance (β = 0.541, $p < 0.001$), KI and KF (β = 0.538, $p < 0.001$), and KO and KI (β = 0.450, $p < 0.001$). The predicted positive and direct relationships between IS and KI (β = −0.014, $p > 0.05$) and KO and KF (β = 0.078, $p > 0.05$) are not supported. Thereby, H1 and H4 are supported. In other words, IS and KF directly and positively influence project performance.

Table 7. Summary of path coefficient.

Hypothesis	Path	Path Coefficient (β)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	*p* Values
	IS -> KI	−0.014	0.070	0.193	0. 847
	IS -> KO	0.388	0.058	6.686	0.000
H1	IS -> PP	0.320	0.053	6.113	0.000
H4	KF -> PP	0.541	0.055	9.846	0.000
	KI -> KF	0.538	0.088	6.065	0.000
	KO -> KF	0.078	0.092	0.850	0.396
	KO -> KI	0.450	0.075	5.926	0.000

Note: IS = Information sharing; KO = Knowledge organization; KI = Knowledge integration; KF = knowledge formation; PP = Project performance.

5.3.2. Mediating Effect Tests

The analysis procedure was used to assess the mediation hypotheses based on indirect and direct effects [101]. Subsequently, product confidence limits for indirect effects (PRODCLIN) were adopted to measure the confidence intervals of the specific indirect mediating effects [102].

First, the direct effects of IS on KO (β = 0.388, $p < 0.001$), information sharing on project performance (β = 0.320, $p < 0.001$), KO on KI (β = 0.450, $p < 0.001$), KI on KF (β = 0.538, $p < 0.001$), and KF on project performance (β = 0.541, $p < 0.001$) are significant. Second, the statistical significance of indirect effects was determined through 5000 bootstrap iterations at the 95% confidence interval. Table 8 shows the total indirect effect of IS on project performance, which is statistically significant (point estimate = 0.063, $p < 0.01$). Additionally, the test of the mediation of KO on the relationship of IS and KI shows a significant point estimate (point estimate = 0.175 and 95% BCa CI [0.106, 0.2757]), and thus, H2 is supported. The test of the mediation of KI on KO and KF shows a significant point estimate (point estimate = 0.242 and 95% BCa CI [0.135, 0.382]), and thus, H3 is supported. Finally, the test of the multiple mediations of KM, KI, and KF on the relationship between IS and project performance shows a significant point estimate (point estimate = 0.063 and 95% BCa CI [0.020, 0.131]), and thus, H5 is supported, which explains the full path of how IS affects project performance.

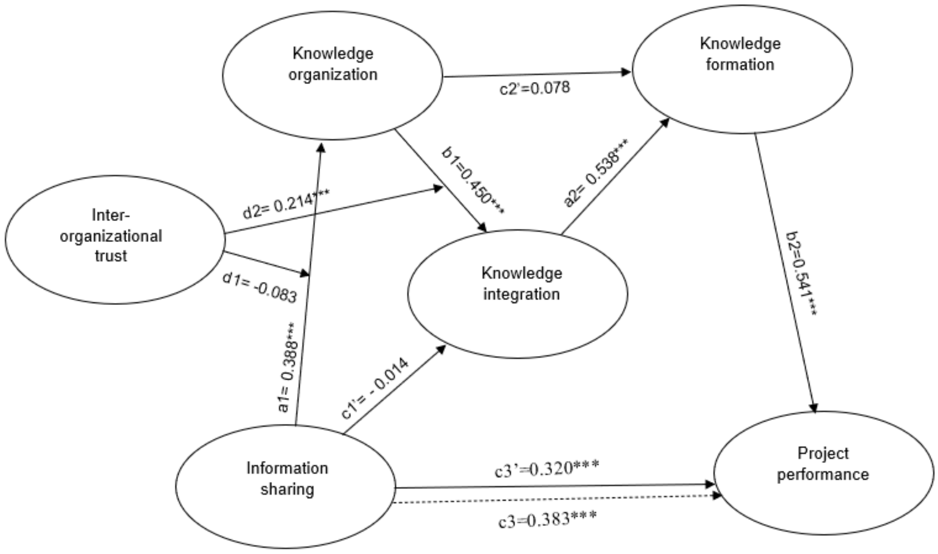

Figure 1. Structural model: A multiple mediation model. Note: *** indicates a significance level of $p < 0.001$; c1′, c2′ and c3′ denote direct effect whereas c3 represents total effect.

Table 8. Summary of mediating effects tests.

Hypothesis	Effects	Product of Coefficients		95% BCa Confidence Interval	
		Point Estimate	*p* Values	Lower	Upper
H2	a1b1(via KO)	0.175	0.000	0.106	0.257
H3	b1a2(via KI)	0.242	0.000	0.135	0.382
H5	Total indirect effect = a1c2b2 + a1b1a2b2 + c1a2b2 (via KO, KI and KF)	0.063	0.008	0.020	0.131

Note: IS = Information sharing; KO = Knowledge organization; KI = Knowledge integration; KF = knowledge formation; PP = Project performance. Moderating effect tests.

Moderating effects are caused by variables that affect the strength or direction of the relationship between the exogenous and the endogenous variables [103]. If the coefficient of the moderate variable is significant, it indicates that the moderating effect exists. Table 9 reports the moderating effects. Inter-organizational trust does not moderate the relationship between IS and KO ($\beta = -0.083$, $p > 0.05$), and thus, H6 is supported. However, inter-organizational trust does moderate the relationship between KO and KI ($\beta = 0.214$, $p < 0.001$), and thus, H7 is also supported.

Table 9. Summary of moderating effect tests.

Hypothesis	Path	Path Coefficient (β)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	*p* Values
H6	IS*GT -> KO	−0.083	0.045	1.856	0.064
H7	KO*GT -> KI	0.214	0.033	6.587	0.000

Note: KO = Knowledge organization; KI = Knowledge integration; GT = Inter-organizational trust.

6. Discussions and Conclusions

6.1. Theoretical Contributions and Practical Implications

This study expands knowledge management theory by analyzing the impact of IS, KO, KI, and KF on project performance in complex infrastructure projects. Our findings have clarified the practice of knowledge management for complex-problem-solving processes in improving complex infrastructure project performance in three valuable ways.

First, this study uncovered the path from IS to improving complex infrastructure project performance, extending the literature on knowledge management of enterprises [53,104]. The findings show that IS has a significant direct effect on project performance, but it also has a significant total effect on project performance and mainly manifests as multiple mediation roles among KO, KI, and KF. Effective information sharing can promote information flow among tasks more effectively and realize the integration of project members, thereby improving project quality, reducing costs, and shortening project duration. However, the direct impact of IS on KI and that of KO on KF are not significant. This indicates that each stakeholder internalizes shared information into its personal knowledge and experience to accomplish assigned tasks through KO which focuses on knowledge acquisition and storage. Complex problem solving in complex infrastructure projects requires the integration of new heterogeneous knowledge achieved through project members' cooperation.

Second, this research has revealed that KF in complex infrastructure projects relies on KI. The results show that the direct effect of KO on KF is not significant, but the total effect of KO and KF is significant, indicating that KI plays a full mediation role. This shows that the foundation of KF requires the establishment of a common knowledge base that is contributed to by all team members. KF is essential for inter-organizational flows of knowledge, particularly in the domain of complicated and complex problems [31]. This finding empirically confirms the theory identified in an existing study that KF is only created through the synthesizing of explicit and experiential knowledge [5]. In this regard, formalization in complex infrastructure projects can be used to retain experiential knowledge and combined with new applications to improve project performance [105]. KI serves as a tool or platform to integrate heterogeneous knowledge from multiple sources through inter-organizational cooperation. Considering that conflicts and misunderstandings often occur between project members from different organizations or disciplines, a common knowledge base and knowledge transfer are used as the basis for cooperation [50]. Some studies have pointed out that a common knowledge base is a prerequisite for stakeholders to share, assess, and integrate their domain-specific knowledge, especially for their tacit knowledge and experience [106].

Third, this study explored the moderating role of inter-organizational trust. The literature has emphasized the importance of trust between organizations for project performance, especially for cross-organizational business processes [107,108]. However, there has been no detailed investigation of the moderating effect of trust on KO. Considering that the quality of the relationship between project members would significantly affect the cooperative behavior [64], this research has investigated the moderating role of inter-organizational trust during the phases of knowledge transfer. The results show that inter-organizational trust does not play a moderating role in the effect of IS on KO. However, inter-organizational trust significantly moderates the effect of KO on KI. This indicates that the higher the inter-organizational trust, the more the project members can acquire knowledge, understand the expertise from their team members as well as reflect their work mistakes, and improve the work methods along with their team members to convert them into useful knowledge. KI can be achieved by constructing, articulating, and redefining the shared beliefs of members [51]. This aspect allows inter-organizational trust to play an important role when project members would like to acquire useful information from other team members and integrate the knowledge they gained to produce innovative ideas and resolve complex issues in complex infrastructure projects. To achieve this, the construction organizations are required to improve their employees' capacities in handling new knowledge [109] and enhance their social cognitive skills [73,110].

Apart from the above theoretical contributions, this research also has meaningful and practical implications for complex infrastructure projects. IS is a prerequisite for project implementation and its value becomes apparent after KI and KF. This finding provides useful guidance and steps for all stakeholders in complex infrastructure projects. For example, after obtaining information from multiple sources, each organization needs to store and use that knowledge to form an internal KO system. Subsequently, a KI platform is used to initiate interaction with other organizations' knowledge systems to create new knowledge (KF) for resolving complex issues. Hence, it is necessary for the project stakeholder to establish an organizational context to consolidate control strategies, including high-order organizing principles and self-organization [42]. This practice would gradually lead to the formation of inter-organizational trust via frequent communication and promote mutual interest to improve the effect of KF for improving overall project performance.

6.2. Limitations

Certain limitations need to be considered in interpreting the above research results. Although the questionnaire survey targeted large-scale projects, the results could vary depending on the size and number of stakeholders involved in complex infrastructure projects. This research is limited to infrastructure projects of 54 municipal districts under the jurisdiction of the Jiangsu Provincial Department of Transportation in China. Perspectives from various types of stakeholders ranging from project owners, contractors, consultants, etc., were collected and analyzed. The scope that the authors studied may not be complete; however, the observed variables are of a general nature. As the data were obtained from stakeholders who were involved in infrastructure projects that exceeded RMB 1 billion, the results of this study could be applied to complex infrastructure projects which are of a similar scale. The study focuses on investigating the relationship among knowledge management components, IS, KO, KI and KF, future research could extend the study to analyzing the effect of KF on project performance via knowledge application. This could be useful to identify how KF developed from KI could influence knowledge application to affect project performance. Future studies should consider the dynamic changes and impact of this complex-project-specific KF from the perspectives of stakeholders of other types of construction projects. Inter-organizational cooperation is identified as one of the factors that influence KF. Future studies could extend this knowledge area by investigating the form of inter-organizational cooperation that affects the level of KF and their applicability in general construction projects. Additionally, a new stakeholder management framework should be integrated with the KF process through a dynamic social network analysis. This will contribute toward the ongoing theoretical developments in complex infrastructure project management.

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