

Research Article**A BIM-Driven Collaborative Management Model for Design–Construction Integration in Building Projects in Xi’an: A Conceptual Framework and Research Design**

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Abstract

Building Information Modelling (BIM) is now widely adopted in Chinese construction, yet its collaborative benefits are not automatic. Empirical evidence from the Chinese market shows that BIM application is shaped by contractual, organisational and relational conditions rather than by software use alone. The design–construction interface therefore remains vulnerable to information discontinuity, responsibility ambiguity, late coordination and fragmented workflows. This paper addresses the gap between barrier diagnosis and management design. Drawing on a structured review of recent BIM and construction-management literature, together with international and Chinese information-management standards and national and local policy, it makes three contributions. First, it synthesises eight literature-informed candidate barrier domains—organisational, responsibility and governance, collaboration and relational, process, information management, technological, human and competency, and institutional and contractual—and positions BIM as a socio-technical enabling environment rather than a stand-alone solution. Second, it proposes a Structured Barrier–Evidence–Requirement Mapping procedure that converts empirically identified critical barriers into traceable collaborative management requirements, supported by a Barrier–Evidence–Requirement Traceability Matrix. Third, it outlines a requirements-driven model development and modified Delphi validation design for a context-adapted collaborative management model for building projects in Xi’an, a national intelligent-construction pilot city. The proposed approach connects the identification of barriers, the determination of requirements, model

development, and validation, providing a transparent and auditable process for developing an expert-validated management model.

Keywords

Building information modelling, Design–construction integration, Collaborative management, Critical barriers, Information management, Xi'an

1. Introduction

The architecture, engineering and construction (AEC) industry is undergoing a transition in which project information is increasingly created, exchanged and managed through digital environments rather than isolated documents. Building Information Modelling (BIM) is central to this transition because it provides a model-based means of representing building information and linking it to design, coordination, construction planning and project control. In China, BIM has become one of the most widely recognised digital technologies in construction enterprises, yet digital transformation continues to be constrained by fragmented data, uneven technical capability, shortages of competent personnel and incomplete standards and organisational arrangements (Zhang et al., 2023). Technological availability alone therefore does not guarantee integrated project delivery.

The design–construction interface is particularly important. Design decisions define the technical intent of a project, while construction organisations must translate that intent into workable sequences, procurement decisions, temporary works, resource plans and site operations. When information is transferred late, in incompatible formats, without clear ownership or without reliable change control, the interface becomes a source of rework, delayed decisions and coordination risk. BIM can support closer cooperation and coordination, but evidence from the Chinese construction market shows that its collaborative benefits are shaped by contractual, organisational and relational conditions rather than by software use alone (Gao et al., 2022). Reviews similarly emphasise that BIM-related collaboration requires attention to risk allocation, trust, responsibilities and information-sharing practices in addition to digital tools (Ali et al., 2022).

This paper therefore treats BIM as an enabling environment for collaborative management rather than a stand-alone technical solution. Focusing on building projects in Xi'an, Shaanxi Province, it proceeds in five parts: BIM and design–construction integration (Section 2); the eight candidate barrier domains (Section 3); standards and policy as evidence for requirement derivation (Section 4); a Structured Barrier–Evidence–Requirement Mapping procedure (Section 5); and the research design and model-validation logic (Section 6).

2. BIM and Design–Construction Integration

2.1. BIM as structured information management

BIM has evolved from a model-centred representation approach into a broader method of creating, managing and exchanging structured project information, characterised by object-based information, coordinated digital representations and integration with common data environments, cloud platforms and project-management systems. The significance of this evolution lies in the shift from using a three-dimensional model primarily for visualisation to using structured information as a basis for coordination and decisions across project stages. The Chinese national *Unified Standard for Building Information Modeling* (GB/T 51212-2016) similarly defines BIM applications in relation to the creation, use and management of building information across the life cycle rather than limiting BIM to three-dimensional drafting. Zhang et al. (2023) found BIM to be the most commonly used digital technology among surveyed Chinese enterprises, while identifying organisational, technological and management constraints that continue to shape digitalisation outcomes. Ye et al. (2025) identified collaboration, communication, information and data as dominant themes in BIM-enabled project management, showing that BIM research has moved beyond geometric modelling and clash detection toward information quality, integrated decision processes and digital maturity.

2.2. The design–construction interface and information continuity

The design–construction interface is a critical boundary because it combines a change in project stage with a change in organisational responsibility, information purpose and decision context. Information detailed enough for design approval may not be structured enough for procurement or construction planning, while site teams may require information about sequence, temporary conditions, access, tolerances or work packaging that was not represented explicitly in the design model. Information continuity should therefore not be interpreted as the unchanged preservation of all model content; it refers to maintaining the identity, meaning, status, responsibility and usability of information as it is transformed for a different task.

Research has repeatedly identified discontinuity at interfaces as a persistent issue. Park and Ock (2022) observed that different BIM authoring tools can create information discontinuities during exchange and reduce confidence in integrated model information, while studies of common data environments show that a CDE can support a single source of information yet remains challenged in practice by inconsistent workflows, user practices and organisational expectations (Jaskula et al., 2024). Technical interoperability and management continuity are thus related but distinct: a neutral exchange format may preserve objects yet fail to preserve approval status or responsibility, while a cloud platform may preserve document versions yet fail to ensure that downstream teams understand which information is authorised for use. The ISO 19650 series makes this distinction explicit by treating BIM as information management; ISO 19650-4:2022 specifies a decision process and quality criteria for

information exchange so that the resulting model is suitable for its intended purpose. The critical question is therefore not whether information has been transmitted, but whether it has been checked, approved, properly identified, delivered in an agreed form and received with a clear status for subsequent action.

For the present purpose, information continuity at the design–construction interface can be conceptualised through five linked properties: traceability, controlled status, semantic consistency, task suitability and responsibility visibility. Traceability allows the origin and revision history of information to be followed; controlled status distinguishes work in progress, shared, reviewed and authorised information; semantic consistency reduces ambiguity when information crosses software or organisational boundaries; task suitability requires information to contain what the receiving activity actually needs; and responsibility visibility identifies who creates, checks, approves, receives and acts upon information. These properties provide a bridge between barrier identification and collaborative management requirements.

2.3. Why BIM does not automatically produce integration

A federated model may contain coordinated geometry while contractual responsibility remains fragmented; a common data environment may provide shared access while decision rights remain unclear; and a model may be updated technically while field teams continue to rely on parallel documents. Gao et al. (2022) demonstrated that BIM application is associated with project collaboration in China, but the strength of this relationship is affected by contract specificity and fairness perceptions. Bunse et al. (2025) found that BIM-supported design does not automatically produce better collaboration; digital working can increase the need for communication and expose weaknesses in organisational structure and stakeholder capability. Ali et al. (2022) found that collaboration and risk remain central themes in BIM research, Ma et al. (2022) showed that BIM barriers in China span organisational, technological, legal and human dimensions, and Datta et al. (2023) identified costs, interoperability, skills, resistance, inadequate standards and insufficient managerial commitment as recurring impediments.

The persistence of these barriers explains why organisations can invest in BIM without achieving continuous design–construction integration. Organisations may use BIM for visualisation or clash detection but continue to manage approvals, changes, responsibility and contractual records through separate channels, creating a hybrid environment in which some project information is model-centred while authoritative decisions remain document-centred. Hybrid arrangements are not inherently ineffective, but they require explicit linking rules; without them, a project may contain multiple parallel representations of the same decision, creating uncertainty about which representation is current or contractually authoritative.

This paper therefore uses the term BIM-driven rather than BIM-based in a narrow software sense. BIM-driven integration means that BIM information and functions are used to trigger, support and evidence collaborative management activities, with emphasis on how design information is linked to review, approval, coordination, responsibility assignment, feedback and construction decision-making. This requires a clear distinction between digital integration, which concerns the technical ability to connect information, models and systems, and managerial integration, which concerns whether responsibilities, decisions and workflows are coordinated around that information. The two are related but not identical, and progress in one does not automatically produce progress in the other.

3. Collaborative Management and the Eight Candidate Barrier Domains

3.1. Collaborative management in BIM-enabled projects

Collaborative management in BIM-driven design–construction integration concerns the coordinated organisation of people, responsibilities, information and processes so that interdependent decisions can be made and implemented across organisational and stage boundaries. It extends beyond general teamwork because collaboration in a building project is constrained by contractual roles, formal approval authority, information status and the sequence of project activities.

Five interrelated characteristics distinguish it. It is interdependent, because decisions made by one participant affect the information, timing or resources required by others. It is cross-boundary, because the relevant actors frequently belong to different organisations or professional disciplines. It is information-intensive, because collaboration depends on a sufficiently common understanding of the issue being resolved. It is governed, because authority, responsibility, review and approval cannot be left entirely informal where project liability is involved. It is iterative, because design–construction issues are resolved through cycles of clarification, review, modification and confirmation rather than a single transaction.

These characteristics explain why collaboration should not be measured only by frequency of meetings or messages. High communication volume can coexist with weak collaboration when information is duplicated, responsibilities are ambiguous or decisions are not closed. Effective collaborative management requires a controlled relation among information, task and responsibility: a coordination issue should ideally be linked to an identifiable location or model object, an accountable party, a required action, a due date, supporting evidence and a closure status. Cross-organisational collaboration also requires boundary objects—shared representations that different disciplines can use while retaining their specialised perspectives, such as coordination views, issue registers and interface matrices. Such objects, however, require governance: a federated model is useful only if participants understand the origin and status of its component models, and an issue register is useful only if entries

are maintained consistently.

3.2. The case for a domain-based synthesis

Barriers to BIM-driven design–construction integration cannot be represented adequately by a single category such as “technology adoption”. A systematic review by Ali et al. (2022) showed that collaboration, integration and implementation barriers remain central themes in BIM research, while comparative work in developing countries identified interacting organisational, technological, human and institutional conditions (Ariono et al., 2022). Waqar et al. (2023) grouped critical barriers into technical adoption, behavioural, implementation, management and digital-education dimensions; Mishra et al. (2024) distinguished pre-adoption from post-adoption barriers and found that costs, supply-chain uptake, skills, client understanding and user resistance remain consequential after initial implementation; and Lourenço et al. (2025) showed that limited cooperation, insufficient top-management support, skill shortages and weak evaluation mechanisms form an interdependent barrier system rather than independent obstacles.

Terminology nevertheless varies considerably across studies. Similar conditions may be described as management support, organisational readiness, strategic commitment or leadership; information issues may appear as data quality, interoperability, information sharing or CDE problems; governance concerns may be reported as contractual, legal, responsibility or role-related barriers. Directly combining published factor labels would therefore create duplication and conceptual ambiguity.

The synthesis adopted here follows a management-mechanism logic: barriers are grouped according to the primary condition through which they disrupt integration. Lack of senior-management support is organisational because it affects strategic commitment and resources; unclear approval authority is governance-related because it concerns decision rights; poor willingness to share information is relational because it concerns collaborative behaviour; repeated manual transfer is process-related when the main issue is workflow but technological when the cause is system incompatibility; and inconsistent model status belongs to information management because it concerns control of information. This approach avoids treating every published label as a separate construct and makes the candidate domains sufficiently distinct for instrument design, internal coding and descriptive comparison.

3.3. The eight candidate barrier domains

Integrating three bodies of evidence—recent BIM barrier literature, studies of BIM-enabled collaboration and information management, and the specific logic of the design–construction interface—produces eight literature-informed candidate domains. They are analytical categories derived from recurring themes in the literature, not eight predetermined factors assumed to exist empirically in

Xi'an. Table 1 summarises their operational boundaries.

Table 1

Operational boundaries of the eight candidate barrier domains

Candidate domain	Primary conceptual boundary	Illustrative focus
Organisational Factors	Internal strategic, structural and resource conditions	Management support, resources, organisational alignment
Responsibility and Governance Factors	Authority, accountability and decision rights	Role clarity, approval, issue ownership
Collaboration and Relational Factors	Quality of interaction and joint working	Trust, communication, willingness to share
Process Factors	Sequence and integration of workflows	Early involvement, review gates, change workflow
Information Management Factors	Quality and control of information	Version, status, coding, traceability
Technological Factors	Digital capability and interoperability	Software exchange, integration, usability
Human and Competency Factors	Knowledge, skills and readiness	Training, role-specific BIM capability
Institutional and Contractual Factors	External rules and formal arrangements	Policy, procurement, contracts, standards

The structure deliberately separates governance from organisation because unclear authority can exist even in organisations that strongly support BIM; collaboration from governance because formal clarity does not guarantee cooperative behaviour; information management from technology because poor information status or version control can occur on technically capable platforms; and institutional and contractual factors from internal organisational conditions because policy, procurement and legal arrangements operate at a broader level.

A domain was retained when it represented a distinct management mechanism that could require a different response in later requirement derivation and model development. Insufficient management support and unclear approval authority may both appear organisational, but they imply different remedies: the former concerns strategic commitment and resources, the latter governance and decision rights. Likewise, poor interoperability and unreliable version control are related but not identical; the first is a technological capability issue, the second an information-governance issue. This logic is consistent with recent barrier research showing that broad categories can conceal different causal

pathways (Mishra et al., 2024; Lourenço et al., 2025).

Table 2

Representative recent empirical evidence supporting the candidate domains

Study	Context and method	Key evidence
Ali et al. (2022)	Systematic literature review of BIM collaboration and risk	Collaboration, integration and implementation barriers remain central themes
Gao et al. (2022)	296 respondents, Chinese construction market	BIM application relates to cooperation and coordination; contract specificity affects coordination
Chen et al. (2022)	Grounded-theory study across 34 BIM-enabled projects	Integrated coordination, communication, shared responsibility and flexibility matter
Waqar et al. (2023)	235 Malaysian professionals; EFA and SEM	Technical, behavioural, management and digital-education barriers persist
Jaskula et al. (2024)	Systematic review plus interviews with 15 BIM experts	Multiple CDEs create accountability, transparency and reliability problems
Mishra et al. (2024)	218 respondents from 125 Indian organisations	Pre- and post-adoption barriers include costs, skills, client understanding and resistance
Yi and Nie (2024)	175 respondents, Sichuan Province, China	Contractual flexibility and trust support performance; BIM level moderates governance
Lourenço et al. (2025)	Literature review, Delphi, ISM and MICMAC in Portugal	Skills, cooperation, resistance, evaluation and management support are interdependent
Lindholm et al. (2025)	Two case studies and industry workshop	Information-delivery planning and production planning remain weakly connected

Note. Each domain carries a distinct management logic.

Organisational factors concern the capacity and willingness of organisations to support BIM-enabled integration, including senior-management commitment, strategic alignment, resource allocation and cross-functional coordination. Zhang et al. (2023) found that organisational and management constraints remain important in the digital transformation of Chinese construction enterprises. Commitment matters because integration requires investment before all benefits can be observed; if BIM is treated as a project-specific technical add-on rather than an organisational capability, teams may receive insufficient time, authority or staffing to use it consistently, producing symbolic adoption in which models satisfy contractual requirements while key decisions continue through established non-BIM channels.

Responsibility and governance factors relate to ambiguity or weakness in authority, accountability

and decision rules. Liu et al. (2022) demonstrated that contractual and relational governance both influence BIM collaboration and implementation, so governance barriers should not be reduced to the absence of a BIM execution plan or contract clause; Cheng et al. (2023) similarly showed that relational norms influence knowledge collaboration and that BIM-related responsibilities require clearer definition. Ambiguity is particularly consequential at the design–construction interface because multiple parties may have legitimate but different authority: a contractor may detect a constructability problem but lack authority to alter the design, a designer may issue a response requiring client approval, and a BIM coordinator may manage the issue record without technical decision authority. Governance barriers can also arise from overlapping rather than missing responsibility, in which several parties hold partial authority without a mechanism for final decision.

Collaboration and relational factors refer to the quality of interaction among participants, including trust, communication, willingness to share information and joint problem solving. The domain is distinct from governance because parties can have clear formal roles yet still collaborate poorly; conversely, strong interpersonal relationships cannot compensate for missing authority. Relational conditions are also influenced by risk perception: participants may avoid early sharing when they fear that preliminary information will be used to assign blame, yet delaying information until it is fully resolved prevents other parties from planning around emerging constraints. Farouk et al. (2023) showed that trust is influenced by knowledge, skills, behaviour, policy, systems, costs and management conditions, indicating that trust is not a simple standalone solution.

Process factors concern the structure, timing and consistency of workflows, including fragmented processes, late contractor involvement, inconsistent procedures, duplicated review routes and ineffective feedback. These barriers matter because even accurate information can arrive too late to influence a downstream decision, and process fragmentation is a source of hidden waste: teams may export information from one system, re-enter it into another, recreate issue lists in spreadsheets or duplicate approvals in separate platforms. Jiao and Cao (2023) proposed bringing downstream participants into the design stage earlier and restructuring the design workflow, while Wang et al. (2024) demonstrated that design-change management benefits from linking BIM objects, schedule information and interoperable exchange. The process domain focuses on how work moves, whereas the information domain focuses on how information is structured, controlled and traced.

Information management factors concern the quality, structure and control of project information, including incomplete or inconsistent data, poor version control, unclear information status, inconsistent classification, fragmented repositories and weak audit trails. Seyis and Ozkan (2024) found that access to accurate, reliable and up-to-date information is the most important benefit of CDE implementation, while failure to plan the CDE during the front-end phase is a critical challenge; Zhang et al. (2024) further demonstrated that integrated BIM and product-lifecycle-management approaches can strengthen

cross-disciplinary information continuity when data and workflow structures are coordinated. At the design–production interface, Lindholm et al. (2025) found continuing difficulties in connecting information-delivery planning with construction-production planning. Separating this domain from technology is essential because technically interoperable models may still contain unverified, outdated or ambiguously authorised information, while well-governed information can be exchanged through relatively simple tools if responsibilities and controls are explicit.

Technological factors relate to the ability of digital systems to support integrated work reliably and efficiently, including software incompatibility, data loss during exchange, weak interoperability and platform fragmentation. Yu et al. (2023) showed why IFC extensions continue to be developed for domain-specific information needs, confirming that interoperability remains an active challenge. A platform limitation may nevertheless appear technological while being amplified by poor information requirements or inconsistent modelling practices. Interoperability also has syntactic and semantic dimensions: an exchange may succeed technically while losing the classification, relationships or attributes needed for downstream decisions.

Human and competency factors concern the knowledge, skills and behavioural readiness required in BIM-enabled integrated processes. Competency here is broader than software operation: a modeller may be technically proficient but have limited understanding of construction sequence, while a site manager may understand constructability but be unable to navigate model-based issue information. Shojaei et al. (2023) found that leading construction firms addressed heterogeneous digital literacy through role-specific internal training and a ‘growing together’ approach, showing that isolated individual training is insufficient where delivery depends on networked competence. Integrated work also requires boundary-spanning ability, because some participants must translate between design, construction and digital-information perspectives.

Institutional and contractual factors concern external rules and formal arrangements that shape BIM-enabled collaboration, including contractual provisions, inconsistent standards, limited regulatory guidance and procurement arrangements that reinforce stage separation. Ma et al. (2022) identified legal and policy-related constraints among BIM implementation barriers in China, while Erpay and Sertyesilisik (2021) identified critical contractual considerations across responsibility allocation, information management, intellectual property and data security. This domain is broader than project governance: governance addresses how authority and responsibility operate within the project, whereas institutional and contractual factors address the formal rules and external environment that shape what parties are required or permitted to do. Table 3 summarises how the domains map onto interface concerns.

Table 3

Domain emphasis across the design–construction interface

Interface concern	Most directly implicated domains
Information produced for design but unusable for construction	Information management; process; collaboration
Unclear authority to resolve cross-stage issues	Responsibility and governance; institutional and contractual
Late or absent construction knowledge in design	Process; organisational; human and competency
Parallel versions and unclear information status	Information management; technological
Uneven capability across organisations	Human and competency; organisational; institutional

4. Standards and Policy as Evidence for Requirement Derivation

Requirements cannot be inferred solely from barrier rankings. A high-ranked barrier indicates where integration is weak, but a requirement must specify what management condition is needed to address that weakness. The evidence base for this translation combines academic literature, which explains mechanisms and recurring practices; standards, which establish normative requirements for information; and policy, which identifies current expectations for digital and integrated construction in China and the local context.

4.1. International and Chinese BIM standards

International BIM standards increasingly frame BIM as structured information management. ISO 19650-1 and ISO 19650-2 establish concepts and principles for information management using BIM and provide requirements for the delivery phase of assets, while ISO 19650-4:2022 addresses the detailed process and criteria for information exchange, emphasising that exchanged information should meet agreed quality criteria and be suitable for its intended purpose. The approach is useful for design–construction integration because it distinguishes information states and responsibilities: information is not assumed to become usable simply because it is uploaded or transmitted, but must pass through appropriate review and authorisation. This directly addresses risks associated with parallel versions, premature use of work-in-progress information and uncertainty over which information is contractually or operationally valid.

China has established national BIM standards directly relevant to this research. GB/T 51212-2016 provides general principles for BIM applications across the building life cycle, emphasising consistent information, unique identification, usability across stages and openness. GB/T 51235-2017 addresses construction-stage BIM applications, providing a national technical basis for model-based construction

management. GB/T 51269-2017 provides classification and coding rules that support information exchange and sharing by reducing ambiguity when data cross software and organisational boundaries. GB/T 51447-2021 specifies BIM data storage structures, common exchange formats and consistency verification. Together, these standards support requirements for unique identification, classification, structured storage, exchange and validation.

The role of these standards should nevertheless be deliberately bounded. They do not establish the eight barrier domains, nor do they prescribe the architecture of any model developed from them; instead, they provide technical and normative requirements that can be mapped to collaborative management needs identified from empirical barriers. This distinction preserves the evidentiary integrity of model development and prevents a methodological error in which a standard is treated as evidence for a researcher-created framework structure.

4.2. National, provincial and local policy

China provides a significant context for examining BIM-driven integration because BIM adoption has developed alongside a broader national agenda for construction industrialisation, digitalisation and intelligent construction. The *Fourteenth Five-Year Plan for the Development of the Construction Industry* calls for improvement of the BIM standard system, stronger integration between BIM and project management information systems, cloud-based information transmission and digital collaborative design, and better connection between design outputs and downstream production and construction (MOHURD, 2022a). This policy direction indicates that BIM is expected to contribute to process integration rather than remain an isolated design visualisation tool. The implementation environment nevertheless remains uneven: BIM-related institutional development differs significantly across Chinese regions and is influenced by economic development, information infrastructure and talent availability (Yang & Xie, 2026). A model derived only from national-level assumptions may therefore overlook the way project practices, organisational capability, local regulatory expectations and market maturity interact in a specific city.

Xi'an is an appropriate setting. In 2022, MOHURD selected Xi'an as one of 24 national pilot cities for intelligent construction, with the pilot programme requiring cities to strengthen policy systems, develop demonstration projects, innovate management mechanisms and explore digital regulatory platforms and BIM-enabled approval and review processes (MOHURD, 2022b). At the provincial level, Shaanxi's implementation opinions on promoting high-quality development of the construction industry call for digital collaborative design, stronger BIM application capability, intelligent-construction demonstration and support for Xi'an as a national intelligent-construction pilot city (Shaanxi Provincial Committee and Shaanxi Provincial People's Government, 2022).

The local context should not, however, be interpreted as evidence that integration problems have

already been resolved. National pilot status establishes a policy direction, not a guarantee of consistent project-level implementation, and design institutes, general contractors, specialist subcontractors, consultants, clients and public authorities may differ in BIM maturity, information-management capability and contractual expectations. Policy evidence is therefore used cautiously: a policy direction demonstrates institutional expectation, not empirical project performance, and can justify requirements for digital coordination, information integration and implementation compatibility without supporting a claim that such mechanisms already operate effectively in Xi'an.

Table 4

Standards and policy evidence used in requirement derivation

Evidence source	Principal contribution	Use in this study
ISO 19650 series	Information-management concepts and controlled exchange	Normative evidence for exchange, status and quality control
GB/T 51212-2016	General BIM application principles	Consistency, unique identification, cross-stage usability
GB/T 51235-2017	Construction-stage BIM applications	Connection of BIM with construction management
GB/T 51269-2017	Classification and coding	Consistent identification and information sharing
GB/T 51447-2021	BIM storage and consistency	Storage, common formats and verification
National/Shaanxi/Xi'an policy	Digital collaborative design and intelligent construction	Contextual and implementation requirements

5. A Structured Barrier–Evidence–Requirement Mapping Procedure

5.1. From barriers to requirements

A barrier and a requirement are not equivalent. A barrier states an undesirable condition, such as unclear responsibility for updating BIM information after a design change. A collaborative management requirement states the control that should exist to prevent, reduce or manage that condition, such as defining an accountable updating role, a trigger for revision, an authorised status change and a verification step. The central problem addressed by this paper is therefore one of translation: many empirical studies conclude by recommending stronger training, better standards, improved communication or greater management support, but such recommendations are often too broad to serve

as direct model-design inputs. Requirement derivation is treated here as an evidence-traceability problem: each requirement should be linked backward to one or more verified barriers and supporting evidence, and forward to the model element that operationalises it. The central logic connects critical barriers with their management implications, supporting evidence, collaborative management requirements, and model design inputs. This ensures that each component of the model has a clear and traceable basis, rather than simply reflecting a collection of desirable features.

5.2. The five analytical operations

The procedure comprises five operations, each of which leaves a record of its input, decision and output.

Interpretation. Each critical barrier is converted into the management problem it creates. A structured worksheet identifies what is actually uncontrolled, unclear, delayed, fragmented or incompatible; the affected interface or stage; the actors whose responsibilities or interactions are involved; and the information, decision or workflow condition that would need to change. If a barrier concerns late contractor and specialist involvement, the implication is not simply “use BIM earlier”: the analysis examines what decisions need construction knowledge, when that knowledge must enter the process, who is responsible for requesting or supplying it, how the resulting decision is recorded, and how the agreed output is reflected in the authoritative model or document set.

Evidence verification. Each initial management implication is checked against at least one relevant evidence source, and where practicable two independent forms of support are sought—for example, a recent empirical study and an applicable standard, or two peer-reviewed studies from different contexts. Verification addresses both support and boundary: a source may support the need for controlled information exchange without supporting a claim that all organisations must use one platform. Conflicting evidence is not concealed; where studies report different arrangements, the requirement is formulated at the common management-principle level and the implementation detail is treated as configurable.

Requirement formulation. Initial requirements are written using a consistent syntax: *management subject* + required *action or control condition* + *management object* + *stage or trigger* + *expected output or evidence*. Requirements avoid product names, organisation-specific job titles and prescriptive technical architectures unless these are required by an authoritative source. They are stated in terms of management capability or control—such as “maintain traceable issue status” rather than “use Platform X”—and are expressed so that a reviewer could determine whether the requirement had been implemented. The word “shall” is used where a control is supported by critical empirical evidence, an authoritative standard, or both, while “should” is reserved for context-dependent good practice where project arrangements may legitimately differ.

Consolidation and classification. Requirements are compared for duplication, overlap, logical dependency and level of abstraction. Two requirements are merged only when they concern the same principal management object, required action, responsible role relationship and expected outcome. The relationship between barriers and requirements is many-to-many: one barrier may generate several requirements if it contains more than one necessary control, and several barriers may converge on one integrated requirement. Weak communication, unclear responsibility and delayed issue closure, for example, may collectively justify a single requirement for a controlled issue-management workflow with defined ownership, response times and verification. Consolidation is therefore analytical rather than mechanical.

Traceability mapping. Each retained requirement is recorded in a Barrier–Evidence–Requirement Traceability Matrix linking the empirical barrier to its interpretation, evidence and resulting requirement. Table 5 shows the minimum fields.

Table 5

Fields in the Barrier–Evidence–Requirement Traceability Matrix

Field	Content recorded	Purpose
Barrier ID and statement	Questionnaire number, internal code, final barrier wording	Preserves link to the empirical instrument
Empirical evidence	Valid N, mean, SD, rank, candidate-domain context	Shows empirical basis and priority
Management implication	Affected actor/interface, failure mechanism, required control condition	Makes the reasoning step explicit
Evidence source(s)	Academic source, standard clause/principle, official policy	Verifies and contextualises the implication
Evidence type/status	Empirical, academic, normative, policy; convergent/conditional/conflicting	Prevents different evidence types being conflated
Requirement ID	Unique requirement identifier	Enables version control and later model mapping
Final requirement statement	Standardised management requirement wording	Defines the design input for model development
Applicability/notes	Lifecycle stage, responsible party, conditions or exclusions	Supports local and project-specific configuration

5.3. Illustrative requirement derivation

Table 6 illustrates the procedure on three barriers that recur across the literature reviewed above.

The examples are illustrative of the method rather than complete derivations; each retained requirement would be supported by at least one defensible evidence basis before entering the design-input set.

Table 6

Illustrative application of the mapping procedure

Barrier condition	Management implication	Evidence basis	Derived requirement (abbreviated)
Unclear responsibility for updating model information after an approved change	Uncertainty in ownership, authorisation and closure of information updates	Liu et al. (2022); Yi & Nie (2024); ISO 19650-2	The designated responsible party shall update and reissue affected BIM information after an approved change, preserving revision status and linkage to the formal change record
Inconsistent model versions and unclear information status across parties	Users cannot determine which information is current or authorised for use	Jaskula et al. (2024); Seyis & Ozkan (2024); ISO 19650-4	Information shall carry a controlled status distinguishing work in progress, shared, reviewed and authorised states, with superseded information explicitly identified
Late or absent construction input into design decisions	Constructability issues are discovered after design change becomes costly	Jiao & Cao (2023); Chen et al. (2022); GB/T 51235-2017	Construction knowledge shall be introduced at defined design-review gates, with required participants, review action, decision record and feedback route specified

These examples illustrate a recurring design principle: requirements are stated as management capabilities, not technology specifications. A requirement for issue traceability may be supported in implementation by issue ownership fields, status controls and audit history, but the requirement itself remains valid even if the underlying platform changes. This technological neutrality improves both transferability and longevity.

6. Research Design and Model-Validation Logic

6.1. Overall research design

The proposed research follows a sequential three-stage design in which the output of each stage becomes an explicit input to the next. This sequencing avoids two common methodological weaknesses: beginning model development from a technology catalogue or generic international framework without first demonstrating which problems are critical in the local context; and translating survey rankings directly into a proposed model without showing how a barrier is converted into a management response.

Stage 1 identifies and prioritises critical barriers through a literature-informed questionnaire survey and statistical analysis. Candidate barriers are operationalised into a final 42-item instrument covering the eight candidate domains, presented to respondents without revealing the internal domain labels so that they are not cued to treat neighbouring items as members of predetermined constructs. Each item is rated on a five-point severity scale, with an explicit N/A option treated as missing rather than as the scale midpoint; forcing an uninformed response into the midpoint would artificially reduce dispersion and distort item means, rankings and critical-barrier identification. Analysis proceeds through eligibility screening, data cleaning, sample description, internal-consistency reliability assessment, item-level mean-based ranking with standard deviation used to resolve ties, and descriptive comparison of the eight domains. A barrier is classified as critical when its mean severity score is 3.50 or above, a study-specific operational rule rather than a universal benchmark.

Stage 2 derives requirements through the Structured Barrier–Evidence–Requirement Mapping procedure described in Section 5, interpreting critical barriers, verifying them against recent literature, BIM standards and applicable policy, and converting them into standardised requirements recorded in the traceability matrix. No separate primary data-collection phase is introduced.

Stage 3 develops the model from the verified requirements and subjects it to expert validation, transforming requirements into model elements by specifying the control objective, accountable actor, management object, process trigger, required action, information needed, BIM-enabled support, expected output and escalation condition.

6.2. Model development principles

Model development is governed by seven principles. First, the model must be requirements-driven: core elements must respond to a verified requirement or an explicitly documented mandatory normative requirement. Second, evidence traceability must be preserved from barrier to requirement to model element. Third, design–construction continuity must be represented across stages rather than by treating design BIM and construction BIM as separate technical activities. Fourth, responsibility and authority must be distinguished clearly, especially where BIM coordination supports but does not replace professional technical approval or contractual decision authority. Fifth, information must be treated as controlled project information with identifiable status, source, revision, permitted use and traceability. Sixth, BIM is treated as an enabling mechanism rather than as the management model itself. Seventh,

the model must contain a stable core while allowing project-specific configuration.

Interface orientation is preferable to a purely departmental model because integration problems often occur between organisational units rather than within them. Design–construction integration is not a single transition point; it comprises a sequence of interfaces, including development of design information, multidisciplinary coordination, constructability review, preparation for procurement and work packaging, release of construction information, specialist or contractor input, site clarification, design change and feedback. At each interface, four questions recur: what information is required; which actors participate; who decides or approves; and how the result is recorded and transferred.

Two further principles are parsimony and technological neutrality. The model should contain enough elements to explain and control the identified problem without unnecessary complexity, since overly elaborate models become difficult to validate and to apply. Technological neutrality requires the model to specify required capabilities—such as version control, visual coordination or issue linkage—without mandating a named commercial platform, allowing progressive maturity in which a project may initially implement a traceable issue workflow through a basic common data environment and later automate notifications or integration through open exchange formats and application programming interfaces. Finally, the model should distinguish stable-core elements (traceability, role clarity, controlled information status, issue closure, explicit decision authority and evidence-linked requirements) from configurable parameters (stage names, organisation titles, platform choice, delivery formats, approval routes and exchange schedules).

6.3. Expert validation through a modified Delphi method

Validation uses a modified Delphi method, appropriate because the evaluation task requires structured judgement from people with specialised knowledge, repeated opportunities to reconsider judgements, controlled feedback and a transparent consensus rule. The procedure is *modified* because the first-round instrument is not generated de novo by the panel but developed from the evidence-based preliminary model: experts evaluate an existing research artefact rather than beginning with an open brainstorming round, while the central Delphi features of individual rating, anonymity, iteration and statistical group feedback are preserved.

At least two rounds are planned. Round 1 evaluates the preliminary model and collects quantitative ratings and written comments; the researcher analyses ratings, classifies comments and produces a revised model. Round 2 presents the revised model with anonymised group-level feedback and asks experts to re-evaluate. A third targeted round is used only if major model elements remain below the predefined consensus criteria or if Round 2 produces new substantive changes requiring re-rating. This stopping logic prevents unnecessary rounds while ensuring that unresolved core issues are not hidden by averaging.

Each major model element is rated on four dimensions using a five-point scale: necessity/relevance, clarity, feasibility, and verifiability/applicability. The dimensions are separated so that an element can be considered important but insufficiently clear or currently difficult to implement. Experts are encouraged to explain low ratings and to identify missing controls, duplicated elements, unclear responsibility, impractical sequencing, local regulatory conflicts, unnecessary technological assumptions or terminology requiring revision.

Consensus is defined before the results are examined. For a model element to satisfy the principal criterion on an evaluation dimension, the median must be at least 4.0, the interquartile range no greater than 1.0, and at least 75% of valid experts must assign a score of 4 or 5. These three conditions combine central tendency, dispersion and affirmative agreement; a percentage criterion alone can conceal wide disagreement, while a median alone can conceal a substantial minority of low ratings. Kendall's coefficient of concordance (W) is calculated as a supplementary measure of relative agreement and is not a replacement for the element-level criteria.

Every substantive comment receives a decision status—accepted, partially accepted, not incorporated or deferred—and the revision log records the issue in anonymised form, the decision, the reason, the affected requirement or model element and the resulting revision. A low quantitative score triggers review but does not automatically dictate a specific redesign; conversely, a strongly worded individual comment does not automatically override group evidence where it conflicts with standards or the study scope.

Table 7

Modified Delphi evaluation dimensions and consensus criteria

Dimension	Core expert judgement	Consensus criterion
Necessity/Relevance	Is the element needed and appropriate for BIM-driven design–construction collaboration?	Median ≥ 4.0 ; IQR ≤ 1.0 ; $\geq 75\%$ of ratings at 4 or 5
Clarity	Is the element, role or workflow understandable and unambiguous?	As above
Feasibility	Could the element reasonably be implemented under real project conditions?	As above
Verifiability/Applicability	Can implementation be checked, and is the element suitable for the Xi'an context?	As above

6.4. Scope of the validation claim

The model is described as expert-validated when the predefined consensus requirements have been met for the retained core content and no unresolved major concern remains regarding responsibility, information control, statutory compatibility or practical feasibility. This wording is deliberately

narrower than “field validated” or “performance validated”. The Delphi procedure can establish that knowledgeable experts consider the model relevant, clear, feasible and applicable within the defined scope; it cannot demonstrate the magnitude of cost, schedule, quality, safety or productivity benefits that would result from implementation in a live project. Such performance validation would require a separate longitudinal or comparative implementation study and is identified as a future research direction.

7. Conclusion

Empirical evidence from the Chinese construction market shows that BIM’s collaborative benefits depend on organisational, contractual, process, information and competency conditions rather than on technology alone. The design–construction interface remains vulnerable to fragmented information, disconnected workflows and unclear responsibilities, and the transition from barrier diagnosis to management design is frequently left implicit in existing research.

This paper has addressed that gap in three ways. First, it has synthesised eight literature-informed candidate barrier domains—organisational, responsibility and governance, collaboration and relational, process, information management, technological, human and competency, and institutional and contractual—and positioned BIM as a socio-technical enabling environment whose value depends on governance, workflow, information control and competency conditions. Second, it has proposed a Structured Barrier–Evidence–Requirement Mapping procedure that converts critical barriers into traceable collaborative management requirements, supported by a Barrier–Evidence–Requirement Traceability Matrix separating empirical, academic, normative and policy evidence. Third, it has outlined a requirements-driven model development and modified Delphi validation design for a context-adapted collaborative management model for building projects in Xi’an.

The resulting chain comprising barrier, requirement, model, and validation offers three contributions. Theoretically, it connects diagnostic evidence, a translation layer and a design response within one evidence chain, and it makes explicit the distinction between digital integration and managerial integration. Methodologically, it treats requirement derivation as an auditable analytical operation rather than a list of researcher preferences, using an intermediate requirement layer to avoid the common leap from barrier rankings directly to a conceptual diagram. Practically, it responds to a recurring implementation problem in which organisations invest in software or personnel before defining the management problem to be solved; the proposed logic reverses that sequence by beginning with critical barriers and management requirements and only then identifying the BIM-enabled mechanisms that support them. For Xi’an, the approach offers a route through which broad digital-construction policy objectives can be translated into project-level collaborative management practice while remaining compatible with nationally and internationally accepted information-management

principles.

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