

Identifying Construction-Stage Management Problems in Super High-Rise Projects: A Qualitative Study of BIM and Smart-Site Practices in Xi'an, China

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Abstract: The increasing use of Building Information Modelling (BIM), Internet of Things devices, and smart-site platforms has expanded the amount of information available during construction, but it has not necessarily resolved the management problems created by fragmented responsibilities, disconnected data, and rapidly changing site conditions. This study identifies and explains the principal construction-stage management problems affecting super high-rise projects in Xi'an, China. An interpretive qualitative design was adopted. Fifteen practitioners representing project management, BIM and digital construction, safety and environmental management, quality and technical management, equipment and mechanical-electrical-plumbing management, and regulatory inspection participated in semi-structured interviews. The data were analysed through a problem-centred thematic procedure based on Braun and Clarke's six phases, supported by NVivo 14, cross-role comparison, saturation monitoring, and independent coding of 20% of the transcripts. Four domain-specific problems were identified: disconnection between foundation-pit monitoring data and BIM spatial objects; fragmentation of core-tube construction and quality-status information; absence of integrated vertical-transportation coordination; and discontinuity in work-at-height safety management. Across all four domains, a meta-problem of information coordination failure was evident in duplicate data entry, unsynchronised model and site status, isolated management systems, informal communication, and unclear ownership of cross-domain events. The findings show that the central difficulty is not a lack of digital tools, but the inability to convert dispersed digital records into shared, spatially located, responsibility-linked management information. By separating problem diagnosis from later framework development, this paper provides an empirically grounded account of where and why current BIM and smart-site practices fail during super high-rise construction.

Keywords: Building Information Modelling (BIM); Smart Construction Site; Super High-Rise Building; Management Problems; Thematic Analysis; Information Fragmentation; Xi'an

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1. Introduction

Super high-rise construction concentrates structural complexity, logistical pressure, safety exposure, and multi-organisational coordination within a vertically constrained production environment. As building height increases, decisions concerning

deep excavations, structural-core cycles, material lifting, access, and work at height become more interdependent and time-sensitive. Delays in locating an abnormal condition or identifying the responsible work package can therefore propagate quickly across safety, quality, schedule, and resource-management processes. In this study, the empirical setting comprises projects between 200 m and 350 m in height, allowing the analysis to focus on construction environments in which these pressures are particularly pronounced rather than relying on a disputed universal height threshold.

BIM and smart-site technologies are widely promoted as means of improving construction information management. BIM provides object-based spatial representations and a basis for coordinating design and project information, while smart-site systems collect operational data through sensors, positioning devices, surveillance systems, mobile applications, and equipment-monitoring interfaces (Succar, 2009; Azhar, 2011; ISO, 2018a, 2018b). Research has demonstrated the potential of BIM-IoT integration to improve visibility, traceability, and decision support (Dave et al., 2016; Zhong et al., 2017). Nevertheless, the existence of multiple digital systems does not by itself create an integrated management process. Models may remain static, field records may be stored in separate applications, and alerts may be communicated informally without a complete responsibility and closure chain.

This implementation problem is especially important in Xi'an. The city lies within China's loess region, where wetting-induced collapse and settlement require careful geotechnical investigation and monitoring (Li et al., 2024). Super high-rise projects must also coordinate rapid structural cycles, limited vertical-transport resources, changing work-at-height risk zones, and multiple specialist subcontractors. These conditions do not necessarily create entirely new categories of construction management, but they intensify the consequences of fragmented information and delayed coordination. Generic claims about the benefits of BIM or smart sites are therefore insufficient; it is necessary to establish how management failures are experienced in this specific construction context.

Previous research has examined BIM adoption barriers, interoperability, digital twins, real-time monitoring, and technology-enabled safety management (Volk et al., 2014; Pan & Zhang, 2021; Deng et al., 2021; Opoku et al., 2021). Much of this literature begins with a technology or proposed system and then evaluates its capabilities. Fewer studies begin with detailed practitioner accounts of problematic construction events and distinguish the visible problem, its immediate and underlying causes, its management consequences, and the limitations of the digital tools already in use. Without this diagnostic step, proposed solutions risk addressing available technologies rather than the problems that most strongly affect site management. Accordingly, the objective of this study is to identify and explain the principal construction-stage management problems associated with BIM and smart-site practices in super high-rise projects in Xi'an. The study asks: What recurring management problems are experienced in these projects, and how are their manifestations, causes, and consequences related? The paper intentionally stops at problem diagnosis. Stakeholder needs, functional requirements, framework design, and expert validation belong to later research phases and are not reported as findings here. This boundary enables a clearer contribution: an evidence-based problem structure that can support, but is analytically distinct from, subsequent solution development.

The remainder of the paper is organised as follows. Section 2 reviews construction-stage BIM, smart-site technologies, super high-rise management, and information fragmentation. Section 3 explains participant selection, interview design, thematic analysis, cross-case comparison, and quality controls. Section 4 reports four domain-specific problems and the cross-cutting meta-problem connecting them. Section 5 discusses theoretical and practical implications, and Section 6 presents conclusions and future research directions..

2. Literature Review

2.1 BIM in Construction-Stage Information Management

BIM has developed from three-dimensional modelling into a broader set of policies, processes, and technologies for managing built-asset information (Succar, 2009). During construction, common applications include clash detection, constructability review, four-dimensional schedule simulation, quantity control, work-package visualisation, and as-built documentation (Eastman et al., 2011; Azhar, 2011). These applications can improve coordination when model information is current, accessible, and linked to the decisions made by site personnel. However, BIM value is not automatically realised by producing a model. Love et al. (2014) emphasised that benefits depend on organisational processes and active benefits

management, while ISO 19650 positions information management as a structured collaborative process rather than a software task.

Construction-stage use remains vulnerable to a separation between the model and the evolving physical site. Design models may not be updated at the frequency needed for field control, and monitoring data may lack stable links to model objects, zones, floors, or work packages. Studies of BIM and digital twins similarly distinguish a static or intermittently updated model from a digital representation connected to changing operational data (Deng et al., 2021; Opoku et al., 2021). This distinction is important for management research: when the model does not represent current site status, it cannot serve as a reliable common reference for locating events, coordinating responsibility, or reconstructing causal chains.

2.2 Smart-Site Technologies and the Integration Problem

Smart-site systems extend digital management through IoT sensors, mobile inspection applications, equipment monitoring, personnel positioning, video analytics, and environmental data collection. Studies have shown how connected technologies can support more timely production control and improve real-time visibility and traceability (Dave et al., 2016; Zhong et al., 2017). Artificial-intelligence research further demonstrates the potential for hazard recognition, prediction, and automated interpretation of construction data (Pan & Zhang, 2021).

Yet technical connectivity and managerial integration are not equivalent. A project can operate several capable subsystems while still requiring personnel to re-enter data, compare multiple drawings, search separate applications, or communicate exceptions through telephone calls and messaging groups. The resulting weakness is socio-technical: incompatible formats and missing interfaces interact with inconsistent procedures, departmental boundaries, subcontracting arrangements, and unclear responsibility for events that cross functional domains. The collaboration literature has long identified fragmented information flows and organisational boundaries as barriers to project performance (Ahuja et al., 2009; Xue et al., 2010). Smart-site technologies can reduce this fragmentation, but they can also reproduce it digitally when each management function is implemented as a separate application.

2.3 Management Complexity in Super High-Rise Construction

Super high-rise projects intensify the coordination demands already present in conventional building construction. Deep excavations require continuous interpretation of deformation and groundwater conditions. Core-tube production depends on short, repeated cycles involving climbing formwork, reinforcement, embedded items, concrete placement, surveying, and inspection. Vertical transportation is a shared and capacity-constrained production resource, while work-at-height hazards move as floors, façades, temporary edges, platforms, and access routes change. Each domain involves multiple specialist parties and generates information at different temporal and spatial scales.

The vertical configuration of these projects magnifies the cost of information delay. A record that identifies a problem only by document number or sensor code may be insufficient when managers need to know its floor, zone, component, construction activity, responsible party, and current status. Similarly, an alert is not a complete management outcome if it is not connected to task assignment, corrective action, reinspection, and closure. These characteristics suggest that the relevant unit of analysis is not merely technology adoption, but the management event and the information relationships required to understand and control it.

2.4 Information Fragmentation as a Management Problem

Information fragmentation is often presented as an interoperability problem, but its management consequences extend beyond data exchange. Fragmentation can delay abnormal-condition recognition, weaken quality traceability, create competing resource requests, obscure responsibility, and reduce the evidentiary completeness of safety and compliance records. Volk et al. (2014) identified model updating, uncertain information, and interoperability as persistent BIM challenges. Digital-twin reviews similarly report that the synchronisation of physical and digital states remains incomplete in many built-environment applications (Deng et al., 2021; Opoku et al., 2021).

For problem diagnosis, three levels should be distinguished. Technical causes include incompatible data structures, absent interfaces, and static model states. Procedural causes include non-standard identifiers, inconsistent inspection formats, informal task requests, and incomplete escalation rules. Organisational causes include separate reporting lines, subcontractor

boundaries, asymmetric access, and ambiguous ownership. These levels can reinforce one another: a missing interface creates manual work, manual work becomes an informal procedure, and the procedure leaves responsibility dependent on personal relationships. A qualitative design is suitable for revealing these interactions because practitioners can explain not only what failed, but also how the failure unfolded across roles and systems.

2.5 Research Gap and Study Positioning

The review identifies three gaps. First, a substantial share of BIM and smart-site research is technology-led, whereas systematic empirical diagnosis of management problems before solution design remains limited. Second, studies often examine safety, quality, logistics, or monitoring separately, leaving the relationships among these domains underexplored. Third, the interaction between super high-rise construction conditions and Xi'an's local geotechnical context is rarely investigated through cross-role practitioner evidence. This study addresses these gaps by using semi-structured interviews and problem-centred thematic analysis to identify domain-specific problems and the coordination mechanisms shared across them.

3. Research Methodology

3.1 Research Design

An interpretive qualitative design was adopted because the research sought to understand how practitioners experienced, explained, and managed recurring construction problems within their organisational and technical contexts (Creswell & Poth, 2018). The unit of analysis was the management problem as reconstructed from a specific event or recurring work process. Analysis followed the chain: construction context → problem manifestation → technical, procedural, and organisational causes → current response → management consequence. This chain prevented the analysis from treating general dissatisfaction or preferred technologies as problems unless participants could relate them to observable management conditions.

3.2 Participant Selection and Sampling

Purposive maximum-variation sampling was used to obtain perspectives across roles, organisations, and management domains (Patton, 2015). Inclusion required relevant experience in building construction, project management, BIM, site supervision, or regulatory inspection; participation in Xi'an projects, preferably complex high-rise or super high-rise work; familiarity with construction-stage processes; normally at least five years of relevant experience; and informed consent. Recruitment used professional networks, project contacts, and limited snowball referral. Fifteen practitioners participated, with a mean of 9.7 years of relevant experience. Their projects ranged from 200 m to 350 m in height. Table 1 reports the role composition in aggregate to protect participant identity.

Table 1. Composition of the Interview Sample

Participant category	Number	Primary perspective represented
Project/construction management	3	Overall coordination, programme interfaces, subcontractor management
BIM/digital construction	3	Model use, data exchange, system integration, status updating
Safety/environmental management	3	Hazard identification, notification, rectification, compliance records
Quality/technical management	3	Core-tube processes, inspection, surveying, defect traceability
Equipment/MEP management	2	Tower cranes, hoists, logistics demand, equipment interfaces
Regulatory inspection	1	Compliance evidence, event records, accountability and closure
Total	15	Maximum variation across major construction-stage roles

Source: Compiled by the authors from the interview sample.

3.3 Interview Design and Data Collection

Semi-structured interviews were chosen to combine comparable coverage with the flexibility to probe events, work processes, and responsibility relationships (Kallio et al., 2016). The interview guide was informed by the study objective, prior literature, ISO 19650, GB/T 51212-2016, Xi'an's construction context, and the responsibilities of different project roles. Questions followed the sequence of background, event, manifestation, cause, current handling, consequence, and recurrence.

Participants were first invited to identify problems without prompts. Deep foundation pits, core-tube construction, vertical transportation, and work at height were introduced only when necessary to explore whether these contexts were relevant to their experience.

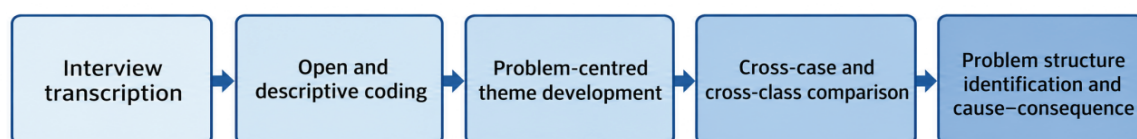
A pilot interview was used to assess clarity, neutrality, and coverage, leading to minor changes in wording and probe order. The final interviews lasted 30–42 minutes and were conducted face to face where possible. With consent, interviews were audio-recorded, transcribed verbatim, checked against the recordings, anonymised as P01–P15, and imported into NVivo 14. Quotations reported in English were translated from Chinese and checked against the original meaning. Field memos documented project context, technical terminology, critical events, and preliminary analytical observations immediately after each interview.

3.4 Thematic and Cross-Case Analysis

Thematic analysis followed Braun and Clarke's (2006, 2021) six phases: familiarisation, initial coding, candidate theme development, theme review, theme definition, and reporting. A combined deductive-inductive strategy was used. The initial analytical fields—context, manifestation, cause, consequence, and limitation of current management or digital systems—provided a consistent structure, while the specific codes and themes were developed from the transcripts. Initial line-by-line coding produced 124 in-vivo and descriptive codes. Iterative merging, splitting, and definition refinement resulted in a final codebook of 118 codes. For the present paper, analysis was restricted to 99 codes directly related to problem identification; codes concerning stakeholder needs or possible functions were retained in the broader doctoral dataset but excluded from this paper's results.

Cross-case matrices compared the occurrence and meaning of candidate problems across roles. A theme was retained when it was supported by a clear management event or recurring process, had identifiable causes and consequences, and was confirmed from more than one professional perspective or supported by especially information-rich evidence. Negative and divergent cases were examined to define the conditions under which a problem occurred. The analysis then compared the four domain themes to identify recurring mechanisms across them. This step produced the cross-cutting meta-problem of information coordination failure; it was not treated as an additional application domain, but as an explanatory pattern linking the domain-specific problems. Figure 1 summarises the analytical process.

Figure 1. Problem-Centred Thematic Analysis Process



Source: Developed by the authors based on Braun and Clarke (2006, 2021).

3.5 Saturation, Reliability, and Trustworthiness

Saturation was monitored after each interview through a log recording new codes, new categories, and new relationships. The first eight interviews generated most initial codes; Interviews P09–P12 refined the core-tube, quality-traceability, and coordination patterns; and Interviews P13–P15 generated no new problem category. Saturation was therefore judged to have been reached after Interview P12, with three subsequent interviews used for confirmation. This decision is consistent with evidence that relatively homogeneous, focused qualitative studies can achieve meaning saturation within a bounded interview sample, although saturation always depends on study scope and sample specificity (Guest et al., 2006; Hennink & Kaiser, 2022).

A second researcher with six years of construction-management research experience independently coded 20% of the transcripts. Cohen's kappa was 0.81, indicating strong agreement under the commonly used Landis and Koch (1977) interpretation. Disagreements concerned mainly the boundary between procedural and organisational causes and were resolved through discussion and code-definition revision. Credibility was supported by maximum-variation sampling, event-focused probing, cross-role comparison, and confirmation of technical terms with selected participants. Dependability and confirmability were supported by an audit trail containing interview-guide versions, transcript checks, codebooks, theme

revisions, and analytical memos. Transferability was addressed through explicit description of the Xi'an setting, project height range, participant categories, and construction contexts (Lincoln & Guba, 1985). Ethical approval was obtained before data collection, and participation was voluntary and confidential.

4. Results

The interviews produced approximately 87,000 Chinese characters of transcript data. Problem-focused analysis identified four domain-specific management problems and one cross-cutting meta-problem. Table 2 summarises their manifestations, principal causes, and consequences. The sections that follow retain the distinction between a problem domain and a proposed solution: they report what fails in current practice and why, without translating the findings into modules or functional requirements.

Table 2. Summary of Identified Construction-Stage Management Problems

Problem domain	Principal manifestation	Recurring causes	Management consequences
Deep foundation pit	Monitoring-point results are not directly associated with BIM zones, support segments, or current excavation activities.	Incompatible interfaces; no shared point-to-object identifiers; monitoring subcontractor outside the main BIM workflow.	Delayed anomaly location; weak causal verification; incomplete response records.
Core-tube construction	Climbing-formwork, concrete, survey, inspection, and model-status records are distributed across departments and systems.	Static design model; separate quality and schedule tools; split reporting lines among specialist teams.	Slow defect reconstruction; rework; inaccurate status and progress assessment.
Vertical transportation	Crane/hoist status, floor demand, delivery changes, and schedule priorities lack a shared coordination view.	No equipment-schedule interface; informal requests; separation of equipment and production planning.	Task conflicts; waiting time; inefficient allocation; increased lifting exposure.
Work at height	Hazard discovery, notification, rectification, reinspection, escalation, and closure do not form one traceable event chain.	No spatial hazard register; inconsistent inspection records; informal communication; asymmetric access.	Persistent hazards; delayed correction; unclear responsibility; weak investigation evidence.
Cross-cutting meta-problem	Digital systems and departments do not maintain a shared interpretation of location, status, responsibility, and closure.	Siloed systems; duplicate entry; unsynchronised status; ambiguous cross-domain ownership.	Delayed decisions and repeated coordination failures across safety, quality, schedule, and equipment management.

Source: Thematic synthesis of interviews P01–P15.

4.1 Participant Coverage and Saturation

The sample provided both managerial and specialist views of the same construction processes. Foundation-pit evidence came mainly from project, safety, technical, and regulatory participants; core-tube evidence was distributed across project, BIM, quality, surveying, and regulatory perspectives; vertical-transport evidence was strongest among project and equipment personnel but was corroborated by safety and specialist-trade accounts; and work-at-height safety was discussed by all participants. The final three interviews confirmed the established themes without creating a new problem category. This cross-role recurrence was analytically important because each problem crossed at least two formal responsibility boundaries.

4.2 Domain-Specific Management Problems

4.2.1 Disconnection in Deep Foundation-Pit Monitoring

Six participants with foundation-pit experience described a recurring difficulty in connecting instrument readings to the spatial and operational context required for action. Monitoring reports identified inclinometer, settlement, or groundwater points by code, but those codes were not consistently linked to the corresponding support segment, excavation zone, dewatering activity, nearby structure, or BIM object. Safety and project personnel therefore had to compare monitoring reports with drawings and work records before they could interpret an abnormal value.

P02 described a sudden daily deformation increase of 8 mm at inclinometer A-3: 'The monitoring report only gave the point

number, not the exact support structure segment. We had to cross-check three different drawings to find which excavation zone it corresponded to. By then, the dewatering pump had already been moved to another zone, so we could not verify whether the anomaly was caused by dewatering or by soil collapse.’ The importance of the event was not the isolated numerical increase, but the delay created by the missing relationship among the sensor identifier, location, construction activity, and responsible party.

Three layers of cause were identified. Technically, monitoring instruments and BIM tools used incompatible formats and lacked a stable exchange interface. Procedurally, projects did not maintain a standard point-to-object coding rule across drawings, reports, and models. Organisationally, geotechnical monitoring was often performed by a specialist subcontractor outside the general contractor’s daily BIM workflow. These conditions delayed hazard localisation and weakened the evidence needed to reconstruct whether an abnormality resulted from wetting, excavation, dewatering, support behaviour, or another activity. Xi’an’s collapsible-loess context increases the importance of timely interpretation, but the management problem itself is the disconnection between monitored change and actionable project context.

4.2.2 Fragmentation of Core-Tube Construction and Quality Status

Ten participants discussed core-tube construction. They consistently described status information as being divided among the BIM model, climbing-formwork records, concrete-pour documentation, surveying results, schedule reports, inspection photographs, and subcontractor files. The design model contained geometry and specification data but did not reliably indicate the current formwork configuration, actual pour sequence, inspection status, or as-built deviation of each floor or component. A quality director (P09) recalled that a 12 mm verticality deviation was identified on Floor 42 after the climbing formwork had already advanced to Floor 44: ‘Because the climbing formwork had already been raised and the concrete pour records for Floors 42–43 were stored in a separate system, it took three days to reconstruct the causal chain.’ The event illustrates a temporal as well as technical mismatch. The physical production system had advanced, while the information needed to interpret an earlier condition remained distributed across systems and teams.

The technical cause was not simply insufficient model detail. More fundamentally, the model was not maintained as a shared representation of construction status. Procedural causes included separate quality, surveying, schedule, and concrete records without a common floor/component identifier or consistent update point. Organisationally, the concrete, climbing-formwork, surveying, BIM, and quality teams reported through different channels. The result was slow defect traceability, increased reconstruction effort, risk of rework, and uncertainty in progress reporting. Participants therefore experienced the core-tube problem as a failure to maintain a coherent construction-state history rather than as a lack of visualisation.

4.2.3 Absence of Integrated Vertical-Transportation Coordination

Eight participants identified vertical transportation as a recurrent production bottleneck. Tower-crane and hoist status, floor-level requests, delivery changes, and schedule priorities were not visible within a common coordination environment. Equipment allocation was commonly organised through morning whiteboards, radio calls, telephone calls, or messaging groups. These arrangements could produce a workable daily plan but were unable to preserve a reliable shared status when priorities changed.

P12 explained: ‘We have two tower cranes and three hoists. Every morning I draw a schedule on the whiteboard. But by 10 a.m., the concrete team says they need an extra lift, the steel team says their truck arrived early, and the MEP team says they have an urgent pipe delivery. I have no real-time view of which crane is doing what, which floor is waiting, and whether the next two hours are already fully booked.’ The problem arose from competing legitimate demands rather than a single scheduling error. Because request status and equipment availability were not shared, each team optimised its own work without seeing the effect on the whole production system.

Technically, equipment-monitoring and project-schedule systems were disconnected. Procedurally, lifting requests lacked a standard format, priority rule, time window, and update mechanism. Organisationally, equipment management, production planning, and specialist trades held different information and incentives. Consequences included waiting, repeated negotiation, inefficient crane and hoist use, and increased exposure when urgent or overloaded operations were inserted into an already constrained plan. The evidence indicates that the principal problem is coordination under changing demand, not

the absence of an optimisation algorithm.

4.2.4 Discontinuity in Work-at-Height Safety Management

All fifteen participants referred to work-at-height risks, and safety personnel and the regulatory inspector provided the most detailed event evidence. Hazard identification, notification, rectification, reinspection, escalation, and closure were not consistently recorded as stages of one management event. Site inspections generated photographs or checklist entries, but notifications were often made verbally or through messaging groups. These communications were fast but did not reliably preserve a unique hazard identity, deadline, responsible party, or closure status.

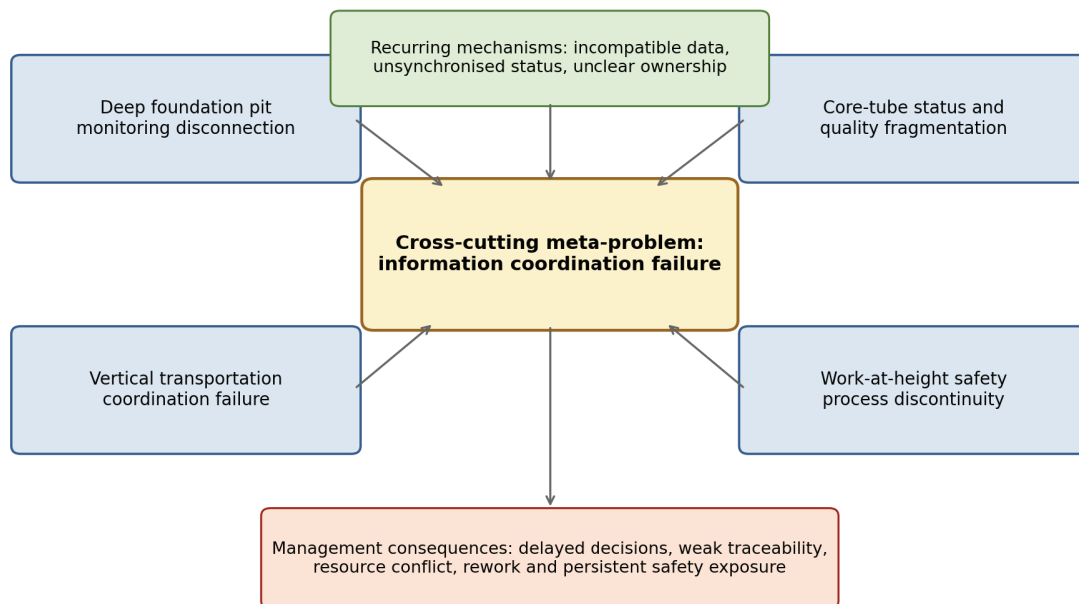
P05 described a recurring situation: ‘I found an unprotected edge on Floor 56, took a photo, and sent it to the subcontractor’s WeChat group. They said, okay, we will fix it. But there is no ticket number, no deadline, no automatic reminder. Three days later, I find the same hazard still there, and the subcontractor says they thought that was a different one.’ This account shows how an observed condition can become disconnected from its location and history even when a photograph and message exist.

Technical causes included the absence of a spatial hazard register connected to floors, zones, current work, and responsible organisations. Procedural causes included variation in inspection formats and incomplete escalation rules. Organisational causes included asymmetric access and uncertainty about who should confirm completion when several trades shared a work area. Consequences were persistent exposure, delayed correction, duplicated inspections, and incomplete evidence for audit or accident investigation. The management discontinuity occurred after detection: the site could identify hazards, but it could not consistently maintain their status through verified closure.

4.3 Cross-Cutting Meta-Problem: Information Coordination Failure

Across all fifteen interviews, the four domain themes were connected by a broader failure of information coordination. Participants did not describe a complete absence of data. On the contrary, projects possessed BIM models, monitoring reports, equipment systems, schedules, quality applications, inspection records, and communication channels. The recurring problem was that these resources did not maintain a shared relationship among physical location, current status, construction activity, responsible party, and management closure.

Figure 2. Integrated Structure of the Identified Management Problems



Source: Developed by the authors from the thematic and cross-case analysis.

P03 summarised the pattern: ‘We have a BIM model, a monitoring system, a schedule system, a quality app, and a safety app. Each one is excellent in its own domain. But they do not talk to each other. So when a problem happens, it exists in the gaps between these systems, and nobody owns it because each department thinks it is the other department’s system that should have caught it.’ This evidence reframes the digitalisation problem. More tools can increase data volume while leaving

managers dependent on manual reconciliation at exactly the moment when rapid cross-role judgement is required.

Four recurring mechanisms formed the meta-problem: duplicate entry of the same event in different formats; unsynchronised status between models, reports, and site reality; isolated systems without stable shared identifiers; and ambiguous ownership when an event crossed departmental or contractual boundaries. These mechanisms intensified the consequences in every domain. In the foundation pit, they delayed spatial interpretation; in the core tube, they broke the construction-state history; in vertical transportation, they prevented shared prioritisation; and in work-at-height safety, they interrupted responsibility and closure. Figure 2 presents this integrated problem structure.

4.4 Problem Boundaries and Divergent Evidence

The four problems were not equally experienced by every role. Participants without direct foundation-pit responsibility sometimes viewed monitoring reports as sufficiently formal, whereas safety and project managers emphasised the delay involved in interpreting them. BIM personnel tended to frame core-tube difficulties as updating and identification problems, while quality personnel emphasised the loss of causal history after the production cycle advanced. Equipment personnel considered informal negotiation unavoidable, but also acknowledged that the current process provided no reliable common status. These differences did not invalidate the themes; they clarified how the same information gap was experienced according to responsibility.

The analysis also avoided treating every inconvenience as a digital-system failure. Some transport conflicts reflected genuine scarcity and changing production priorities that no information system could eliminate. Some safety hazards resulted from inadequate physical protection rather than information discontinuity. The identified problems therefore concern situations in which the management response was delayed, obscured, or left incomplete because information relationships and responsibility chains were fragmented. This boundary is important for later framework development because it prevents digitalisation from being presented as a substitute for engineering control, adequate resources, or managerial judgement.

5. Discussion

5.1 Digital Abundance and Coordination Failure

The central finding is a paradox of digital abundance: the projects contained many digital records and specialised applications, yet practitioners lacked an integrated basis for acting on cross-domain events. This finding is consistent with BIM research showing that model availability does not ensure updated, interoperable, and decision-relevant information (Volk et al., 2014; Love et al., 2014). It also complements digital-twin reviews that distinguish connected physical-digital synchronisation from static or periodically updated representations (Deng et al., 2021; Opoku et al., 2021).

The empirical contribution lies in showing how this limitation appears in management practice. A point code without a spatial object delays foundation-pit interpretation. A geometric model without construction-state history weakens core-tube traceability. Equipment telemetry without shared demand status does not resolve lifting conflict. A safety photograph without an event identity and closure chain does not ensure rectification. Across the cases, information becomes managerially useful only when it is connected to place, time, work activity, status, responsibility, and evidence of closure.

5.2 The Socio-Technical Nature of the Problems

The findings further show that the identified problems cannot be explained solely by software interoperability. Technical, procedural, and organisational causes formed recurring combinations. Missing interfaces required manual transcription; inconsistent identifiers made that transcription difficult to verify; separate reporting lines discouraged routine sharing; and ambiguous ownership left cross-domain events unresolved. This supports the collaboration literature's argument that information technologies operate within inter-organisational arrangements and cannot independently overcome fragmented project structures (Ahuja et al., 2009; Xue et al., 2010).

This socio-technical interpretation is particularly relevant to smart-site research. Technology-led studies often emphasise sensor accuracy, automated recognition, or predictive capability. Those capabilities may be valuable, but the present evidence suggests that more basic coordination failures can prevent their benefits from reaching management practice. For the studied projects, the immediate challenge was often not the prediction of an event, but the reliable connection of an already observed event to the correct location, current activity, responsible party, and verification process.

5.3 Contextual Intensification in Xi'an Super High-Rise Projects

The identified problems combine general mechanisms with context-specific intensification. Information fragmentation is not unique to Xi'an, but collapsible-loess conditions increase the importance of connecting monitoring changes to excavation and water-related activities. Core-tube repetition means that information delays can persist across several production cycles before a deviation is reconstructed. Extreme vertical logistics make transport capacity a shared constraint, while moving hazard zones make location and status essential for work-at-height control. The local and project contexts therefore shape the severity, timing, and consequences of the coordination problem rather than creating a wholly separate digital-management theory.

5.4 Theoretical and Methodological Contributions

Theoretically, the study connects three levels that are often treated separately: domain-specific site problems, cross-cutting information mechanisms, and management consequences. The four domains explain where failures become visible; the meta-problem explains what they share. This distinction avoids reducing all findings to a generic statement that 'information is fragmented' while also avoiding the opposite error of treating safety, quality, logistics, and monitoring as unrelated applications.

Methodologically, the study demonstrates the value of separating problem identification from requirement or artefact design. By requiring evidence of manifestation, cause, and consequence before considering a theme to be a management problem, the analysis reduces the risk of inferring problems from preferred technologies. Cross-role comparison also exposes responsibility interfaces that may be invisible within a single occupational group. The result is a bounded problem diagnosis that can later inform framework development without presenting an unvalidated solution as a finding of the present study.

5.5 Practical Implications

For project organisations, the findings suggest that digital-management reviews should assess information continuity rather than simply count deployed systems. Managers should examine whether abnormal events can be traced across their full history: where they occurred, what activity was underway, which data supported the judgement, who received responsibility, what action was taken, and whether closure was independently verified. This diagnostic perspective can be applied before procurement or development of any new platform.

The results also indicate priority areas for governance. Projects need consistent identifiers for floors, zones, components, monitoring points, equipment, and management events; explicit update responsibilities; and agreed ownership when an issue crosses departments or subcontractors. These are management principles derived from the identified problems, not a functional requirement set. The design and validation of a formal BIM-based smart-site management framework should remain a separate research phase.

5.6 Limitations

Several limitations should be acknowledged. First, the sample was confined to Xi'an and emphasised projects between 200 m and 350 m, so transferability to other cities, geological conditions, procurement systems, or lower-rise projects requires contextual judgement. Second, the study focused on the construction stage and did not examine design-stage coordination or operational asset management. Third, findings were based on practitioner accounts and documentary reconstruction rather than direct longitudinal observation of the reported events. Recall bias and role-specific attribution are therefore possible, although event-focused probing, cross-role comparison, member clarification, and negative-case analysis were used to reduce this risk. Fourth, this paper does not evaluate the prevalence or statistical effect size of the problems. Its purpose is analytical identification and explanation. Finally, no proposed framework or technical solution was validated in this phase; those activities must be reported separately after appropriate design and expert evaluation.

6. Conclusions

This study identified four recurring construction-stage management problems in super high-rise projects in Xi'an: disconnected foundation-pit monitoring information; fragmented core-tube construction and quality status; unintegrated vertical-transportation coordination; and discontinuous work-at-height safety management. Across the four domains, a meta-problem of information coordination failure was manifested through duplicate entry, unsynchronised status, isolated systems,

informal communication, and unclear ownership of events crossing organisational boundaries.

The findings show that the principal challenge is not an absolute lack of data or digital tools. It is the inability to maintain shared relationships among location, time, construction activity, current status, responsible party, and verified closure. Technical, procedural, and organisational causes interact to turn information fragmentation into delayed decisions, weak traceability, inefficient resource coordination, rework, and continued safety exposure. The qualitative, problem-centred approach makes these mechanisms visible and provides a stronger empirical foundation for subsequent research than a technology-first specification.

Future research should use the identified problem structure to develop and validate an appropriate management framework, while preserving the distinction between empirically observed problems and proposed design responses. Comparative studies in other Chinese and international cities could test which mechanisms are transferable and which depend on local geology, regulation, project organisation, or platform maturity. Longitudinal observation and process-log analysis could also measure how frequently the identified failures occur and how strongly they affect safety, quality, schedule, and productivity outcomes.

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