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Revisiting collaboration dilemmas among stakeholders in digital projects: A transaction cost lens

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ABSTRACT

Building Information Modeling is recognized as a key socio-technical system driving stakeholder collaboration in the construction industry. However, at the project level, it often encounters the paradox of difficult collaboration. Previous research has primarily compiled static lists of barriers, overlooking the processual challenges and stakeholders' behavioral responses during collaboration. To address this gap, this study applies transaction cost economics to examine the challenges stakeholders encounter throughout the collaborative process. Drawing on empirical data from expert focus groups and semi-structured interviews, the study first contextualizes a transaction cost map. Secondly, it identifies the learning and training costs arising from high asset specificity within organizations and uncertainty-driven coordination costs across organizations. The findings explain that under pressure from high transaction costs, stakeholders tend to adopt low-risk strategies, leading to collaboration dilemmas. This study offers a new perspective for understanding digital collaboration dilemmas and provides practical implications for project management.

1. Introduction

Project management in the Architecture, Engineering, and Construction (AEC) industry is undergoing profound changes in the midst of ongoing digital transformation (Papadonikolaki et al., 2019). The rapid evolution of information and communication technologies is profoundly transforming traditional approaches to project planning, design, and construction (Javaid et al., 2024). In particular, Building Information Modeling (BIM) has been at the center of the discussion of digital transformation (Succar & Kassem, 2015; Ahmed & Kassem, 2018). For decades, BIM has been promised as a transformative collaboration approach that supports efficient communication and information exchange among multiple stakeholders throughout the project lifecycle, enhancing overall project performance (Azhar, 2011).

Although BIM is introduced to facilitate collaboration, its use in practice often leads to superficial or fragmented collaboration rather than integrated working practice (Dossick & Neff, 2010; Matthews et al., 2018; Oraee et al., 2019). In this study, we refer to this practical paradox as the BIM collaboration dilemma. For example, in many projects, especially in China, BIM is often passively implemented after the completion of 2D design in a so-called "post-BIM" manner, or confined to specific project stages or purposes, serving mainly for visualization, checking, or compliance rather than as a shared platform for collaboration (Cao et al., 2015; Herr & Fischer, 2019). Such applications fall short of achieving comprehensive optimization in project schedule, quality, and cost, deviating from BIM's original collaborative intent.

For over a decade, scholars in project management and construction management have sought to address the challenges in BIM collaboration (Dossick & Neff, 2010; Oraee et al., 2019; Chen et al., 2021; Liu et al., 2022). There have been dozens of studies that attempt to explain the unsatisfactory BIM collaboration results by compiling barriers from technical, managerial, financial, and legal perspectives (Chan et al., 2019; Lidelöw et al., 2023; Sun et al., 2017). However, there is limited attention to the BIM collaboration process and its stakeholders, including the practical challenges they face and their behavioral responses.

Project stakeholders are not unaware of the value of BIM; instead, they clearly recognize that it is a complex socio-technical system (Sackey et al., 2015). Achieving effective BIM collaboration requires not only learning and mastering new technical skills but also adapting to workflow restructuring, organizational paradigm shifts, and role and responsibility redefinition (Oraee et al., 2019; Papadonikolaki et al., 2019). These changes introduce additional workload and risks, prompting distinct behavioral responses among stakeholders (Tan et al.,

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2025). For example, developers often act cautiously due to the absence of effective contracts to bind third parties (Sun et al., 2020; Chien et al., 2014). Designers frequently express dissatisfaction with the substantial labor training costs and the increased responsibility for managing BIM data (Xie et al., 2022). General contractors, who often encounter incomplete or unreliable BIM data, are forced to devote extra time to coordination and supervision, which fosters resistance to BIM implementation (Zheng et al., 2017).

From the perspective of transaction cost economics (TCE), stakeholders' interactions in BIM collaboration entail additional burdens and risks, known as transaction costs (TCs). These costs may discourage stakeholders from actively adopting new technologies that appear profitable on the surface (Kiss, 2016; Wu et al., 2019; Williamson, 1985). However, such costs have been largely overlooked in existing theoretical studies and are not reflected in formal project financial records (Wu et al., 2019). Nevertheless, for project participants, these TCs are a tangible burden that directly influences stakeholder attitudes and, in turn, shapes behavioral choices, ultimately affecting the realization of BIM's value (Zheng et al., 2017). Notably, the conventional barrier-list research perspective fails to adequately explain the TCs borne by stakeholders in BIM collaboration and their more profound behavioral implications.

To address this research gap, this study revisits the BIM collaboration challenges faced by stakeholders in China's construction industry by integrating the process and stakeholder perspectives with the TCE lens. By delving into the different stages and specific task contexts of stakeholder collaboration, the study seeks to address the following three core research questions:

RQ1: What kinds of transaction costs do stakeholders face at different stages of BIM collaboration?
RQ2: What are the characteristics of these transaction costs?
RQ3: How do these transaction costs influence stakeholder collaboration behaviors and contribute to the formation of BIM collaboration dilemmas?

The main contributions of this study are threefold. First, adopting the process and stakeholder perspectives, the study links collaboration dilemmas to stakeholders' hidden cost burdens and behavioral responses, thereby deepening the understanding of BIM collaboration challenges. Second, it develops a transferable analytical framework that offers a theoretical foundation for examining other forms of digital, cross-organizational collaboration. For researchers, this study provides a replicable analytical approach to extend research into digital project collaboration. For practitioners, it offers actionable managerial insights and practical guidance for identifying and mitigating bottlenecks in digital collaboration.

The paper is structured as follows. Section 2 identifies the research gap, the limited understanding of BIM collaboration dilemmas from both process and stakeholder perspectives, and then integrates transaction cost economics (TCE) to develop the analytical framework. Section 3 presents the research design and data analysis methods. Section 4 reports the research findings. Section 5 discusses the findings of research questions RQ1–RQ3 in relation to existing literature, elaborates on the theoretical and practical implications, and outlines the study's limitations and future research directions. Section 6 concludes the paper.

2. Theoretical background

This section aims to establish the theoretical foundation and analytical framework for understanding BIM collaboration dilemmas. First, Sections 2.1 and 2.2 review the key manifestations of stakeholder collaboration challenges in BIM and the limitations of existing research, thereby identifying the research gap. Second, Section 2.3 explains the underlying mechanisms of BIM collaboration dilemmas through the lens of transaction cost economics (TCE). Finally, building on the preceding discussion, Section 2.4 develops a theoretical framework for analyzing BIM collaboration dilemmas, grounded in process, stakeholder, and TCE perspectives, which provides the foundation for the subsequent research design and empirical analysis.

2.1. BIM collaboration dilemmas

Construction projects are characterized by temporality, inter-organizational collaboration, and high information intensity (Hall et al., 2018). Project stakeholders are required to engage in highly interdependent collaboration across multiple stages of the project (Martinsuo & Ahola, 2022). BIM is theoretically expected to facilitate information sharing and integration and is widely regarded as a crucial enabler of cross-disciplinary collaboration (Liu et al., 2017). However, extensive practice reveals that stakeholders often struggle to collaborate effectively through BIM in practice (Oraee et al., 2019; Papadonikolaki et al., 2019). Rather than supporting integrated working practices, BIM collaboration often remains superficial, manifesting as minimal compliance or limited implementation. Stakeholders frequently exhibit conservative, cautious, or even resistant and avoidant behaviors as forms of risk aversion, which contribute to the formation of the BIM collaboration dilemma (Tan et al., 2025; Wang et al., 2020).

2.2. Processual challenges faced by stakeholders in BIM collaboration

Over the past decade, scholars have extensively examined BIM collaboration from technological, economic, organizational, and managerial perspectives, often summarizing constraining factors in the form of barrier lists (Chan et al., 2019; Lidelöw et al., 2023; Sun et al., 2017). These studies provide valuable insights into the complexity of BIM collaboration but exhibit notable limitations. They neither capture the actual challenges stakeholders face in the process nor explain the underlying low-risk, conservative behavioral logic.

BIM collaboration is not merely a software application activity but a cross-disciplinary and inter-organizational interaction process centered on a shared digital platform and spanning multiple project stages (Papadonikolaki et al., 2019). Its effectiveness depends on the level of engagement and coordination among different stakeholders in specific tasks (Sampaio et al., 2023). From a process perspective, however, BIM collaboration entails stakeholders' continuous efforts and risk exposure, often exceeding the demands of traditional working practices (Chien et al., 2014; Sun et al., 2020). In the project preparation stage, developers are required to devote substantial time and effort to collecting and evaluating BIM-related information to support decision-making (Gu & London, 2010; Porwal & Hewage, 2013; Xu et al., 2014). During the design stage, designers are required to integrate interdisciplinary models, bear significant data verification costs (Xie et al., 2022), and meet compliance and review requirements from multiple parties (Olanrewaju et al., 2022). During construction, contractors rely on design models for cost and schedule control and assume responsibility for coordinating with downstream subcontractors and suppliers (Zheng et al., 2017). Therefore, BIM collaboration at each stage involves additional investments of time, effort, and risk, resulting in implicit burdens that are difficult to quantify directly.

From the stakeholder perspective, when these implicit burdens are perceived to exceed an acceptable threshold, they often trigger risk-averse behavioral responses (Tan et al., 2025). For example, ambiguous responsibility boundaries and the absence of standardized contracts compel stakeholders to invest additional effort in identifying and mitigating potential risks, thereby reducing their willingness to collaborate and leading them to meet only the minimum requirements of BIM application (Bosch-Sijtsema et al., 2017; Liao et al., 2021). In addition, frequent cross-organizational communication and coordination intensify collaboration pressures, often generating resistance and even prompting some participants to revert to traditional CAD-based work modes (Brewer & Gajendran, 2011; Cao et al., 2021; Murguia et al., 2023). Furthermore, disordered workflows and unclear task allocations undermine participants' trust and confidence, thereby reducing their willingness to replicate BIM practices in future projects (Bosch-Sijtsema et al., 2017; Siebelink et al., 2021). These behaviors are not incidental but represent responses by stakeholders facing high-cost, high-risk situations (Tan et al., 2025), which ultimately give rise to the BIM collaboration dilemma.

Accordingly, an analytical framework that integrates process-related hidden burdens with stakeholder perspectives is needed to gain deeper insight into the underlying mechanisms of BIM collaboration dilemmas, as elaborated in the following section.

2.3. Understanding BIM collaboration dilemma through the lens of transaction cost economics

Transaction cost economics (TCE) provides an analytical framework for understanding BIM collaboration dilemmas when integrated with process and stakeholder perspectives. First introduced by Coase (1937) and later systematically developed by Williamson (1985, 1998), TCE views "transactions" as inter-organizational interaction processes, emphasizing their dynamics and the behaviors of transactors. This theoretical perspective aligns closely with the context of BIM collaboration. As a form of cross-organizational digital collaboration, BIM entails continuous information exchange, process adjustment, and responsibility coordination among stakeholders (Papadonikolaki et al., 2019) and can be regarded as a multi-round "transaction process." From the integrated perspective, the challenges of BIM collaboration are not static or structural barriers but emergent frictions arising from stakeholder interactions —namely, transaction costs (TCs). These costs are dynamic and context-dependent and can only be fully understood by situating them within specific collaboration processes and stakeholder roles (Ebrahimigharehbaghi et al., 2020; Wu et al., 2019).

At the same time, it goes beyond the limitations of traditional barrier-list studies, enabling a deeper understanding of the origins of the hidden costs borne by stakeholders in BIM collaboration and their behavioral implications. According to Williamson (1985, 1998), transaction costs do not arise naturally. However, they are driven by the combined effects of transaction attributes, asset specificity, uncertainty, and transaction frequency, as well as behavioral assumptions such as bounded rationality and opportunism. In the context of BIM collaboration, stakeholders are typically required to meet a range of BIM-specific requirements, including professional skills, knowledge reserves, staffing arrangements, and contractual structures (Succar & Sher, 2014; Oraee et al., 2019). These investments demonstrate high asset specificity, as their value is difficult to transfer or recover outside BIM projects. Once collaboration fails, these investments become sunk costs, significantly increasing stakeholder risk (Liu et al., 2017; Lui et al., 2009). In addition, stakeholders are required to devote substantial effort to data validation, monitoring, and coordination throughout the collaboration process (Sun et al., 2020; Zhao et al., 2018). These additional costs often stem from technological and institutional uncertainties in BIM environments, as well as potential opportunistic behaviors (Gao et al., 2022; Zheng et al., 2017). In complex BIM collaboration contexts, bounded rationality prevents stakeholders from fully anticipating or managing potential risks (Gao et al., 2022; Yi & Nie, 2024). To avoid potential losses, they tend to adopt risk-averse and conservative behavioral strategies (Tan et al., 2025). Therefore, BIM collaboration dilemmas are not merely a static accumulation of barriers. Instead, they may emerge from the interplay of key factors, such as asset specificity, uncertainty, and opportunism, that generate high TCs, prompting stakeholders to adopt risk-averse behaviors and perpetuating the ongoing collaboration dilemma.

Building on the above theoretical foundation and the identified research gap, the following section develops an integrated analytical framework to interpret the transaction costs borne by stakeholders across BIM collaboration and to explain their collaborative behaviors.

2.4. A theoretical framework for the BIM collaboration dilemma integrating process, stakeholder, and transaction cost perspectives

Building on the preceding literature review and theoretical analysis, this study develops an analytical framework that integrates process, stakeholder, and TCE perspectives. Specifically, the framework consists of three key components:

(1) **Process:** defines the stages and tasks where transaction costs arise, reflecting the process-oriented nature of BIM collaboration;
(2) **TCE: (a)TC determinants:** identify the sources and mechanisms underlying the formation of TCs; **(b) TC types:** characterize the specific manifestations of different kinds of TCs;
(3) **Stakeholders and behavioral implications:** analyzes the role characteristics of various stakeholders and their behavioral reactions under high transaction cost conditions.

Table 1 systematically summarizes the categories and explanations of the above dimensions, providing a theoretical support for the subsequent research design and empirical analysis.

3. Methodology

This study adopts a qualitatively driven mixed-methods approach (Li et al., 2013), aiming to understand the transaction costs (TCs) borne by different stakeholders in BIM collaboration and how these costs influence collaborative behavior. The research design comprises four sequential stages. First, an initial analytical TC framework for BIM collaboration was developed based on the TCE literature, incorporating project stages, key tasks, TC items, and corresponding stakeholders. Second, pilot interviews were conducted to refine the framework, followed by a focus group validation to examine its completeness and rationality and to identify the relative importance of each TC item. Finally, semi-structured interviews guided participants to elaborate on the manifestations, determinants, and behavioral implications of TC in specific collaborative contexts. The empirical materials collected through these steps served as the foundation for the study's results and supported the subsequent analysis and discussion (see Fig. 1).

The rationale for the methodology lies in three aspects. First, transaction costs often manifest as additional time, effort, and coordination burdens that are difficult to capture through quantitative data alone (Fan et al., 2018). Expert interviews are better suited to uncover their complexity and hidden characteristics (Kiss, 2016; Wu et al., 2019). Especially in highly specialized BIM collaboration contexts, such burdens are often shaped by stakeholders' cognitive frames and experiential backgrounds (Papadonikolaki et al., 2019). Therefore, expert interviews provide richer explanatory insights than large-scale surveys (Fan et al., 2018). Second, as transaction costs primarily arise from multi-party interactions, focus groups allow participants to discuss based on shared experiences and help build consensus (Akinade et al., 2018). Third, since this study is guided by a theoretical framework rather than a fully exploratory approach, it follows a sequential design combining focus groups and semi-structured interviews. The focus groups were used to validate the TCs framework, identify priorities, and provide focus for subsequent interviews while reducing ambiguity. The semi-structured interviews contextualized TCs and verified focus group ratings through role-based narratives and frequency validation, enhancing both explanatory strength and credibility.

3.1. Sampling strategy

This study was conducted in Jiangsu Province, China. Jiangsu is among the earliest regions in the country to promote BIM adoption. Its advanced construction industry provides extensive BIM practical experience. In addition, fiscal decentralization has led to policy variations across cities, resulting in diverse challenges in BIM implementation (Li

Table 1
Theoretical framework of BIM collaboration.

Dimension	Category	Under BIM Context	Source
Process (where transaction costs arise)	P1 Preparation stage	Feasibility study, Signing BIM contracts, Establishing a BIM team	(Gu & London, 2010; Xu et al., 2014; Porwal & Hewage, 2013)
	P2 Design stage	BIM modeling, Model integration, Cost estimation, Design review	(Olanrewaju et al., 2022)
	P3 Construction stage	General contractor tendering, Construction system simulation, Model updates, Material calculation, Offsite construction, Site management, Project review	(Cao et al., 2015; Xu et al., 2014)
TC Determinants (sources of TC)	A1 Professional knowledge	BIM requires specialized knowledge and skills (e.g., modeling, integration, and management), demanding dedicated time and effort for training and learning.	(Succar & Sher, 2014)
	A2 Specific information	BIM-related standards, case studies, and policy information are fragmented and specialized, resulting in high access and verification costs.	(Olanrewaju et al., 2022)
	A3 Specific contracts	BIM contracts lack standardization and remain incomplete, triggering negotiation and enforcement risks.	(Liao et al., 2019; Liu et al., 2022)
	A4 Professional personnel	Professional BIM teams and personnel are often irreplaceable, creating dependency and increasing coordination and replacement costs.	(Succar & Sher, 2014)
	U1 Technological uncertainty	BIM collaboration involves multiple stakeholders, and issues such as poor software compatibility and incomplete standards complicate integration and increase change-related risks.	(Chien et al., 2014; Zhao et al., 2018)
	U2 Institutional uncertainty	The absence of unified norms and standards, coupled with a volatile policy and institutional environment, is a concern.	(Sun et al., 2020)
	U3 Behavioral uncertainty	When contract boundaries are unclear and responsibilities are ambiguous, some participants may behave opportunistically, leading to reduced delivery quality or responsibility shifting.	(Gao et al., 2022; Zheng et al., 2017)
TC Types (manifestations of transaction costs)	I Information searching cost	Efforts are required to collect information on BIM-related standards, policies, partners, and case practices.	(Ebrahimigharehbaghi et al., 2020; Jia et al., 2021; Kiss, 2016)
	L Learning and research costs	Costs associated with training and education to acquire BIM-related knowledge and skills.	(Coggan et al., 2010; Wu et al., 2019)
	C Coordination and negotiation costs	Additional burdens arise from inter-organizational communication, contract negotiation, and conflict resolution.	(Fan et al., 2018; Kiss, 2016)
	M Monitoring and enforcement costs	Costs associated with data validation, model review, progress monitoring, and delivery verification.	(Coggan et al., 2010; Wu et al., 2019)
Stakeholders and behavior implications	S Stakeholders	Local government (LG), developer (D), design company (DC), cost consultant (CC), general contractor (GC), subcontractor (S), component supplier (CS)	(Liu et al., 2017; Papadonikolaki et al., 2019; Sampaio et al., 2023)
	B Behavioral tendencies under High TC	Risk avoidance, conservative strategies, reduced willingness to cooperate, minimum compliance, complaints, and limited use	(Cao et al., 2021; Tan et al., 2025; Wang et al., 2020)

et al., 2023). Therefore, Jiangsu serves not only as an ideal setting for observing BIM collaboration practices in China but also as a representative case for understanding the diverse collaboration dilemmas that emerge under varying institutional conditions.

This study employed a snowball sampling approach to recruit participants. We first contacted professionals who had presented at the "Jiangsu Civil Architecture Society BIM Application Committee Annual Conference and Intelligent Construction Research Forum". We invited them to recommend other experts to ensure sample diversity. The selection criteria included: (1) coverage of key stakeholder groups such as developers, designers, cost consultants, general contractors, subcontractors, BIM consultants, and local government. BIM consultants were affiliated with design or construction companies rather than independent third parties, to focus on how traditional stakeholders adapt their roles during digital transformation; (2) inclusion of both managerial and frontline professionals; and (3) extensive project experience, with priority given to experts with at least five years of project experience and three years of BIM practice in residential and public building projects. A total of 28 experts met these criteria and participated in the study (see Appendix A for details).

3.2. Data collection

3.2.1. Pilot interviews

The pilot interview aimed to refine the initial BIM collaboration TCs framework and to test the clarity and feasibility of the interview tools to support subsequent focus groups and semi-structured interviews. The four most experienced experts representing the four core stakeholder roles — developer, designer, general contractor, and subcontractor — were invited to participate in the pilot interviews (see Appendix A). Each expert had both frontline and senior managerial experience, with at least six years of BIM practice. The participants were asked to (1) assess the relevance and completeness of the initial BIM collaboration TCs framework, (2) identify missing or ambiguous items, and (3) evaluate the clarity of the interview guide. To minimize conceptual ambiguity, a conceptual translation approach was adopted, avoiding the direct use of the term “transaction cost.” Instead, more practice-oriented expressions such as “additional time, effort, or trouble” were used (Wu et al., 2019). For example: “What kinds of difficulties or trouble did you encounter during the preparation, design, or construction stages?” and “What additional effort was required to complete these tasks?” After the pilot interview, the initial framework was revised based on the feedback, with four additional TC items (TC3 Search for BIM partner, TC15 Model coordination for reviewing, TC24 Model optimization, and TC27 Training for BIM management) incorporated to enhance its completeness and practical applicability.

3.2.2. Focus groups

The focus group aimed to validate the completeness and rationality of the TCs framework and to provide the focus for guiding subsequent semi-structured interviews. Thirteen participants were invited to the focus group, representing major stakeholder groups, including local government, developers, design companies, BIM consultants, cost consultants, general contractors, and subcontractors. Most participants held managerial positions with more than five years of BIM experience (see Appendix A). They combined hands-on experience with cross-organizational management perspectives, enabling them to compare different types of TCs and make balanced judgments, thereby enhancing the reliability of the discussion and scoring. To minimize conformity bias and power imbalance, no hierarchical or financial relationships existed among participants.

Before the meeting, the researchers distributed the revised TCs framework (refined based on the pilot interview) to all participants and provided a brief overview of the session procedure. At the start of the session, the group members reviewed the overall completeness of the TC framework and examined the validity of the role assignments for each

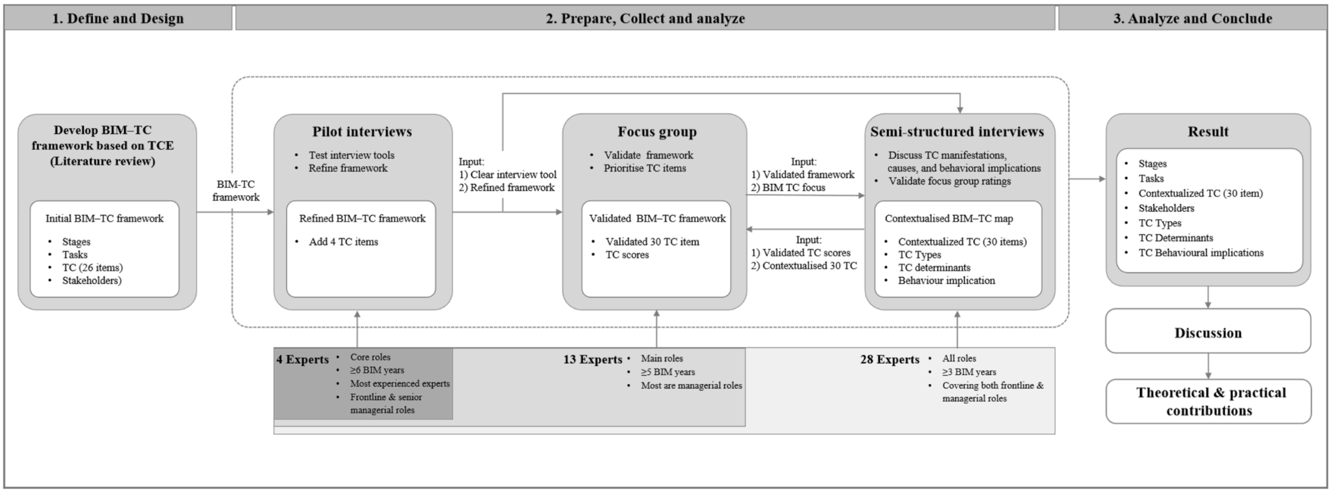

Fig. 1. Research design (by the authors).

item, distinguishing between the "bearing stakeholder" (directly bearing the TCs) and the "related stakeholder" (affected by or involved in the TCs). During the scoring phase, participants rated the TC items they had directly experienced as bearing stakeholders, following the established five-point scale for perceived effort ("No effort = 1″ to "Considerable amount of effort = 5") (Fan et al., 2018). To ensure reliability, participants rated only items based on their direct experience, leaving others blank to avoid speculation. The researchers recorded all scores in real time and used the median value of each item as its representative score. The resulting scores helped identify high-burden TC items and provided focal points for the subsequent semi-structured interviews.

3.2.3. Semi-structured interviews

The semi-structured interviews, in turn, sought to build upon the focus group findings by eliciting richer insights to deepen the understanding of TCs and stakeholder behaviors, as well as to verify the focus group scoring results. A total of 28 industry experts participated in the semi-structured interviews, including 15 who had not participated in the focus group or pilot interview. The participants included both managerial and frontline personnel to ensure a comprehensive range of role perspectives (see Appendix A).

This study followed Bryman's (2016) methodological principles for qualitative inquiry, beginning with introductory questions and then moving to follow-up and contextualized questions to encourage participants to provide open, detailed narratives. Before the interviews, all participants received a one-page summary introducing the study background, but they were not informed of the specific hypotheses or core questions in advance to minimize social desirability and interviewer bias (Friedrich & Wehnert, 2025; Witzel & Reiter, 2012). The interviews followed a semi-structured guide comprising four main sections: (1) understanding the respondent's project background, specific responsibilities, and role positioning to ensure that discussions on transaction costs were grounded in authentic project experience; (2) using the TCs framework validated in the focus group to guide respondents in describing the manifestations, determinants, and behavioral implications of TCs they experienced as cost bearers or related in specific contexts; (3) asking respondents to identify and summarize the TC items they perceived as particularly burdensome; (4) exploring whether and how these TCs affected their level of engagement and collaborative practices in projects, with reference to concrete examples or situational cases. It is noteworthy that the researchers used the focus group scoring results solely as a reference to guide and probe interview questions, without disclosing them to participants to avoid potential response bias or framing effects.

During data collection, we used timely follow-up questions and examples to ensure that each interviewee's information was thoroughly explored (Bryman, 2016). At the overall sample level, 28 experts were interviewed. As the interviews progressed, the contextual manifestations of TCs, their determinants, and behavioral implications gradually emerged. In the final five interviews, although additional contextual details were obtained, no new themes or conceptual insights emerged. Considering the comprehensive coverage of key stakeholder roles, the study was therefore deemed to have achieved overall data saturation (Saunders et al., 2018).

All interviews were conducted one-on-one, lasting approximately 45–60 min, either in participants' familiar office settings or through online platforms. With informed consent obtained, all interviews were audio-recorded and transcribed in full. To ensure record accuracy, a participant verification process was implemented, allowing interviewees to review their transcripts to minimize factual bias. The interview protocol was reviewed and approved by the Human Ethics Research Committee (HERC) of the authors' affiliated institution.

3.3. Data analysis

All interviews were transcribed and anonymized immediately after completion by the research team. The data were organized and analyzed using ATLAS.ti, following a theory-driven coding and analysis approach.

The research team first treated semantically complete sentences or segments as the basic coding units and classified them under corresponding tasks in the project preparation, design, or construction stages. Each segment was then analyzed in terms of (1) TC scenario, (2) TC types, (3) TC determinants, and (4) behavioral implications, and mapped onto the predefined analytical categories of the TCE framework (see Table 1).

For example, one interviewee (DC2) stated: "Learning BIM software does not take long, perhaps a few months[…]but it takes at least two years and experience in two to three complete projects to train a truly competent BIM designer[…]Team members often complain that[…]in addition to their daily work, they still need to spend extra time learning BIM." This excerpt was coded as: (1) TC scenario: design companies bear short-term BIM software learning costs and long-term project-based training costs; (2) TC type: learning and training costs; (3) TC determinant: asset specificity (professional knowledge); and (4) behavioral implication: complaints. Finally, TC items identified as highly burdensome by at least two non–focus group participants from the same stakeholder role (as TC bearers) were compared with the focus group scores to achieve triangulation and enrich contextual interpretation.

To enhance credibility, dual independent coding was conducted, and discrepancies were resolved through discussion to reduce interpretive bias and improve analytical consistency. After completing the analysis, the team revisited the original transcripts to verify the coding's completeness and accuracy. Finally, selected participants were invited to review and confirm the core themes and analytical interpretations to further strengthen the credibility of the findings.

4. Results

Table 2 presents the 30 transaction costs (TCs) identified in the BIM collaboration process, categorized by project stage, specific task, bearing stakeholder, related stakeholder, TC types, determinants, and scenario. The TC scenario section was derived from semi-structured interview data and summarizes how each TC manifests in real BIM collaboration contexts. The arrows in the figure indicate the direction of the relationships from the stakeholder bearing the transaction cost to the related stakeholder. Gray-shaded cells indicate TCs with a median score above 3 in the focus group evaluation, with the shade intensity corresponding to the score level. The symbol "★" indicates TCs identified as heavily burdensome by two or more non–focus group participants of the same role (TC bearers) during the semi-structured interviews. It needs to be noted that the focus group ratings were largely consistent with the interview findings, with only two minor discrepancies: (1) TC10 Monitoring BIM design contracts received a score above 3 in the focus group, but most interview participants categorized it as a more specific form of practical coordination burden; (2) TC28 Monitoring site management scored below 3 in the focus group, yet several interviewees considered it complex and time-consuming to execute.

Building on this, the following section further analyzes the distribution patterns, key determinants, and characteristics of TC across project stages, and explores stakeholder behavioral tendencies under high-TC conditions.

4.1. Preparation stage

In the preparation stage, five TCs related to BIM collaboration were identified. Among them, developers bore the heaviest burden, primarily associated with TC4 BIM contract negotiation, TC3 Search for BIM partners, and TC2 Decision making.

4.1.1. Determinants and types of TCs

The determinants of TC4 include specific contracts, institutional uncertainty (the lack of standardized contracts), and behavioral uncertainty (opportunistic behavior under incomplete contractual conditions). This TC manifests primarily as inter-organizational negotiation and coordination costs. As noted by designer DC2: *"Each BIM contract is customized for a specific project and lacks standardization[…]The pricing of BIM contracts directly affects the overall project cost for the developers, usually depending on the project's scope and complexity"* (Quotation-1).

The determinants of TC2 include specific information and institutional uncertainty (lack of unified standards), while TC3 is driven by asset-specific professional personnel and behavioral uncertainty (opportunistic behavior under incomplete contracts). Both types of TCs are characterized by additional information searching costs. As developer D2 confirmed: *"The BIM service market is very fragmented, and there are no unified standards[…]We spent a considerable amount of time at the early stage searching for and assessing the capabilities of different BIM service providers"* (Quotation-2).

4.1.2. Stakeholder behavioral tendencies under TCs

During the preparation stage, TCs related to information collection and contract negotiation (TC2, TC3, and TC4) were frequently mentioned by interviewees. Developers' behaviors were commonly characterized as cautious and limited in adoption. Regarding BIM decision-making and the search for BIM partners (TC2 and TC3), several interviewees noted the lack of market transparency and severe information asymmetry, which forced developers to invest considerable time and effort in selecting BIM service providers, leading to a conservative tendency. As developer D3 stated, *"It is difficult for us to obtain transparent and reliable information[…]It is hard to tell whether the promised value of BIM can truly be realized, so we need to be cautious"* (Quotation-3). Subcontractor S2 added from another perspective, *"The rationality and cost-effectiveness of BIM application largely depends on the designer's expertise, but developers cannot usually judge this, so they tend to play it safe"* (Quotation-4).

Regarding TC4 (BIM contract negotiation), interviewees commonly reported the lack of unified contract templates and standards, leading to frequent, time-consuming negotiations. As developer D2 stated, *"Without a standardized contract template, it is difficult to define responsibilities and ensure compliance"* (Quotation-5). Subcontractor S3 further remarked, *"The BIM market is chaotic, and developers find it difficult to assess the real value of BIM technology[…]After being misled several times, developers gradually lose confidence and even develop resistance toward BIM"* (Quotation-6). Similar views also emerged in the interviews with designers. Designers DC1 and DC2 both noted, *"Developers are reluctant to adopt BIM largely because they have never experienced genuinely high-quality BIM implementation"* (Quotation-7).

4.2. Design stage

In the design stage, ten TCs related to BIM collaboration were identified, with design companies bearing the heaviest burden. Specifically, TC6 BIM learning and training, TC7 BIM model data verification, TC8 Model coordination for design, and TC14 Review of compliance were particularly prominent. Meanwhile, TC9 Dispute resolution, borne by developers, and TC13 BIM model data for cost verification, borne by cost consultants, also represented relatively high burdens.

4.2.1. Determinants and types of TCs

The determinant of TC6 is professional knowledge, and its transaction cost type is manifested as long-term learning and research costs. As designer DC2 noted, *"Learning BIM software does not take long, perhaps a few months[…]but it takes at least two years and experience in two to three complete projects to train a truly competent BIM designer"* (Quotation-8).

The determinants of TC7 and TC13 are technical uncertainty, primarily reflected in information loss due to poor compatibility and functional limitations across different professional software. These TCs are manifested as monitoring and enforcement costs. As designer DC3 explained, *"The tolerances for architectural and interior design differ, and the lack of interconnection between component models requires large adjustments, which significantly increases the workload"* (Quotation-9). Cost consultant CC1 further emphasized, *"Although Revit can calculate quantities, its functions are incomplete and lack detailed information on concrete and walls, so continuous verification is required"* (Quotation-10).

The determinants of TC8 and TC9 are institutional uncertainty, mainly reflected in the lack of unified BIM modeling standards and unclear divisions of responsibility. These TCs are characterized as inter-organizational negotiation and coordination costs. As designer DC1 stated, *"Everyone has different modeling habits, so coordinating and resolving disputes across disciplines often takes considerable time"* (Quotation-11). Interviewee DC3 added, *"We often take on additional guidance responsibilities in projects[…]When developers or other stakeholders are unfamiliar with BIM, we have to act as instructors or consultants"* (Quotation-12).

The determinants of TC14 include specific information and institutional uncertainty, primarily reflected in inconsistent review standards. This type of TC manifests as information search costs. Interviewee BC1 noted, *"Intelligent drawing review platforms require models to meet certain specifications, but platform standards vary across regions, and the systems are not interoperable"* (Quotation-13). Interviewee BC2 further added, *"Although some BIM review policies have been issued, it remains difficult to ensure consistency between drawings and models[…]Review feedback also differs across platforms"* (Quotation-14).

Table 2
Transaction costs in the BIM collaboration process.

Stage	Task	TC No.	Medium-to-high	Stakeholder Bearing	Stakeholder Related	TC Types	TC determinants	TC scenario
Project preparation	Feasibility study	TC1 Search for BIM information		D→	LG	I	A2-Specific information	Developers need to collect and compare BIM-related policies, guidelines, and standards to support decision-making.
		TC2 Decision making ★		**D→**	LG	I	A2-Specific information U2-Institutional uncertainty	In the absence of unified standards and reference cases, developers spend additional time analyzing the benefits and feasibility of BIM implementation to make a decision.
		TC3 Search for BIM partner ★		**D→**	DC	I	U3-Behavioral uncertainty A4-Professional personnel	Given market fragmentation and varying supplier capabilities, developers spend considerable time selecting and verifying design companies with adequate BIM competence.
	Signing BIM contracts	TC4 BIM contract negotiation ★		**D→**	DC	C	A3-Specific contracts U3-Behavioral uncertainty U2-Institutional uncertainty	In the absence of standardized contracts, developers need to engage in multiple rounds of negotiation with design companies to clarify the scope, cost, and deliverables of BIM services, while guarding against opportunistic behavior.
	Establishing a BIM team	TC5 Establishing professional teams		**DC**		C	A4-Professional personnel	Design companies devote time to establishing specialized BIM teams, defining role responsibilities and interdisciplinary coordination procedures (architecture, structure, and MEP), and scheduling project workflows accordingly.
Design stage	BIM Modeling	TC6 BIM learning and training ★		**DC**		L	A1-Professional knowledge	Design companies need to bear short-term BIM software learning costs and long-term project-based training costs.
		TC7 BIM model data verification ★		**DC**		M	U1-Technical uncertainty	The integration of architectural, structural, and MEP models requires extensive coordination due to software incompatibility and missing information.
	Model integration	TC8 Model coordination for design ★		**DC→**	D	C	U2-Institutional uncertainty	Design companies frequently assist developers in coordinating BIM model integration among multiple stakeholders.
		TC9 Dispute resolution ★		**D→**	DC	C	U2-Institutional uncertainty	Developers spend substantial time mediating and resolving BIM-related disagreements among stakeholders.
		TC10 Monitoring BIM design contracts		**D→**	DC	M	U3-Behavioral uncertainty A3-Specific contracts	Developers verify whether design deliverables meet contractual and regulatory requirements.
	Cost estimation	TC11 BIM learning for cost estimation		**CC**		L	A1-Professional knowledge	Cost consultants need to learn and master BIM-based procedures for quantity measurement and estimation.
		TC12 Model coordination for cost calculation		**CC→**	DC	C	U2-Institutional uncertainty	Cost consultants repeatedly verify BIM model details with designers to ensure accurate quantity estimation, incurring additional communication costs.
		TC13 BIM model data for cost verification ★		**CC→**	DC	M	U1-Technical uncertainty	Cost consultants need to spend substantial time on BIM software integration, model consolidation, and data validation due to software issues.
	Design review	TC14 Review of compliance ★		**DC→**	D-LG	I	A2-Specific information U2-Institutional uncertainty	Design companies need to review different local regulatory requirements and adjust their BIM models to ensure compliance.
		TC15 Model coordination for reviewing		**DC→**	D-LG	C	U2-Institutional uncertainty	Design companies spend additional time and effort on addressing conflicting review opinions from drawings and models.
Construction stage	General contractor tendering	TC16 Search for BIM partner		D→	GC	I	U3-Behavioral uncertainty A4-Professional personnel	Developers carefully select and evaluate general contractors with BIM experience.
		TC17 Contract negotiation ★		**D→**	GC	C	A3-Specific contracts U3-Behavioral uncertainty U2-Institutional uncertainty	In the absence of standardized contracts, developers need to engage in multiple rounds of negotiation with contractors to clarify the scope, cost, and deliverables of BIM services, while guarding against opportunistic behavior.
	Construction system simulation	TC18 BIM learning and training ★		**GC**		L	A1-Professional knowledge	General contractors invest significant time and effort in training their staff to develop the skills necessary to support practical BIM implementation.

(*continued on next page*)

Table 2 (*continued*)

	TC19 Model coordination ★		**GC**		C	U1-Technical uncertainty	The general contractors need to take on additional time to resolve conflicts between BIM technicians and project managers.
	TC20 Dispute resolution ★		**GC→**	S-DC	C	U2-Institutional uncertainty	General contractors need to invest significant time resolving BIM disputes or conflicts with subcontractors or design companies.
	TC21 BIM learning and training ★		**S**		L	A1-Professional knowledge	Subcontractors need to possess advanced BIM software skills and the ability to collaborate to adapt to BIM workflows.
	TC22 BIM model data verification		**S**		M	U1-Technical uncertainty	Subcontractors spend time reviewing models, resolving software issues, integrating models, and validating data.
Model updates	TC23 Liability disputes ★		**D→**	GC-DC	C	U2-Institutional uncertainty U3-Behavioral uncertainty	Developers mediate disputes regarding BIM model ownership and responsibility between designers and contractors.
	TC24 Model optimization ★		**S→**	GC-D-DC	C	U2-Institutional uncertainty	Subcontractors engage in frequent communication and provide updates to general contractors, developers, and designers for model optimization.
Material calculation	TC25 BIM data verification for materials calculation★		**GC→**	CC	M	U1-Technical uncertainty	The general contractor and cost consultant repeatedly verified the BIM model details and component properties to ensure the accuracy of material calculations.
Offsite construction	TC26 Dispute resolution		**S→**	CS	C	U2-Institutional uncertainty	Subcontractors and suppliers often face discrepancies in model parameters and tolerances, requiring additional clarification and coordination.
Site management	TC27 Training for BIM management ★		**GC→**	S	L	A1-Professional knowledge U3-Behavioral uncertainty	General contractors dedicate significant time and resources to training subcontractors on BIM-based construction management procedures.
	TC28 Monitoring site management ★		**GC→**	S	M	A1-Professional knowledge	General contractors monitor on-site personnel to ensure compliance with digital reporting and traceability requirements, which is time-consuming to enforce and follow up on.
Project review	TC29 Monitoring BIM contracts		D→	GC	M	A3-Specific contracts	Developers oversee the BIM updates work in construction processes.
	TC30 Delivery disputes		GC→	D-LG	C	U2-Institutional uncertainty	General contractors coordinate with developers and regulatory reviewers to confirm model completeness and handover standards.

Note: LG=Local Government; D= Developer; DC=Design Company; CC=Cost Consultant; GC= General Contractor; S=Subcontractor; CS= Component supplier

I=Information searching costs; L=Learning and research costs; C=Coordination and negotiation costs; M=Monitoring and enforcement costs

★ Indicates a TC identified as relatively burdensome by at least two non-focus group interviewees of the same stakeholder role

The median focus group rating (3-5)

→ Stakeholders bearing the TC point to the relevant stakeholders.

4.2.2. Stakeholder behavioral tendencies under TCs

During the design stage, multiple interviewees frequently referred to TCs related to learning and coordination (TC6, TC7, TC8, and TC14). In interviews with design companies, participants generally expressed dissatisfaction with the additional learning burden and complex coordination processes, and tend to adopt a minimum compliance strategy as a coping response. Meanwhile, developers and cost consultants assumed different roles and attitudes during this stage, taking responsibility for supervision, coordination, and data verification.

Interviewees repeatedly mentioned learning and training costs (TC6). Designer DC3 noted, *"There is a clear gap between learning basic knowledge and applying it in actual projects[…]The initial time investment in BIM is much greater than in CAD, while project schedules remain extremely tight"* (Quotation-15). Designer DC2 added, *"Team members often complain that[…]in addition to their daily work, they still need to spend extra time learning BIM"* (Quotation-16). Regarding coordination and verification costs (TC7 and TC8), interviewees repeatedly mentioned uncertainty, schedule pressure, and compliance-oriented coping strategies. Designer DC1 stated, *"There are too many uncertainties in the BIM coordination process, and project timelines are extremely tight[…]The pressure is huge, so our main goal is simply to meet contractual and review requirements"* (Quotation-17). Some respondents (DC4, DC5) also referred to the practice of minimum compliance: *"Doing more brings no benefit, in fact, it often causes additional trouble"* (Quotation-18). General contractor GC2 confirmed this from another perspective: *"Design companies are in a passive position in BIM coordination[…]With tight schedules and high communication costs, and developers unwilling to pay extra, they often have no choice but to cope minimally"* (Quotation-19).

Developers were also frequently mentioned as bearing additional coordination and supervision costs (TC9). Designer DC2 observed, *"BIM is not a one-off delivery process[…]Without the developer's ongoing involvement and coordination, we can only meet the minimum contractual requirements"* (Quotation-20).

Cost consultants, facing heavy burdens in model verification and data coordination, generally expressed dissatisfaction with data-checking efforts. Cost consultant CC2 explained, *"When converting data between Glodon (China's mainstream cost estimation software) and Revit, data loss and missing often occur[…]It is sometimes more efficient to rebuild the model from scratch than to spend time verifying omissions in the BIM model"* (Quotation-21).

4.3. Construction stage

In the construction stage, fifteen TCs related to BIM collaboration were identified, with general contractors bearing the heaviest burden. These burdens were mainly concentrated in TC18 BIM learning and training, TC19 Model coordination, TC20 Dispute resolution, TC25 BIM Data verification for materials calculation, TC27 Training for BIM management, and TC28 Monitoring site management. The TCs undertaken by subcontractors are primarily associated with TC21 BIM Learning and training, and TC24 Model optimization. In contrast, developers' TCs are mainly reflected in TC17 Contract negotiation and TC23 Liability disputes.

4.3.1. Determinants and types of TC

The determinants of TC18, TC21, TC27, and TC28 are professional knowledge. The first three are characterized by long-term learning and research costs, while TC28 is manifested as monitoring and enforcement costs. Interviewees generally emphasized that the localization of BIM capability depends on continuous training and the accumulation of interdisciplinary experience. As subcontractor S2 explained, *"Our company conducts one month of intensive training[…]followed by at least six months of further learning[…]It may take up to five years of project experience to truly develop BIM optimization capabilities"* (Quotation-22). Among them, TC27 and TC28 were frequently mentioned by interviewees, involving project-level digital training, supervision, and management activities that need to be repeated in nearly every new project. As general contractor GC2 emphasized, *"The only thing that can be saved in repeated projects is software costs. Management costs never decrease[…]Each new project requires retraining"* (Quotation-23).

The determinants of TC19 and TC25 are technical uncertainty. TC19 reflects the misalignment between modeling skills and actual project requirements, resulting in additional negotiation and coordination costs. As general contractor GC3 stated, *"Communication and re-modeling often take a long time because modelers do not fully understand the project's technical requirements and cannot determine whether the model is accurate enough[…]These issues require extensive communication to resolve"* (Quotation-24). In contrast, TC25 primarily reflects issues of poor software compatibility. BIM data is frequently converted across different platforms during construction, requiring repeated verification and cross-checking, thereby increasing monitoring and enforcement costs.

The determinants of TC20, TC23, and TC24 are institutional uncertainty, with their transaction costs manifested as inter-organizational negotiation and coordination costs. TC20 is mainly associated with differences in modeling standards. As general contractor GC1 explained, *"Different subcontractors create BIM models based on their own schemes, and the general contractor needs to integrate them into a single unified model […]This requires a substantial amount of communication and adjustment time"* (Quotation-25). TC23 concerns ambiguous divisions of responsibility, which also involve behavioral uncertainty. Designer DC3 stated, *"Designers are only required to meet the BIM standards for the design stage[…]we are not obligated to produce construction-level models, that is the contractor's responsibility"* (Quotation-26). Developer D1 added, *"We often have to coordinate issues of responsibility between design and construction teams"* (Quotation-27). TC24 concerns the iterative feedback involved in model optimization and updating. Several subcontractors (S1, S3) remarked, *"Model updating is the most time-consuming part[…]We have to report to the general contractor first, then communicate with the developer and the design company[…]The biggest BIM challenge lies in coordination with other parties"* (Quotation-28).

The determinants of TC17 include specific contracts, institutional uncertainty (lack of standardized contracts), and behavioral uncertainty (opportunistic behavior under incomplete contracts). This transaction cost is characterized as inter-organizational negotiation and coordination costs.

4.3.2. Stakeholder behavioral tendencies under TCs

During the construction stage, interviewees repeatedly referred to transaction costs associated with training and coordination (TC18, TC21, TC27, and TC28). Interviews with general contractors and subcontractors commonly revealed behavioral tendencies such as limited application, minimum compliance, and internal use. Meanwhile, developers and design companies demonstrated distinct attitudes and role orientations during this stage, assuming responsibilities for coordination, supervision, and technical support.

First, the high and ongoing costs of learning, training, and supervision (TC18, TC27, and TC28) were considered significant burdens for contractors. General contractor GC1 explained, *"BIM project management requires a closed-loop system in which every participant, including construction crews, is involved[…]Most workers are over forty and have limited education; they naturally resist digitalization. Training and supervision consume excessive effort and are very troublesome, so it is best to use BIM only in core processes"* (Quotation-29). General contractor GC2 added, *"Each project requires repeated briefings and training[…]This consumes a great deal of time and effort and is not cost-effective"* (Quotation-30).

Inter-organizational communication and coordination costs (TC20 and TC24) were also frequently mentioned by interviewees. Interviewees repeatedly emphasized the complexity of collaboration and the prevailing tendency to use BIM primarily for internal management. General contractor GC3 noted, *"We hope to reuse the design model, but much of it fails to meet expectations and requires rework, so we often have to remodel from scratch"* (Quotation-31). General contractor GC4 further commented, *"Design companies are reluctant to share their models, and communication is too troublesome[…]We end up creating our own models for internal use"* (Quotation-32). Subcontractor S2 expressed a similar view: *"BIM is indeed helpful for construction, but there are too many parties involved and communication costs are too high[…]so we only use it internally for MEP management"* (Quotation-33).

Some respondents also mentioned that the efforts invested in model optimization and refinement are neither recognized nor compensated by developers, leading practitioners to meet only minimum requirements or restrict BIM use to internal management. General contractor GC4 stated, *"Full BIM implementation requires professionals to continuously refine and optimize the model. This effort constitutes a hidden cost that developers do not see; they only care about final outcomes. So we just meet the minimum requirements"* (Quotation-34). Subcontractor S3 added, *"Developers usually just need a single model[…]the refinement and optimization work is done only for our internal management needs"* (Quotation-35).

Regarding developers, interviewees consistently highlighted the importance of their ongoing involvement in the BIM implementation process. Developer D3 noted, *"Even after signing a BIM contract, we still need to provide continuous supervision and coordination; otherwise, the project outcome is unlikely to meet expectations"* (Quotation-36). Subcontractor S2 confirmed this from another perspective: *"Without the developer's active engagement and participation, BIM can hardly play a meaningful role in the project"* (Quotation-37).

Moreover, although design companies were not the primary bearers of TCs during construction, interviewees reported undertaking additional on-site coordination efforts. Designer DC2 commented, *"We have to continuously coordinate on site[…]if contractors lack BIM skills, we need to guide their work, and such efforts usually go unrewarded"* (Quotation-38).

4.4. Interconnections between stakeholders, process, and TCs in BIM collaboration

Based on Sections 4.1–4.3, this section synthesizes the relationships between medium-to-high TCs (focus group scores > 3), the BIM collaboration process, and stakeholders, as illustrated in Fig. 2.

The figure shows, first, across the BIM collaboration process, the distribution of TCs among stakeholders is dynamic, shifting across project stages. Second, stakeholders bear different types of TCs in intra-organizational and inter-organizational contexts. Learning and training costs are mainly incurred within organizations, whereas coordination and negotiation costs arise primarily at organizational interfaces. Third, when these patterns are considered together, developers, design companies, and general contractors emerge as the stakeholders experiencing the most sustained and concentrated TC pressures throughout the BIM collaboration process. On this basis, the subsequent discussion is structured around these three dimensions.

5. Discussion

5.1. The processual dynamics of TC in BIM collaboration (RQ1)

The results reveal that TCs in BIM collaboration exhibit clear stage-specific and dynamic evolutionary characteristics. Fig. 3 provides a descriptive synthesis of the distribution of medium-to-high TC items across project stages, based on their counts and categorized by (a) bearing stakeholders, (b) TC types, and (c) TC determinants. As shown in the figure, as inter-organizational collaboration expands, the primary bearers of TCs shift from developers in the preparation stage to design companies in the design stage, and then to contractors in the construction stage. Meanwhile, the types of TCs also display a dynamic pattern, shifting from information searching and contract negotiation in the early stages to coordination and monitoring in the later stages. In addition, technological, institutional, and behavioral uncertainties intensify during the design and construction stages, further amplifying the overall complexity of collaboration across project stages.

From the perspective of transaction cost economics (TCE), the evolution of TCs can be explained by the combined effects of asset specificity and uncertainty (Williamson, 1985). In the preparation stage, the asset-specificity of information and contracts, coupled with institutional and behavioral uncertainty, results in high information search and contract negotiation costs for developers. During the design stage, the specificity of knowledge and skills interacts with technological uncertainty, such as poor software compatibility and inconsistencies in modeling standards, requiring designers to invest additional effort in learning, validation, and coordination. During construction, heightened technological uncertainty (e.g., misalignment between models and actual construction, software incompatibility) and institutional uncertainty (e.g., ambiguous responsibilities and inconsistent standards) significantly increase contractors' coordination and management costs in inter-organizational collaboration. Overall, this evolutionary process suggests that TCs in BIM collaboration are not static but dynamically evolve as project stages progress, stakeholder roles shift, and sources of uncertainty change.

5.2. Intra- and inter-organizational characteristics of TCs (RQ2)

5.2.1. Internal BIM learning costs: excluded from project and market accounting

As shown in Sections 4.2 and 4.3, BIM learning costs (TC6, TC11, TC18, TC21, TC27) represent a substantial burden for most stakeholders. Moreover, these costs encompass not only software training but, more importantly, the collaborative competencies developed through years of project-based experience (see Quotations 8 and 22), which are highly asset-specific, difficult to standardize, and difficult to transfer across projects. However, they constitute an essential prerequisite for achieving high-quality BIM collaboration (Olugboyega et al., 2024).

Nevertheless, from the stakeholder perspective, BIM learning costs remain inadequately recognized or compensated at both the project and market levels. At the project level, only one-time BIM service fees are typically covered, neglecting the long-term costs of training (Alsofiani, 2024), as noted in the Peruvian case study by Murguia et al. (2021). At the market level, BIM training programs tend to emphasize rapid acquisition of software skills while overlooking the cultivation of long-term practical capabilities (Succar et al., 2013). As a result, these hidden costs are transferred to the enterprise and individuals. Enterprises face a dilemma between short-term profitability and long-term talent development, while individuals bear the heavy burden and pressure to advance their careers (Tan et al., 2019).

From a TCE perspective, asset-specific investments without adequate governance are likely to become sunk costs, thereby increasing risks (Williamson, 1985, 1998). These uncompensated costs eventually trigger stakeholder resistance and negative attitudes, as evidenced by interviewees' expressions of dissatisfaction and complaints about BIM training (see Quotations 15 and 16), ultimately diminishing stakeholders' willingness to engage in new-technology collaboration (Wu et al., 2019).

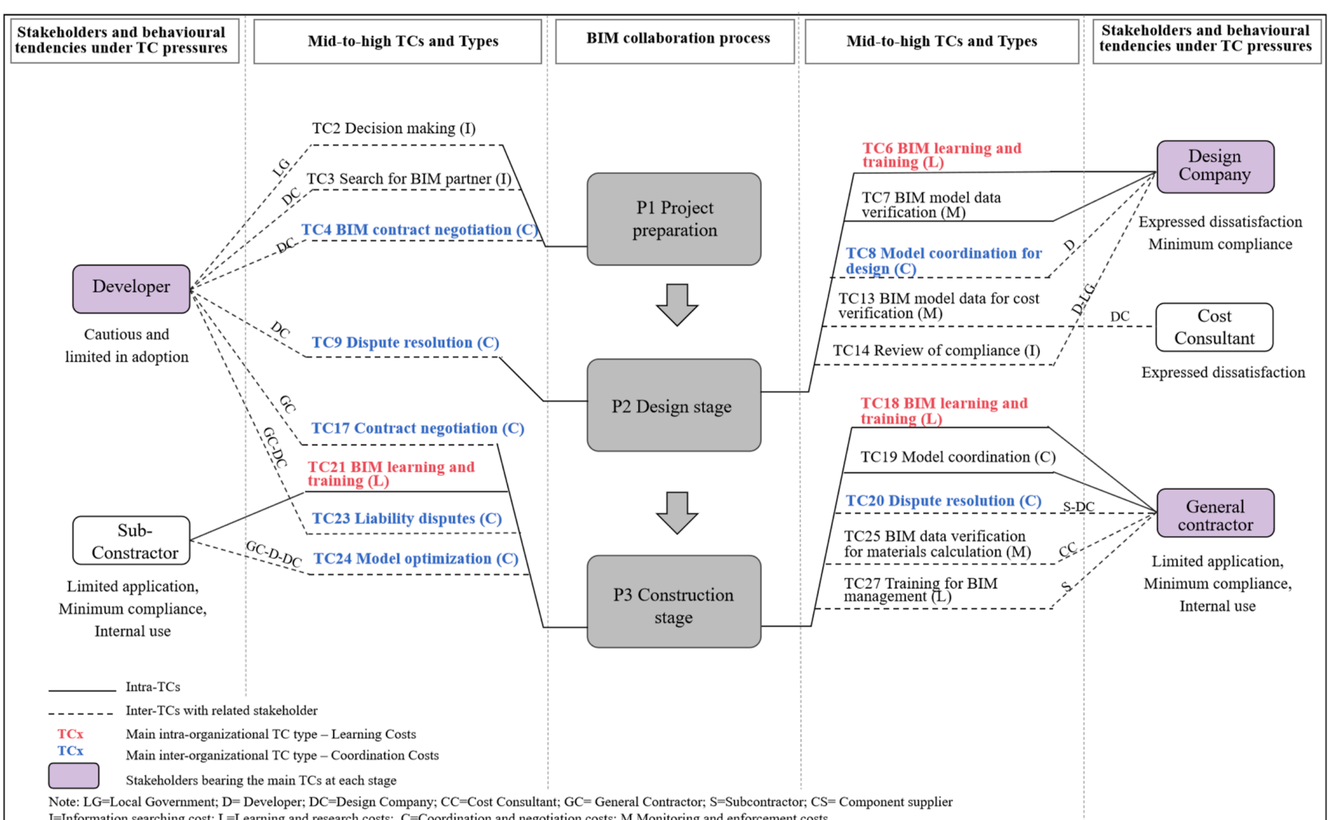

Fig. 2. Connections among stakeholders, process, and TCs (by the authors).

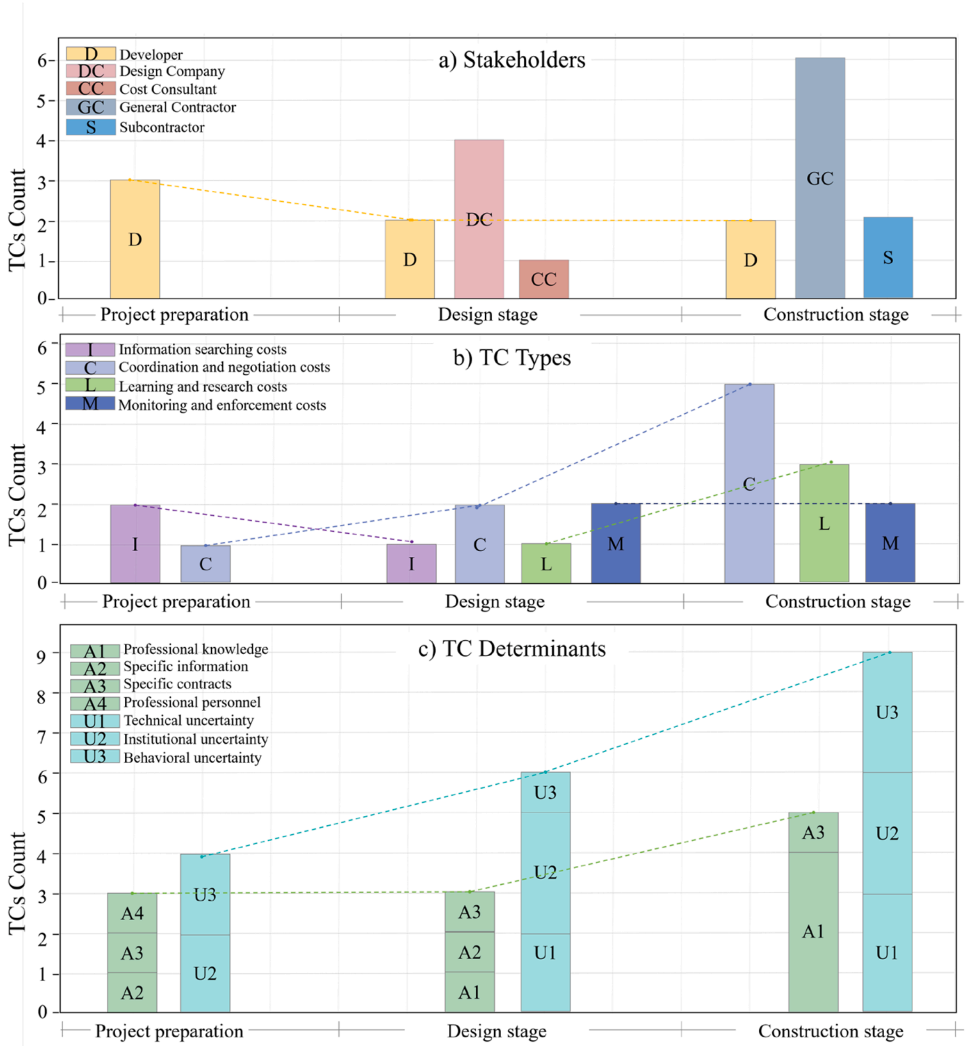

Fig. 3. Descriptive distribution of medium-to-high TC in the BIM collaboration process (by the authors).

5.2.2. Inter-organizational coordination costs: from temporary to permanent routine

As shown in Sections 4.1–4.3, inter-organizational communication and coordination costs were repeatedly mentioned across multiple project stages and were widely regarded by interviewees as a primary burden in BIM collaboration. This finding aligns with the results of Papadonikolaki et al. (2019) and Liu et al. (2017). This study further reveals that such costs arise not only from institutional and technological uncertainties, such as ambiguous standards and responsibilities, and software compatibility issues (Liu et al., 2017; Tan et al., 2019), but also from multi-level communication chains (see TC24). Under the design–bid–build (DBB) model widely adopted in China, approval procedures and role divisions are highly institutionalized, requiring BIM collaboration to follow hierarchical communication (Cao et al., 2015). This structure inadvertently adds coordination burdens and reduces the efficiency of collaboration.

According to classical TCE, the unit TC is expected to decrease with higher transaction frequency (Williamson, 1998). However, in project-based organizational environments, the temporary composition of organizations prevents inter-organizational communication costs from declining through repeated transactions. Each project requires re-establishing cooperative relationships and communication processes (Hall et al., 2018). While increasing project frequency may improve individual proficiency in software operation, it does not substantially reduce inter-organizational management and coordination costs (see Quotations 23 and 30). In project-based contexts characterized by high temporal and uncertain contexts, inter-organizational coordination tends to become routinized as a "regular burden" (Artz & Brush, 2000), reinforcing stakeholders' tendencies to internalize BIM use and weakening cross-organizational collaboration.

5.3. Stakeholder behavioral responses and BIM collaboration dilemma (RQ3)

5.3.1. Developers: the threat of incomplete information and opportunism

The findings indicate that during BIM collaboration, developers are often subject to the dual influences of incomplete information and opportunistic behavior, compelling them to invest significant effort in supervision and coordination (TC4, TC9, TC10). This finding contrasts with the prevailing view in the literature that developers are the primary beneficiaries of BIM and require comparatively less input (Eadie et al., 2013; Jin et al., 2017).

As Williamson (1998) emphasized, when information asymmetry and contract incompleteness coexist, the party in an informationally disadvantaged position must invest additional effort in monitoring and control to constrain potential opportunistic behavior. Compared with other stakeholders, developers generally occupy a relatively disadvantaged position in BIM-related knowledge and information (Liu et al., 2017), making them more vulnerable to opportunistic behaviors such as misinformation and responsibility shifting (see Quotations 4 and 6). As

Gao et al. (2022) pointed out, disparities in BIM capabilities themselves amplify information asymmetry between transaction parties, thereby further encouraging opportunistic behavior. Given their disadvantaged position in information and knowledge, developers need to devote additional effort to supervision and coordination during contract implementation to mitigate potential risks.

Moreover, the non-standardized nature of BIM contracts further exacerbates this issue (Liu et al., 2022). Because contracts often fail to cover all potential contingencies during project execution, their ambiguity creates room for opportunistic behavior (Liu et al., 2022). Consequently, developers need to continually increase their monitoring and coordination efforts to reduce potential losses (see Quotations 36 and 37). However, as Lu et al. (2015) noted, opportunistic behavior undermines trust and satisfaction within collaborative relationships. In such a high-risk collaborative environment, supervision and coordination are necessary rather than optional investments for developers, which explains their cautious attitude toward BIM adoption.

5.3.2. Designers: additional responsibilities and the risk of sunk costs

The findings indicate that for design companies, BIM collaboration entails not only the ongoing pressure of long-term learning and capability development but also an increasing burden of BIM-related responsibilities (TC6, TC7, TC8). In addition, design companies are affected by passive market competition, and this dual pressure collectively undermines their motivation to engage proactively in BIM collaboration (Bos-de Vos et al., 2016).

High-quality BIM collaboration depends on continuous learning and project-based experience among designers, as a mature level of BIM proficiency can only be developed through sustained capacity building (Xie et al., 2022; Liu et al., 2017). However, because developers often have a limited understanding of BIM's value and tend to favor low-cost options (Zheng et al., 2017), design companies with advanced BIM capabilities are paradoxically at a disadvantage in price-driven market competition (Bos-de Vos et al., 2016).

Furthermore, beyond their core design responsibilities, designers frequently undertake additional efforts, such as training and technical guidance (see Quotations 12 and 38), as noted in studies by Porwal and Hewage (2013) and Sebastian (2011). However, such contributions are typically regarded as soft services, with unclear pricing or compensation mechanisms (Zheng et al., 2019), making it difficult for enterprises and individuals to recover their long-term investments.

From the perspective of TCE, asset-specific investments without adequate governance arrangements are likely to become sunk costs rather than sources of competitive advantage (Williamson, 1998). In other words, in a market environment lacking compensation and incentives, designers' investments in BIM learning and additional efforts yield limited returns. The accumulation of sunk costs further diminishes their willingness to collaborate, leading to a minimum compliance strategy in practice (Bosch-Sijtsema et al., 2019).

5.3.3. Contractors: non-diminishing burdens and conflicts with short-term benefits

This study finds that contractors bear multiple inter-organizational burdens during BIM collaboration, including training, communication, coordination, and supervision (TC20, TC27, TC28), consistent with observations from Zheng et al. (2017). However, these inter-organizational coordination costs do not appear to decline significantly with accumulated experience (see Quotations 23 and 30). The temporary, highly fragmented nature of the construction industry forces general contractors to rebuild cooperative relationships with new subcontractors on each project, hindering the accumulation and transfer of experience (Hall et al., 2018). As Zheng et al. (2019) noted, uncertainty about sustaining collaboration among stakeholders within project networks diminishes the potential for experience diffusion to future projects, thereby reducing contractors' motivation to engage in BIM collaboration.

More importantly, these high and unavoidable inter-organizational coordination costs fundamentally conflict with the short-term incentive logic embedded in traditional contracting systems. Conventional low-cost tendering contracts typically prioritize the cost efficiency of individual projects rather than the overall benefits of long-term collaborative relationships (Hall et al., 2018). In this context, even when contractors acknowledge the potential value of BIM, they tend to limit its application to internal management to avoid additional sunk costs associated with inter-organizational collaboration and to safeguard short-term profitability (Zheng et al., 2017).

5.3.4. BIM collaboration dilemma under TC lens

From an integrated process, stakeholder, and TCE perspective, the dilemma of BIM collaboration does not arise from the failure or passive attitudes of a single stakeholder, but rather from the collective outcome of low-risk strategies adopted by multiple stakeholders under persistent high-cost and risk pressures in the BIM collaboration. In other words, the coexistence of numerous TCs within the process erodes trust and interdependence among developers, designers, and contractors, thereby preventing the full realization of collaborative potential.

For designers and contractors, investments in learning, coordination, and supervision are often borne independently, while the resulting benefits are dispersed across the entire project (Boton & Forgues, 2018). For developers, information asymmetry, contractual incompleteness, and bounded rationality may increase their input without yielding directly observable BIM benefits (Forsythe et al., 2015). Under such conditions, all stakeholders tend to adopt cautious, minimum-compliance, or internalized approaches to risk avoidance, thereby undermining inter-organizational collaboration (Tennakoon et al., 2025). This behavioral logic runs counter to BIM's fundamental aim of creating value through close coordination among developers, designers, and contractors (Sun et al., 2021; Zheng et al., 2019). As Liu et al. (2017) noted, although BIM appears to offer significant collaborative and managerial benefits to all stakeholders, in practice, each participant incurs new costs that are rarely offset by project returns. Under the constraints of high TCs, stakeholders are more likely to prioritize their own interests over collective outcomes, thereby limiting the realization of BIM's potential benefits throughout the project lifecycle (Zheng et al., 2017).

5.4. Implications and limitations

5.4.1. Contribution to the advancement of TCE theory

This study extends transaction cost economics (TCE) in several ways. First, Williamson (1998) and subsequent scholars have repeatedly called for deeper investigation into how transaction costs shape stakeholders' behavior (Ketokivi & Mahoney, 2016; Rindfleisch et al., 2010). This study addresses that call by demonstrating that in BIM collaboration, high learning costs and unavoidable inter-organizational coordination costs drive stakeholders to adopt low-risk behavior strategies. Accordingly, this study extends the explanatory power of traditional TCE in understanding collaborative behaviors within project collaboration.

Second, in the field of project management, existing TCE research has largely focused on organizational structures and contractual governance (De Schepper et al., 2015), emphasizing ex-ante and ex-post costs of individual transactions while overlooking the dynamic evolution of TCs throughout the project process. By introducing a process perspective, this study reveals the dynamic evolution of TCs across different stages of BIM collaboration, thereby extending the applicability of TCE within project management contexts.

Third, this study overcomes the traditional TCE limitation of focusing solely on dyadic transactions (Cuypers et al., 2021) by distinguishing between intra-organizational and inter-organizational TCs. This dual perspective reveals that the BIM collaboration dilemma does not stem from a single burden but instead arises from internal and external cost pressures. The proposed analytical framework not only deepens understanding of the mechanisms underlying BIM collaboration dilemmas but also offers a transferable theoretical lens for other digital project collaboration settings facing similar challenges of cross-organizational interaction (Korotkova et al., 2024).

Finally, from a broader theoretical standpoint, this study challenges the core TCE proposition that increased transaction frequency reduces costs (Williamson, 1985), revealing its potential boundary conditions within project environments characterized by temporality and uncertainty. In such contexts, repeated transactions do not necessarily yield cost-reducing effects. However, they may instead institutionalize coordination efforts as routine burdens that persist across projects, thereby reinforcing risk-averse behavior among stakeholders.

5.4.2. *Knowledge contributions to the field of digital project management*

This study contributes insights to the field of digital project management by using BIM collaboration as an example to examine how digital technologies are introduced and enacted in project-based and inter-organizational settings.

First, this study advances an analytical approach that integrates process and stakeholder perspectives, responding to calls to move beyond static barrier lists by Tan et al. (2025) and understand temporary organizations as processual and practice-based phenomena by Brunet et al. (2025). This analytical logic is not BIM-specific but reflects broader patterns commonly observed in digital transformation processes, where different stakeholders experience challenges differently over time (Hwabamungu & Shepherd, 2024).

Second, the findings highlight a general mechanism of digital innovation in project environments. Although digital technologies are typically introduced with the expectation of improving coordination and efficiency, their implementation is often followed by substantial invisible costs (Marnewick & Marnewick, 2022). These costs are often unevenly distributed across stakeholders and stages, shaping stakeholders' willingness to engage in collaborative digital practices (Lavikka et al., 2021). This mechanism helps explain why the promised benefits of digitalization are frequently underrealized in practice, not only in BIM collaboration but also in other forms of digitally enabled project work (Coombs, 2015).

Third, the transaction cost–based framework developed in this study provides a transferable analytical tool for examining digitalization in construction and other project-based industries. Although different digital technologies vary in functionality, they similarly require asset-specific investments and are subject to technological, institutional, and behavioral uncertainties during the practice process (Marnewick & Marnewick, 2022). The framework can offer a structured way to identify where and for whom digitalization generates hidden burdens, thereby supporting more informed intervention strategies in future digital transformation initiatives. For instance, the uneven growth in digital construction across Europe, as acknowledged by Kapogiannis et al. (2024), may benefit from a TCE perspective, which can help identify and mitigate institutional frictions, thereby supporting more efficient and equitable digital transformation.

5.4.3. *Implications for practice and policy*

This study provides practical insights to advance open, digitally enabled project collaboration. The findings reveal that BIM collaboration entails a series of hidden TCs that shift across project stages and organizational levels, driving stakeholders to adopt low-risk, conservative behavioral strategies. Based on these findings, three managerial and practical implications are proposed, which also offer broader lessons for managing digitalization in project-based settings.

First, consider a stage-based process perspective to anticipate and manage TCs.

The results indicate that TCs exhibit distinct migration patterns across BIM collaboration stages. The TCs map proposed in this study could serve as a diagnostic tool to help project managers systematically identify the distribution of burdens across stages and anticipate potential collaboration bottlenecks at critical stages. From a broader perspective, this stage-based diagnostic logic is also applicable to other digital collaborations, where requirements, uncertainties, and coordination demands vary over the project lifecycle.

Second, pay attention to both intra-organizational and inter-organizational cost burdens.

The findings show that the learning and training costs borne internally by organizations exhibit high asset specificity and are often not compensated at either the project or market level, thereby becoming long-term sunk-cost risks. This implies that the industry could establish unified training and certification systems (Cao et al., 2021; Wu et al., 2021) to distribute and mitigate the investment burdens and risks faced by individual organizations during digital transformation. Meanwhile, inter-organizational coordination costs are particularly salient during the design and construction stages, primarily due to technological and institutional uncertainties and the temporary nature of project-based organizations. It is suggested that integrating industry-level standardization efforts, such as model delivery requirements, data interface specifications, and more explicit contractual provisions (Alreshidi et al., 2017; Chen et al., 2021), with project-level relational governance practices, such as co-location (Hall et al., 2018), can reduce repetitive coordination costs. Furthermore, exploring longer-term collaboration models or partnership networks beyond individual projects may help alleviate the routinized burdens caused by organizational temporality (Manning, 2017). These insights are equally relevant for managing broader digital practices that require both internal capability building and sustained cross-organizational coordination.

Third, consider differentiated interventions based on stakeholder roles and burdens.

The findings indicate that developers, designers, and contractors experience different types and levels of transaction costs and therefore adopt distinct behavioral strategies. This suggests that the management of digital collaboration needs to recognize that stakeholders are not a homogeneous group of technical users but differ in their roles, burdens, and considerations, highlighting the relevance of differentiated interventions. For instance, targeted training and education on BIM knowledge can enhance developers' understanding of BIM and reduce opportunistic risks arising from information asymmetry (Zheng et al., 2019). Meanwhile, clear incentive and compensation mechanisms may encourage designers and contractors to participate more actively in inter-organizational collaboration (Laan et al., 2011; Ma et al., 2023).

5.4.4. *Limitations and directions for future research*

Despite its significance, this study has three major limitations that should be acknowledged. First, the primary limitation of this study is its data scope, which is restricted to China, and 28 industry experts were recruited through a snowball sampling approach. The geographic and sample-size constraints limit the generalizability of the findings, and their applicability to other national or industry contexts requires further verification. Future research could expand the sample to include diverse regions, project types, and institutional environments, as well as other digital technology applications.

Second, the study primarily focuses on the Design–Bid–Build (DBB) governance model, which is widely adopted in China's construction industry (Cao et al., 2015), and incorporates BIM consultants within the internal roles of design and construction parties without separately examining the role of independent third-party consultants. Prior studies have highlighted that the diffusion of BIM relies on transforming traditional project roles (Porwal & Hewage, 2013). Accordingly, the adopted role classification in this study helps uncover the core challenges that designers and contractors face in transitioning from traditional CAD-based workflows to BIM-enabled collaboration. However, under alternative governance models such as EPC (Engineering–Procurement–Construction) or IPD (Integrated Project Delivery), or in contexts involving independent BIM consultants, the composition and distribution of TCs may differ substantially. Future research could conduct comparative analyses across different procurement models and role configurations to further examine how governance structures influence the formation of collaboration dilemmas.

Finally, this study primarily relies on focus groups and semi-structured interviews to explore the hidden TCs and behavioral effects within BIM collaboration. While this approach enables an in-depth understanding of stakeholder roles and the mechanisms underlying collaboration dilemmas (Xie et al., 2022; Liu et al., 2017), the findings may be influenced by respondents' subjective perceptions and the uneven representation of stakeholder groups. In addition, the study does not empirically test the causal relationships between TCs and behavioral variables. Future research could integrate survey-based methods and large-sample statistical analyses to further validate and quantify the relationships.

6. Conclusion

In the context of the ongoing digital transformation in the construction industry, BIM has been widely recognized for improving the efficiency of project collaboration. However, its collaborative potential remains underexploited in practice, warranting further examination. Drawing on focus groups and semi-structured interviews with 28 industry experts, this study provides a new explanation of the BIM collaboration dilemma. The findings reveal that although BIM theoretically facilitates collaboration, stakeholders in practice bear substantial process-related TCs during BIM collaboration (addressing RQ1). These costs primarily arise from organization-internal learning and training investments driven by high asset specificity, as well as inter-organizational coordination and monitoring burdens induced by institutional, technological, and behavioral uncertainties (addressing RQ2). Under the pressure of these high and hidden TCs, developers, designers, and contractors tend to adopt cautious, limited, minimally compliant, or internalized strategies to mitigate potential risks (addressing RQ3). Building on these findings, the study proposes three managerial implications. Collectively, these analyses and recommendations provide a new theoretical perspective and practical pathway for understanding and improving project collaboration in the context of digital transformation.

CRediT authorship contribution statement

Yuanyuan Tan: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel Hall:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Ad Straub:** Writing – review & editing, Supervision, Formal analysis. **Queena K Qian:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Respondents' profile

Stakeholder	Code	Profile	Working Year	BIM Experience (Year)	Pilot Interviews	Focus Group	Semi-Structured Interviews
Local government	LG1	Deputy Director of the Housing and Urban-Rural Development Bureau	30	10			√
	LG2	An officer from the Planning and Natural Resources Bureau	8	5		√	√
Developer	D1	Project Manager	8	6	√	√	√
	D2	Project Manager	7	5		√	√
	D3	Senior Engineer	8	5			√
	D4	Engineer	5	5			√
Design company	DC1	Architect, Project Director	14	8	√	√	√
	DC2	Architect, Project Manager	10	7			√
	DC3	Architect	13	5			√
	DC4	Structural Designer, Project Director	12	6			√
	DC5	MEP (Mechanical, Electrical, and Plumbing) Designer	10	10		√	√
BIM consultant	BC1	Director of the BIM Design Center (Design party)	14	7			√
	BC2	BIM Modeler (Design party)	7	7		√	
	BC3	BIM Engineer (Construction party)	4	4			√
	BC4	Deputy Director of the BIM Engineer, Digital Engineering Department (Construction party)	16	6		√	√
Cost consultant	CC1	Quantity Surveyor	6	4		√	√
	CC2	Quantity Surveyor	7	5		√	√
	CC3	Quantity Surveyor	6	4			√
	CC4	Quantity Surveyor	5	3			√
General contractor	GC1	Construction Engineer, Project Manager	30	8	√	√	√
	GC2	Construction Engineer, Project Manager	13	8		√	√
	GC3	Construction Engineer, Project Director	14	7			√
	GC4	Construction Engineer	8	6			√
Subcontractor	S1	Installation Engineer, Installation Manager	20	12	√	√	√
	S2	Installation Engineer	10	6			√
	S3	Installation Engineer, Installation Director	12	8		√	√
	S4	Installation Engineer	6	4			√
Component supplier	CS1	Seismic Support Supplier	7	5			√

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