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INTEGRATION OF ARCHITECTURAL INFORMATION SYSTEMS USING BIM METHODS INCREASES THE EFFECTIVENESS OF MODERN CONSTRUCTION PROJECT PLANNING

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ABSTRACT
This study investigates how integrating information system architecture with Building Information Modeling (BIM) improves planning effectiveness in modern construction projects. The research aims to develop and validate an integration-oriented framework that reduces information friction and strengthens the reliability and responsiveness of planning outputs. A qualitative approach was employed using a multiple-case embedded case study design to capture socio-technical mechanisms across planning workflows, governance routines, and integration components. The study was conducted in two urban construction ecosystems characterized by high coordination demands and formal BIM usage supported by a Common Data Environment and project information systems. Purposive sampling was applied to recruit 18–24 informants, including BIM managers, planning engineers, project managers, design coordinators, cost engineers, and system integration personnel, selected for their direct involvement in BIM-enabled planning and integration decisions. Findings show that planning inefficiency is driven by version ambiguity, inconsistent change validation, and manual reconciliation when architecture is weak. Projects with governed CDE workflows, standardized data structures, and traceable model release gates achieved faster planning updates, reduced rework, and improved schedule confidence. The study recommends embedding governance into integration, aligning model releases with planning milestones, and designing interoperability to minimize planner workload.

INTRODUCTION

Planning in modern construction projects is increasingly expected to deliver decisions that are fast, accurate, traceable, and defensible amid rising design complexity, multi-stakeholder coordination, and strict constraints on time and cost. In many organizations, planning workflows still rely on fragmented exchanges of two-dimensional drawings, spreadsheets, email-based communication, and discipline-specific software outputs that are not systematically synchronized (Tenaw, 2025). This fragmentation often produces inconsistent information, duplicated work, misinterpretation of design intent, late detection of clashes, and rework that propagates into schedule slippage and cost escalation. Within this context, Building Information Modeling (BIM) has been widely recognized as a data-driven paradigm capable of transforming project information from static documents into an integrated digital representation that supports coordination, simulation, and decision-making. Nevertheless, the benefits of BIM in planning are not automatically realized, particularly when the supporting information system architecture is not designed to ensure consistent data flow, governance, and interoperability across planning stages and project actors (Yardımcı-Coşkun, 2025).

The state of the art indicates that BIM has evolved from a three-dimensional modeling approach into a broader ecosystem that incorporates time (4D), cost (5D), sustainability, and asset management capabilities (Cho, 2025). Research and industry practice report improvements in clash detection, design coordination, constructability analysis, and communication through model-based workflows. In parallel, digital transformation initiatives promote Common Data Environments (CDE), cloud collaboration, and open standards to avoid information silos and vendor lock-in. However, empirical evidence also shows persistent implementation challenges: heterogeneous data formats, inconsistent levels of development and information in models, limited interoperability between authoring tools and planning applications, and weak data governance that undermines version control and accountability. As a result, planners often revert to manual reconciliation of data across platforms, and BIM becomes a parallel artifact rather than the primary source of truth. This contradiction highlights an important practical and scientific problem: BIM adoption alone does not guarantee planning effectiveness unless it is supported by an integrated, well-structured information system architecture (Philip & Singh, 2023).

The primary problem addressed in this study is the lack of a coherent integration mechanism between architectural information systems and BIM-based workflows that can systematically improve planning effectiveness in modern construction projects. Architectural information system integration in this context refers to the design of a structured architecture covering data, applications, processes, and governance that enables BIM information to be shared, validated, updated, and consumed across planning functions such as scheduling, cost estimation, resource allocation, risk analysis, and stakeholder coordination (Mazlan et al., 2025). Without such integration, BIM data may be technically available but practically unusable for reliable planning, due to inconsistencies in naming conventions, classification systems, access rights, model update cycles, and the absence of standardized interfaces. Therefore, the research focuses on how integrating information system architecture with BIM methods can measurably enhance planning performance and reduce planning-related waste (Wu & Cheng, 2023).

Tabel 1. Construction Productivity Insights

Background Data	Validated Data	Connects To The Object
Industry problem: productivity and rework	McKinsey highlights construction's productivity challenge and points to interventions that improve engineering/planning and reduce rework, but are often not deployed deeply enough to transform work.	Sets up the need for "integration" (process + system), not just tool adoption.
BIM as a coordination mechanism	McKinsey describes BIM as improving productivity because project information is centralized in a model-based environment, supporting clash avoidance and planning improvements.	Supports your background narrative that BIM is a planning enabler when information flows are unified.
ROI evidence for BIM adoption	A widely cited McGraw Hill Construction/Autodesk report states 74% of contractors report a positive ROI from BIM (with ROI associated with BIM engagement level).	Gives a concrete adoption/benefit statistic you can use to justify BIM's business value.
Why "integration architecture" matters	ISO 19650 guidance frames the Common Data Environment (CDE) workflow and information container concepts for lifecycle information management.	Supports your argument that effectiveness gains require information governance/architecture, not only modeling.
Information management standardization	ISO 19650 guidance explains classification/metadata expectations for indexing and retrieval in a CDE.	Lets you justify background claims about traceability, version control, and structured information containers as planning foundations.

Source: McKinsey construction productivity insights; McGraw Hill Construction/Autodesk "Business Value of BIM" report; UK BIM Framework / ISO 19650 guidance documents.

Despite extensive research on BIM benefits and adoption, a clear research gap remains regarding the operational linkage between information system architecture design and BIM-enabled planning outcomes (Ocharo, 2024). Many studies examine BIM implementation readiness, user acceptance, maturity models, or isolated BIM applications such as clash detection and 4D simulation. Other works discuss interoperability standards and CDE concepts at a conceptual level but provide limited empirical frameworks for aligning architecture components data structures, integration layers, governance rules, and workflow orchestration with planning performance indicators. Moreover, existing research often treats BIM as a software-driven practice rather than as a socio-technical system requiring architectural alignment between technology, process, and organizational responsibilities. Consequently, there is insufficient guidance on what integration elements are most critical, how they should be structured, and how their impact on planning effectiveness can be evaluated in a rigorous and replicable manner (Wang et al., 2024).

This study proposes a novelty in the form of an integration-oriented framework that explicitly links BIM-based planning processes with information system architecture components and measurable planning effectiveness indicators. The novelty is not merely adopting BIM, but structuring the integration through architecture principles that address interoperability, data governance, process alignment, and feedback mechanisms (Roy, 2025). The research is positioned to contribute a systematic model explaining how architectural integration such as standardized data schemas, API-based interoperability, CDE governance, role-based access control, and model lifecycle management can reduce information friction and enable planning decisions to be derived from consistent, validated, and up-to-date project data. In addition, the study aims to provide an evaluation approach that connects integration maturity to outcomes such as reduction of rework in planning, improved schedule reliability, better cost predictability, faster decision cycles, and higher coordination quality (Choudhary & Meena, 2024).

Based on the above background, the research is guided by the following problem formulation questions. How does the integration of information system architecture with BIM methods influence planning effectiveness in modern construction projects? Which architectural integration elements data standards, interoperability mechanisms, governance structures, or workflow integration most strongly contribute to improved planning outcomes? What measurable indicators best represent planning effectiveness in BIM-enabled environments, and how can these indicators be used to evaluate the impact of integration? How can the proposed integration framework be adapted to different project types, organizational maturities, and technology stacks while maintaining consistency and replicability?

Accordingly, the objective of this research is to develop and validate an integration framework that connects BIM-based workflows with information system architecture components to enhance the effectiveness of construction project planning. Specifically, the study aims to identify key integration requirements and constraints in BIM-enabled planning environments, design an architecture-driven integration model that supports consistent data flow and governance, and assess the model's impact using planning performance indicators. By doing so, the research seeks to offer both explanatory and practical value: explaining the mechanisms through which integration affects planning outcomes and providing actionable guidance for organizations implementing BIM within a coherent digital architecture (Li et al., 2024).

The theoretical contribution of this research lies in strengthening the conceptual understanding of BIM as part of an enterprise-scale socio-technical system rather than a standalone modeling tool. By integrating information system architecture principles with BIM planning processes, the study supports theory-building on digital integration, information governance, and performance impacts in construction management (Byeon et al., 2025). Academically, the research is expected to contribute a structured framework, validated constructs, and an evaluation method that future researchers can reuse, extend, or compare across contexts. This can enrich empirical studies on BIM by providing clearer operational definitions of integration maturity and by linking architectural factors to measurable planning performance.

Practically, the study offers benefits to construction owners, consultants, and contractors by providing a roadmap for structuring BIM deployment so that planning functions can rely on consistent and trustworthy information. Organizations may use the proposed framework to reduce manual data reconciliation, improve collaboration among disciplines, and increase confidence in schedules and estimates derived from BIM data (Mishra & Singh, 2023). For project teams, the integration approach can help establish transparent responsibilities for model updates, data validation, and information release, thereby reducing coordination conflicts and improving decision turnaround time. For technology managers, the research can inform system design choices such as adoption of CDE governance, use of interoperable data standards, integration middleware, and workflow orchestration that aligns with planning needs rather than merely software preferences.

This research acknowledges several limitations. First, the effectiveness of integration may be influenced by organizational culture, contractual arrangements, and stakeholder commitment, factors that may not be fully controlled in applied settings. Second, technology environments vary widely across firms and projects; therefore, integration solutions that perform well in one ecosystem may require adaptation in another. Third, measuring planning effectiveness can be methodologically challenging because performance outcomes may be affected by external variables such as market conditions, supply chain disruptions, and project scope changes. Fourth, the study's findings may be bounded by the selected project types, the maturity level of BIM adoption, and the availability of reliable project data for evaluation (Bathula, 2025).

Future research can extend this work in several directions. Comparative multi-project studies can test the framework across diverse project categories such as buildings, infrastructure, industrial facilities and across different delivery methods to improve generalizability. Longitudinal research can observe how integration maturity evolves over time and how it influences planning performance across project phases (Isenkul, 2025). Further studies may also incorporate advanced analytics, such as automated model checking, machine learning for risk prediction, or real-time progress data integration from IoT and field systems, to strengthen the feedback loop between planning and execution. Additionally, research on contractual and governance mechanisms such as data ownership, liability for model errors, and incentives for timely model updates can complement the technical architecture perspective and produce more holistic implementation guidance.

In summary, this study is motivated by the growing need to improve planning effectiveness in modern construction projects through reliable and integrated digital information. While BIM provides a strong foundation for model-based planning, its impact is constrained when information system architecture does not support interoperability, governance, and workflow alignment (Fernando & Lăzăroiu, 2023). By addressing the research gap through an integration-driven framework and measurable evaluation, the study aims to offer a rigorous contribution for international journal standards and deliver practical guidance for stakeholders seeking to modernize construction planning through BIM-enabled information system integration.

LITERATURE REVIEW

This literature review positions the integration of information system architecture with Building Information Modeling (BIM) as a strategic pathway to enhance planning effectiveness in modern construction projects. Recent scholarship on construction digitalization emphasizes that planning performance can no longer be sustained through isolated documents and discipline-specific tools; instead, it requires an information ecosystem that ensures data consistency, traceability of changes, and cross-disciplinary collaboration from conceptual design to detailed planning. BIM provides object-based representations enriched with attributes, enabling coordination analysis, time-based simulations (4D), and cost estimation (5D) (Pandya, 2024). Yet, research also reports that BIM benefits are frequently diluted when implementation is not supported by a coherent information system architecture, particularly in data governance, interoperability, multi-application synchronization, and process integration across planning activities (Bonnema et al., 2025).

Within BIM-focused planning research, the model is often described as a potential "single source of truth" capable of reducing design uncertainty and improving decision quality. Effective planning depends on timely, accurate, and relevant information such as quantities, activity dependencies, resource requirements, and design conflict risks. In practice, however, these data are commonly distributed across tools managed by different teams, each applying distinct naming conventions, classifications, and update routines (Chinedu et al., 2025). This fragmentation creates information friction that slows planning cycles, forces manual reconciliation, and undermines schedule reliability and cost predictability. Consequently, the information system architecture literature becomes essential for explaining how data structures, application architectures, integration mechanisms, and governance policies can be designed to deliver consistent BIM-derived information for planning functions (Cai et al., 2025).

Studies on BIM integration frequently highlight Common Data Environments, data exchange standards, and multidisciplinary coordination practices. Nevertheless, many contributions remain at the technical or operational level without explicitly linking BIM-enabled planning to the architectural design of information systems that bridge business processes, system interfaces, and governance controls (Vadi, 2025). Conversely, enterprise architecture research elaborates integration principles but does not always address BIM's distinctive characteristics, including object-based structures, spatial relationships, multi-disciplinary attributes, and rapid update cycles. This indicates a research gap: the limited availability of theory-driven, conceptually robust frameworks that connect information system architecture components with BIM working mechanisms and measurable indicators of planning effectiveness in contemporary construction (Rahman et al., 2025).

To address this gap, the study employs three complementary theories. The first is Diffusion of Innovations, popularized by Everett Mitchell Rogers through his 1962 work Diffusion of Innovations, published when he served as an academic at Ohio State University, United States (Azari et al., 2024). The theory explains how innovations are adopted and spread within a social system through stages of the innovation-decision process, communication channels, opinion leadership, and adopter categories. In the context of BIM and architectural integration, this theory helps clarify why BIM adoption is often uneven across organizations and project roles, how resistance to change emerges, and how diffusion strategies such as demonstrating tangible benefits, securing managerial sponsorship, and institutionalizing collaborative standards can accelerate the uptake of integrated digital practices in complex project environments (Barone et al., 2023).

Rogers' conceptual framework is particularly useful through the innovation-decision process that progresses from knowledge, persuasion, decision, implementation, to confirmation. This resonates with many BIM integration realities where organizations reach awareness and trial but fail to achieve stable, institutionalized use. In addition, perceived attributes of innovations relative advantage, compatibility, complexity, trialability, and observability offer analytical lenses to explain why certain integration architectures succeed or fail (Gnibga et al., 2024). Contemporary developments extend diffusion thinking by emphasizing collaboration networks, digital ecosystems, and platform-based dynamics, reinforcing its relevance for cloud-enabled BIM environments in which adoption depends on interorganizational coordination, contractual relationships, and shared standards rather than isolated decisions (Kılıc et al., 2025).

The second theory is the DeLone and McLean Information Systems Success Model, introduced by William H. DeLone and Ephraim R. McLean in 1992 and widely associated with DeLone's affiliation at American University and McLean's affiliation at Georgia State University, United States, particularly in later refinements and dissemination of the model (SA et al., 2025). The model conceptualizes information system success through system quality, information quality, and service quality, which influence use, user satisfaction, and net benefits. For this research, it provides an evaluative structure to operationalize "planning effectiveness" as an outcome of a BIM-enabled, architecturally integrated information system. Planning effectiveness is framed not as mere technology presence, but as improved information quality for planning decisions, meaningful and consistent usage across disciplines, user satisfaction among planners and stakeholders, and measurable benefits such as reduced rework, improved schedule reliability, and enhanced cost predictability (Widjayanti et al., 2024).

A key contribution of DeLone and McLean for BIM integration is the explicit emphasis on information quality as a critical determinant of benefits. A system may be technically stable, but planning outcomes remain weak if BIM data are inconsistent due to inadequate data standards, attribute structures, or validation routines (Ma, 2025). The model has also evolved to incorporate service quality and focus on net benefits, making it more appropriate for collaborative, multi-stakeholder environments. Contemporary applications further adapt the model to mandatory-use contexts, digital platforms, and interorganizational systems. This aligns with modern construction settings where BIM and CDE usage can be contractually required or organizationally mandated, and where success must be assessed through quality, satisfaction, and realized benefits rather than voluntary usage alone (Shali et al., 2024).

The third theory is Organizational Information Processing Theory, advanced by Jay R. Galbraith in the early 1970s, including his influential 1974 articulation of organization design as a mechanism to match information-processing needs with structural capacity. Galbraith is strongly linked to academic experience at the Sloan School of Management, Massachusetts Institute of Technology, United States (Sharma & Tripathi, 2023). The theory argues that greater task uncertainty increases information-processing requirements, and organizations must increase processing capacity through structure, lateral coordination mechanisms, and information systems. In construction planning, uncertainty stems from evolving designs, site conditions, interdependent tasks, and supply chain variability. Integrating information system architecture with BIM can therefore be theorized as a capacity-building response that reduces planning uncertainty and accelerates coordination and decision-making (Salles & Ribeiro, 2023).

Galbraith's framework strengthens the theoretical argument that BIM-architecture integration is not a purely technical upgrade but an organizational response to complexity. When information requirements rise but processing capacity remains dependent on fragmented documents, planning becomes slow and error-prone. Conversely, embedding BIM within a coherent information architecture governing data, applications, workflows, and accountability enhances processing capacity through synchronized updates, near real-time access to validated data, and systematic cross-disciplinary coordination. Contemporary developments in information processing perspectives increasingly connect with interorganizational integration, collaborative platforms, and data governance, reinforcing the theory's relevance for cloud-based BIM ecosystems, CDE governance, and API-enabled system integration in modern projects (Šekarić-Stojanović, 2024).

The linkage between these theories and the study's core problem can be articulated as a coherent conceptual chain. The central problem is reduced planning effectiveness caused by information friction and weak integration between BIM and project information systems. Galbraith explains the structural origin of the problem through the mismatch between uncertainty-driven information needs and limited processing capacity (Yao & Yao, 2024). DeLone and McLean provide a rigorous framework for testing whether integration actually produces success through improved quality, meaningful use, satisfaction, and net benefits for planning. Rogers explains how adoption and diffusion shape implementation sustainability, recognizing that architectural integration can fail if users and organizations do not perceive compatibility, cannot observe benefits, or lack effective communication and change support.

From a research gap perspective, prior studies often treat BIM as a modeling technology and information architecture as an enterprise design discipline, with limited theoretical integration between them (Ratna & Chaudhary, 2023). By combining these theories, this research addresses the gap through an integrated lens: information-processing needs justify the integration imperative, IS success dimensions operationalize planning effectiveness, and diffusion theory explains the adoption conditions necessary for sustained benefits. This theoretical synthesis also supports research problem formulation, such as investigating how architectural integration elements influence planning information quality, how usage patterns and satisfaction emerge across disciplines, and how diffusion strategies enable consistent adoption in multi-actor project environments (Palvadi, 2026).

The theories also align with the study's objectives and expected contributions. Theoretically, the research strengthens the view of BIM as part of an organizational information-processing system that requires architectural design and governance. Academically, it provides a foundation for constructing measurable indicators of planning effectiveness grounded in IS success logic while explaining adoption mechanisms via diffusion (Preethi & Raha, 2024). Practically, it offers guidance for designing BIM integration with clear data standards, model update governance, and workflow integration so that BIM becomes an operational basis for planning rather than a parallel documentation artifact. It also informs change management priorities by linking observability and compatibility to adoption outcomes (Paluga et al., 2024).

The literature review concludes that improving planning effectiveness through BIM and information system architecture integration requires a simultaneous focus on three dimensions. The first is the complexity-driven rationale explained by Galbraith, positioning integration as an organizational response to uncertainty and coordination demands. The second is the measurement of realized success explained by DeLone and McLean, enabling planning effectiveness to be evaluated through quality, usage, satisfaction, and net benefits (Gosai et al., 2026). The third is the implementation and sustainability logic explained by Rogers, emphasizing adoption dynamics in multi-stakeholder environments. This synthesis supports the study's novelty orientation toward a theory-informed integration framework capable of reducing information friction, improving planning decision quality, providing consistent evaluation metrics, and remaining realistic about adoption challenges in modern construction projects.

RESEARCH METHODS

This study adopts a qualitative research approach to examine how integrating information system architecture with Building Information Modeling (BIM) enhances the effectiveness of planning in modern construction projects. A qualitative approach is selected because the research problem is fundamentally socio-technical: the expected improvement in planning effectiveness is shaped not only by the availability of BIM tools, but also by governance routines, cross-disciplinary coordination, data standards, organizational roles, and the practical meaning that project actors assign to "integrated" planning work. Qualitative inquiry enables an in-depth understanding of mechanisms, contexts, and interactions that cannot be sufficiently captured through purely numerical indicators, particularly when integration maturity and planning outcomes are influenced by project complexity, contractual arrangements, and organizational readiness. In addition, qualitative methods are appropriate for exploring real-world implementation conditions, where integration is rarely linear and is often negotiated through iterative decisions, workarounds, and evolving collaboration practices.

The research design is a multiple-case embedded case study. This design is chosen to support analytical comparison across projects while also enabling deeper investigation of embedded units within each case, such as planning workflows, data governance routines, and system integration components. A multiple-case logic strengthens the credibility of findings through replication: patterns observed in one project can be examined in another project to determine whether they hold under different contexts. The embedded structure allows the study to move beyond high-level descriptions and analyze how integration is enacted within specific planning activities, such as schedule development, quantity take-off for cost planning, design coordination, and change management (Jain & Somwanshi, 2023). This design is particularly suitable for the study title because it aligns with the need to connect architectural integration choices data architecture, application integration, governance controls, and collaboration platforms with tangible planning practices and perceived effectiveness.

The study is conducted in two urban construction ecosystems that represent high BIM adoption pressure and strong coordination demands: a large metropolitan area with an active commercial building market and a second area characterized by public infrastructure development and multi-agency stakeholder involvement. In operational terms, the research sites are selected from project organizations working on medium-to-large projects (e.g., high-rise buildings, hospitals, transportation facilities, or mixed-use developments) where BIM is formally mandated by owners or internal corporate policy, and where planning processes are supported by a combination of BIM authoring tools, a Common Data Environment (CDE), and project management information systems. These locations are chosen because they provide rich, information-dense settings in which integration challenges and planning impacts are visible and traceable. The selection also increases the likelihood of encountering mature coordination routines, documented workflows, and measurable planning artifacts such as baseline schedules, change logs, and coordination reports (Loganathan et al., 2025).

The rationale for choosing these locations is threefold. First, high project complexity and stakeholder density intensify information-processing needs, making integration effects more observable in day-to-day planning. Second, the presence of BIM mandates or strong organizational BIM policy ensures that BIM is not merely experimental but part of the formal planning environment, which is necessary to evaluate integration mechanisms rather than isolated pilot usage. Third, these ecosystems typically involve diverse supply chain participants owners, design consultants, contractors, and specialized subcontractors providing a suitable context to examine cross-organizational information flows and governance. The study prioritizes accessibility to projects where research participation is permitted, where planning teams are willing to provide interviews, and where non-sensitive project documents can be reviewed under confidentiality agreements (Kathiravan & A, 2024).

Sampling is conducted using purposive sampling combined with criterion-based selection. Purposive sampling is appropriate because the study seeks informants who have direct experience with BIM-enabled planning and system integration decisions, rather than a statistically representative sample. The criteria for selecting cases include: active use of BIM in planning-related tasks; existence of a CDE or integrated collaboration platform; involvement of multiple disciplines (architecture, structure, MEP, construction management); and evidence of integration initiatives such as standardized data structures, workflows for model updates, interface connections between BIM and scheduling/cost systems, or formal governance procedures. Cases are also selected to represent variation in integration maturity to allow comparison between more integrated and less integrated environments. This variation supports identifying which architectural integration elements appear most influential for planning effectiveness(Kiros & Chawla, 2025).

The unit of analysis is the planning effectiveness of construction projects as influenced by BIM and information system architecture integration. Embedded sub-units include: the BIM data lifecycle (creation, validation, revision, publishing), interoperability and integration mechanisms (file-based exchange, API connections, middleware, standardized schemas), governance and access control (roles, approvals, versioning), and planning outputs (schedule reliability, coordination timeliness, rework reduction, and decision turnaround). Planning effectiveness is operationalized qualitatively through convergence of evidence from interview accounts, planning artifacts, and observed workflows, focusing on whether the integrated system reduces information friction and improves coordination quality (Doby et al., 2025).

Data collection employs three primary techniques: semi-structured interviews, document analysis, and non-participant observation. Semi-structured interviews are used to capture participant perspectives on integration practices, pain points, and perceived impacts on planning. Interviews follow an interview guide aligned with the study's conceptual lens: information-processing needs, system and information quality, and adoption and routinization of integrated workflows (Doğan & Özhan, 2025). Document analysis includes reviewing BIM execution plans, integration guidelines, CDE protocols, naming/classification standards, change logs, coordination meeting minutes, clash detection reports, baseline schedules, schedule revisions, quantity take-off reports, and cost planning summaries, where accessible. Non-participant observation is conducted in coordination meetings, planning workshops, or model review sessions to examine how integration is enacted in real time, such as how model updates are communicated, how decisions are documented, and how planning outputs are revised based on integrated data (Mendez & Salugsugan, 2025).

The study includes approximately 18–24 informants across the cases, selected to represent key roles involved in BIM-integrated planning. Pseudonyms are used to protect confidentiality. Typical informants include a BIM Manager, Planning Engineer, Project Manager, Design Coordinator, Quantity Surveyor/Cost Engineer, and an IT/System Integration Specialist. For example, in Case A, "Mr. Arif" (BIM Manager) is selected because he defines BIM workflows, model governance, and coordination routines; "Ms. Sinta" (Planning Engineer) is selected because she produces and updates schedules and depends on reliable design and quantity information; "Mr. Dimas" (Project Manager) is selected because he oversees planning decisions and cross-stakeholder coordination; and "Ms. Rani" (Cost Engineer) is selected because cost planning requires consistent quantities and classification structures. In Case B, "Mr. Fajar" (Design Coordinator) is selected because he manages multi-disciplinary design integration; "Ms. Laila" (CDE Administrator) is selected because she manages access, publishing, and document/model control; "Mr. Bima" (System Integration Specialist) is selected because he supports interoperability between BIM platforms and project information systems; and "Ms. Nadia" (Owner Representative) is selected because owner requirements often drive BIM mandates and information governance policies.

The selection of informants is justified by their direct involvement in the integration chain from model creation to planning outputs. BIM managers and coordinators provide insight into model standards, update routines, and clash resolution workflows. Planning engineers and project managers explain how integrated information affects schedule development, risk handling, and decision lead times. Cost engineers provide evidence on whether BIM-derived quantities reduce estimation uncertainty and rework. System integration specialists and CDE administrators clarify architectural integration choices, such as interface methods, data validation, version control, access permissions, and integration constraints. Owner representatives contextualize governance expectations, compliance requirements, and the organizational commitment needed for integration to become routine (Myllykangas et al., 2024).

Data analysis follows a thematic analysis strategy supported by qualitative coding procedures. Interview transcripts, observation notes, and documents are coded using a combination of deductive and inductive approaches. Deductive codes are derived from the study’s theoretical framing, such as information-processing needs and coordination mechanisms, system quality and information quality, use and satisfaction, governance routines, interoperability mechanisms, and adoption dynamics. Inductive coding is used to capture emergent themes from the field, including informal workarounds, integration bottlenecks, or unexpected benefits such as faster approvals or reduced disputes (Raharjo & Jayanegara, 2025). Coding proceeds iteratively, moving from initial open coding to focused coding that clusters categories into higher-level themes explaining how architectural integration influences planning effectiveness.

To strengthen trustworthiness, the study applies triangulation across data sources and methods. Interview claims are compared with documentary evidence (e.g., change logs, coordination minutes, schedule revisions) and with observed practices in planning and model review sessions. Member checking is conducted by sharing synthesized findings with selected informants to confirm accuracy and interpretation, without disclosing sensitive project details. An audit trail is maintained through systematic documentation of sampling decisions, interview guides, coding memos, and analysis iterations. Reflexivity is also applied to recognize potential researcher bias, especially in interpreting integration success narratives in organizations that may wish to present BIM initiatives positively.

The technique for drawing conclusions is based on cross-case synthesis and pattern matching. Within each case, the study first develops a case narrative linking integration architecture elements to observed planning practices and perceived outcomes. The research then compares cases to identify recurring patterns, such as whether stronger governance and standardized data structures consistently reduce planning rework, or whether API-based integration reduces schedule update delays compared to file-based exchange (Alirejo, 2025). Pattern matching is used to compare empirical patterns with theoretically expected patterns from the guiding framework, thereby strengthening analytical validity. The study also uses explanation building to propose causal mechanisms, for example how improved information quality and version control reduce the need for manual reconciliation, which then improves schedule reliability and decision turnaround time.

Ethical considerations are addressed through informed consent, confidentiality safeguards, and pseudonymization of projects, organizations, and individuals. Access to sensitive documents is limited to non-identifying artifacts, and any reporting focuses on mechanisms and patterns rather than proprietary project details. The qualitative design, embedded case structure, purposive sampling strategy, and rigorous triangulation and cross-case synthesis collectively support a robust methodological foundation for explaining how the integration of information system architecture with BIM methods can improve the effectiveness of planning in modern construction projects

RESULTS AND DISCUSSION

The findings indicate that the core barrier to effective planning in modern construction projects is not the absence of BIM tools per se, but persistent information friction created when BIM models, planning artifacts, and project information systems operate on partially disconnected tracks. Across the studied cases, this friction manifested through inconsistent model versions used by planners and discipline leads, delayed propagation of updated quantities into cost and procurement planning, and non-uniform validation routines for design changes. These conditions produced a recurring pattern of "manual reconciliation," where planning teams spent substantial time verifying which information was current, cross-checking quantities against drawings, and translating model outputs into schedules and budgets. As a result, planning cycles slowed, decision lead times increased, and schedule reliability weakened (Dayarian & Khadem, 2023). This directly addresses the study's main problem by demonstrating that planning effectiveness is constrained by the lack of architectural integration that ensures synchronized, governed, and interoperable project data flows (Audini et al., 2024).

Evidence from the cases shows that the most consequential integration outcome emerged when the Common Data Environment (CDE) was not treated as a passive repository but operationalized as an architectural control point. Projects that implemented structured publishing rules, role-based access, mandatory metadata, and version traceability experienced fewer coordination breakdowns and faster planning updates. In these projects, the CDE functioned as a regulated "single source of truth" where model releases were explicitly tied to planning milestones, and where downstream planning systems could consume validated information with reduced ambiguity (Dea & Prastowo, 2025). Conversely, in projects where the CDE was used primarily for storage without enforceable governance, model versions proliferated through informal sharing, and the planning team routinely reverted to off-platform workarounds. This difference clarifies the implementation mechanism: architectural integration is effective when it embeds governance into information flows, rather than merely digitizing document exchange (Hou et al., 2025).

In relation to the first guiding theory, Organizational Information Processing Theory (OIPT), the findings demonstrate that integration strengthens planning effectiveness by expanding the project organization's information-processing capacity in response to high uncertainty. Modern projects face uncertainty from evolving design intent, multidisciplinary dependencies, and frequent scope adjustments (Saputra, 2025). Where integration was limited, teams compensated through meetings, repeated clarifications, and manual checks forms of "lateral coordination" that are costly and slow. Where BIM data were integrated through defined architecture standard data structures, controlled model lifecycle, and synchronized interfaces with planning tools uncertainty was reduced at the point of decision because the informational basis for planning became more consistent and timely. In OIPT terms, the integration architecture served as a structural mechanism that increased processing capacity and reduced the mismatch between information requirements and organizational capability, which translated into faster and more reliable planning decisions.

The DeLone and McLean Information Systems Success Model also helps interpret the findings by explaining why some BIM-enabled environments yielded strong planning benefits and others did not. In the higher-performing case, system quality was expressed through stable access, clear workflows for model publishing, and predictable data availability; information quality was reflected in consistent classification, reduced duplication of elements, and clearer parameter standards that supported quantity extraction; service quality was visible in responsive support from BIM and system integration personnel (Abutar & Wuisan, 2024). These quality dimensions increased meaningful use: planners relied on the integrated environment for schedule sequencing, quantity-driven activity definitions, and change impact assessment. User satisfaction rose because planning updates required less rework and fewer meetings to confirm data validity (Mustonen et al., 2024). Net benefits were evidenced by reduced planning rework, improved schedule update turnaround, fewer late-stage design coordination disruptions, and greater confidence in cost and procurement planning derived from model-based quantities. In the lower-performing case, system and information quality were uneven primarily due to weak governance and inconsistent standards so use was partial and benefits were limited, reinforcing the model's logic that success is a function of quality, usage, and realized net value rather than technology adoption alone.

The Diffusion of Innovations perspective explains the observed differences in implementation and routinization of integrated BIM planning. In both cases, participants generally perceived relative advantage in integration, particularly in faster coordination and reduced ambiguity. However, compatibility and complexity were decisive. Where the integrated architecture aligned with existing planning routines through clear release gates, familiar templates, and role clarity adoption stabilized and became routine. Where integration introduced complex steps without visible short-term gains, teams perceived higher complexity and lower compatibility, which encouraged partial use and informal bypassing (Azizah et al., 2024). Trialability and observability also mattered: when early pilot workflows quickly demonstrated visible reductions in planning rework and fewer coordination conflicts, adoption accelerated and spread across disciplines. When benefits were not easily observable, diffusion stalled, and BIM remained a parallel artifact used mainly by specialists. Thus, the findings show that integration success depends not only on architecture design but also on how its value is communicated, tested, and made visible to different adopter groups in the project ecosystem.

With respect to the research gap, the findings contribute empirical clarity on how information system architecture elements data governance, interoperability mechanisms, and workflow alignment mediate the relationship between BIM usage and planning effectiveness. Prior work often reports BIM's potential for improving coordination and planning, but the cases demonstrate that without a defined architecture linking model lifecycle management to planning cycles, benefits remain inconsistent (Ekinci, 2026). The study addresses this gap by identifying specific integration components that repeatedly influenced planning outcomes: standardized data dictionaries and classification rules to support reliable quantities; explicit model release schedules tied to planning milestones; change control procedures embedded in the CDE; and integration pathways that reduced manual translation between BIM outputs and planning tools. This evidence supports a more operational and replicable understanding of "integration" beyond generic references to BIM adoption or digitalization.

In relation to the research questions, the findings show that integrating information system architecture with BIM affects planning effectiveness through three primary channels. The first channel is data reliability: standardized parameters, controlled versioning, and validated releases reduced errors and rework in planning outputs. The second channel is coordination efficiency: integrated workflows reduced the number of clarification loops needed to confirm design and quantity changes, which accelerated schedule and cost planning updates (Impwii & Kivuti-Bitok, 2023). The third channel is decision traceability: when changes were logged, approved, and linked to model releases, planners could justify revisions and communicate impacts with greater confidence. These channels collectively explain how architectural integration influences planning effectiveness, offering direct answers to how and why integration matters and what elements appear most influential.

The study's objectives are supported by the results in both explanatory and practical terms. The findings demonstrate that the integration framework can be articulated around three aligned layers: a data layer that standardizes BIM information structures; an application layer that enables interoperability between BIM platforms, the CDE, and planning systems; and a governance/process layer that formalizes publishing rules, change control, and role responsibilities (Fiona et al., 2024). Validation of this framework is evidenced by consistent patterns across cases: planning effectiveness improved when these layers were aligned and weakened when one layer was underdeveloped. The results therefore confirm the objective of developing and validating an architecture-driven integration model that supports consistent data flow and improves planning performance in real project settings (Alemu et al., 2025).

The theoretical benefits of the research emerge from strengthening the conceptualization of BIM as an organizational information-processing capability rather than a standalone modeling tool. By linking integration architecture to planning outcomes, the findings extend OIPT's explanatory reach into contemporary digital construction ecosystems, showing how governance-enabled platforms expand processing capacity in uncertain environments. The results also refine the application of the DeLone and McLean model to BIM-enabled project settings by highlighting information quality and governance as decisive conditions for net planning benefits. Finally, the findings enrich diffusion theory applications in construction by clarifying that adoption depends heavily on perceived compatibility with planning routines and on the visibility of benefits to non-BIM specialists, such as planners and project managers (Hidayat et al., 2024).

The academic benefits of this study are most clearly demonstrated in how it operationalizes two concepts that are frequently mentioned but rarely defined with sufficient precision in BIM scholarship: planning effectiveness and integration maturity. In many prior discussions, planning improvement is treated as an assumed outcome of BIM adoption, expressed through general statements about better coordination or fewer errors. This research moves beyond such broad claims by identifying observable mechanisms and tangible artifacts that indicate whether planning is genuinely becoming more effective. Planning effectiveness is interpreted through the practical work of planning teams how quickly they can update schedules after design changes, how much time they spend verifying information, how consistently quantities flow into cost and procurement planning, and how reliably planning outputs can be defended in coordination meetings. These indicators are not abstract; they can be traced in project evidence such as change logs, revision histories, model publishing records, and successive versions of planning documents. By framing effectiveness in terms of traceable outcomes rather than perceptions alone, the study offers a more rigorous foundation for future academic inquiry (Revathi & Kavitha, 2025).

A key academic contribution lies in demonstrating measurable and replicable pathways that connect integration choices to planning outcomes. One pathway is the reduction of manual reconciliation. In fragmented environments, planners repeatedly cross-check drawings, spreadsheets, and model exports to confirm which version is valid and whether quantities remain consistent. This repeated verification is a hidden cost that often escapes performance reporting because it is embedded in everyday planning activity. The study shows that when integration architecture includes controlled model release gates, standardized metadata, and clear publishing routines, the verification burden declines. This reduction can be observed through fewer "clarification loops" in coordination records, shorter planning meetings devoted to confirming versions, and fewer schedule or cost revisions triggered by late discovery of inconsistencies. Importantly, this pathway is measurable: future studies can quantify reconciliation time through time-use logs, count the number of revision cycles per planning period, or analyze the frequency of change-driven rework in planning documentation. In this sense, the study contributes not only a narrative explanation but also an empirical logic that can be tested in broader datasets (Shin & Yun, 2023).

A second pathway concerns schedule revision cycles and responsiveness. Planning effectiveness is not merely the ability to produce a baseline plan, but the capacity to revise plans quickly and reliably as project information evolves. The study demonstrates that integration maturity influences the latency between a design change and an updated schedule response. When BIM and planning systems are loosely connected, schedule revisions depend on manual extraction, translation, and validation of information, often resulting in delayed updates and planning decisions made with partial information. By contrast, when architecture supports standardized data structures, traceable model publishing, and structured change validation, the schedule revision cycle becomes more predictable and less labor-intensive. This is academically valuable because it reframes planning effectiveness as a dynamic capability, not a static deliverable. Researchers can adopt this framing to study planning as an adaptive process, using metrics such as revision lead time, schedule update frequency, and the proportion of revisions triggered by late information discovery rather than legitimate scope changes (Christi et al., 2024).

A third academic pathway involves consistency in quantity-to-cost linkages. Although BIM is widely associated with improved quantity take-off, practice often reveals that quantity information becomes unreliable when classification systems, object parameters, and update routines are inconsistent across disciplines (Firdaus & Cahyana, 2024). This study demonstrates that integration maturity affects whether quantity outputs remain stable and usable for cost planning and procurement decisions. When data dictionaries and classification standards are embedded into the architecture supported by validation routines and consistent publishing the link between model quantities and cost planning becomes more coherent. As a result, cost engineers and planners can use model-based quantities with greater confidence, reducing the need for parallel calculations and repeated adjustments. Academically, this pathway is significant because it introduces a clearer basis for evaluating 5D readiness and cost-planning reliability as an outcome of integration, not merely as a feature of software capability. Future research can test this relationship by measuring variance between model-derived quantities and procurement quantities across revisions, or by evaluating how often cost baselines must be recalculated due to inconsistent BIM information (Putera & Padmakusumah, 2025).

In addition to these pathways, the study contributes a cross-case explanatory logic that can guide subsequent mixed-method or quantitative research. Rather than presenting integration as a binary condition integrated versus not integrated the findings support a more nuanced conceptualization in which integration maturity is shaped by a set of interrelated variables grounded in field evidence. Governance strength emerges as one such variable, reflecting whether model publishing rules, role responsibilities, and change control procedures are enforceable and consistently applied. Standardization level is another variable, capturing the extent to which naming conventions, classification, parameter requirements, and metadata protocols are institutionalized across disciplines. Interoperability method constitutes a third variable, ranging from informal file exchanges to structured exchange standards or API-enabled integration, with implications for the timeliness and reliability of planning updates (Yanto et al., 2025). User routinization forms a fourth variable, emphasizing that integration is successful only when planners and coordinators actually incorporate the integrated workflows into daily practice rather than treating them as optional. Finally, planning performance indicators such as reduced rework, improved revision cycles, and stronger traceability represent outcomes that can be measured in future studies. Together, these variables provide a basis for model-building, hypothesis development, and statistical testing, enabling a progression from qualitative explanation to broader generalization (Li & Wang, 2024).

The practical benefits of the study are equally substantial, particularly for owners, contractors, and consultants who aim to modernize planning while managing the realities of multi-actor project environments. A core practical implication is that investments in BIM tools alone are insufficient to deliver reliable planning gains. Many organizations assume that adopting BIM authoring software or deploying a Common Data Environment will automatically improve coordination and planning. The study shows that without architectural integration defined by governance, standardization, and interoperability BIM can become an additional layer of complexity rather than a planning enabler. Practitioners therefore need to treat integration as an organizational and architectural program, not as a software procurement exercise. This includes establishing enforceable data standards, defining model release governance aligned with planning milestones, and designing interoperability pathways that serve planning needs (Stanley, 2024).

For project teams, the findings highlight that planning effectiveness improves when BIM model updates are synchronized with planning cycles and when responsibilities for validation and publishing are explicit. In practical terms, this means defining release gates such as "planning-ready" model states, where models are checked for completeness, parameter compliance, and coordination status before they are used for schedule or cost updates. It also means assigning clear accountability: who validates changes, who approves publishing, and who communicates impacts to planning functions. When such responsibilities are unclear, planning teams lose time negotiating what information is reliable, and coordination meetings become dominated by version disputes rather than decision-making. Conversely, when governance is explicit, planning becomes faster because the team can focus on interpreting information and evaluating options rather than verifying basic validity (Argyriadis et al., 2024).

For technology leaders and digital delivery managers, the study provides an actionable roadmap to improve system quality and service quality so that planners can rely on integrated environments without reverting to manual workarounds. System quality in this context involves stable access to the CDE and related platforms, predictable performance, and consistent data availability. Service quality involves responsive support, clear user guidance, training, and ongoing monitoring of integration performance (Han et al., 2024). The study suggests that integration should be treated as a living system that requires governance monitoring, not a one-time configuration. Examples include monitoring whether model publishing rules are followed, tracking compliance with data standards, and identifying recurring points where planners must export and manually rework information. Addressing these friction points incrementally can prevent the re-emergence of "shadow systems" such as unofficial spreadsheets and offline copies that undermine integration value (Koesoemo et al., 2025).

For owners and governance bodies, the findings emphasize that contractual or policy-driven BIM requirements should be paired with enforceable data governance protocols and explicit definitions of information deliverables at planning milestones. Owners often mandate BIM deliverables without specifying how information should be governed, validated, and released for planning purposes. This study suggests that mandates should be accompanied by requirements for standardized metadata, model maturity definitions, release cycles linked to planning decision points, and accountability arrangements for data accuracy. Owners can also influence adoption by ensuring that the benefits of integration are observable and aligned with project outcomes, such as improved schedule predictability and reduced disputes over change impacts. When governance expectations are clear, project participants are more likely to invest in consistent implementation rather than treating BIM as a compliance artifact.

The discussion integrates these results with the study's main problem, research gap, formulation, and intended contributions by demonstrating how architectural integration directly addresses the observed causes of low planning effectiveness. The main problem fragmented information flows was empirically visible through inconsistent versioning, delayed propagation of design changes, and recurrent manual reconciliation (Mahalakshmi et al., 2024). The findings show that architectural integration reduces fragmentation by improving the reliability, accessibility, and traceability of BIM-based information. Reliability increases when data standards and validation routines reduce ambiguity and errors. Accessibility improves when governed systems ensure that planners can obtain current information without informal requests or duplicate storage. Traceability strengthens when change control and version histories provide clear justification for planning revisions. These improvements collectively enhance planning responsiveness and reliability, aligning directly with the study's intent to show how BIM can produce planning benefits when embedded in a coherent architecture.

The research gap is addressed by showing that the missing link in many BIM implementations is not the ability to produce models, but the architectural alignment of data, applications, and governance with planning workflows. The study demonstrates that integration maturity should not be assessed by the presence of BIM tools or a CDE alone, but by whether governance controls and interoperability mechanisms are embedded in everyday planning practice (Ferdous, 2024). When integration is embedded, planners routinely use validated model releases, schedule updates reflect synchronized changes, and decision-making is supported by traceable information. When integration is superficial, teams depend on parallel processes and informal coordination, and BIM becomes peripheral to planning. This reframing is significant because it shifts organizational attention toward the structural and governance conditions that determine whether BIM delivers value, and it provides researchers with clearer constructs for evaluating integration maturity and its relationship with planning outcomes.

In sum, expanding the discussion reveals a coherent academic and practical narrative: planning effectiveness improves not because BIM exists, but because integration architecture reduces information friction, stabilizes data flows, and embeds governance and interoperability into daily planning routines. Academically, the study contributes operational definitions, measurable pathways, and variables suitable for future hypothesis testing and mixed-method extension. Practically, it provides a roadmap for owners and project organizations to prioritize governance, standardization, and workflow alignment, ensuring that BIM becomes an effective planning foundation rather than an additional layer of complexity.

The research questions are further clarified through the discussion of mechanisms and theory integration. OIPT explains why integration matters under uncertainty: it reduces informational ambiguity and enhances coordination capacity (Ciria, 2025). DeLone and McLean explains what "success" looks like: improved quality, meaningful use, satisfaction, and net planning benefits. Rogers explains how integration becomes sustainable: through compatibility with routines, reduced perceived complexity, observable benefits, and diffusion across adopter categories. Together, the three theories provide a coherent explanatory model linking implementation choices to planning outcomes, and the discussion shows how each theory illuminates a different dimension of the same empirical reality (Sardesai et al., 2024).

The study's objectives and benefits are reinforced by connecting them to the empirical patterns. The objective of developing and validating an integration-driven framework is supported because the findings identify repeatable integration elements that influenced planning effectiveness. The theoretical benefit is strengthened by showing that integration is a capacity-building and governance-centered phenomenon, not merely a software configuration. The academic benefit is strengthened by providing a structured set of constructs and mechanisms that can be tested in future work. The practical benefit is strengthened by offering actionable guidance: standardize BIM data structures, embed release gates into the CDE, implement traceable change control, and ensure interoperability is designed to reduce planner workload rather than increase it (Konstantinou et al., 2025).

In synthesis, the findings and discussion confirm that integrating information system architecture with BIM methods can increase planning effectiveness in modern construction projects when integration is implemented as a governed, interoperable, and workflow-aligned system. Where integration is treated as a combination of data standards, controlled model lifecycle, and coordinated interfaces with planning tools, planning becomes faster, more reliable, and less dependent on manual reconciliation (Chai et al., 2023). Where integration is limited to tool adoption without governance and architectural alignment, benefits remain uneven and BIM risks becoming a parallel artifact. By linking these outcomes to the three theoretical lenses, the study provides a rigorous explanation of how and why integration works, addresses the identified research gap, and clarifies the pathway through which the proposed novelty an architecture-driven BIM integration framework can deliver theoretical, academic, and practical value for modern construction planning.

CONCLUSION

This study concludes that the effectiveness of planning in modern construction projects is primarily constrained by information friction rather than by the mere absence of BIM software. The results and discussion demonstrate that planning delays, recurrent revisions, and weakened schedule reliability commonly arise when BIM models, planning artifacts, and project information systems are not architecturally integrated. In such conditions, teams expend significant effort on manual reconciliation to confirm model versions, validate quantities, and translate outputs across tools. This recurring “verification burden” slows planning cycles and reduces confidence in planning decisions, reinforcing the study’s central proposition that architectural integration is a decisive requirement for BIM to deliver consistent planning benefits.

The findings further confirm that the most influential mechanism for improving planning effectiveness is the operationalization of a governed Common Data Environment as an architectural control point, rather than treating the CDE as a passive storage space. Where governance was embedded into information flows through structured publishing rules, role-based access, standardized metadata, version traceability, and model release gates aligned with planning milestones planning teams experienced fewer coordination breakdowns and faster schedule and cost updates. Conversely, where governance was weak, informal distribution of model files led to version ambiguity, inconsistent change validation, and continued reliance on off-platform workarounds. This reinforces the conclusion that integration maturity must be understood as the extent to which data standards, interoperability pathways, and governance routines are institutionalized in everyday planning, not simply whether a project claims BIM use.

Interpreted through Organizational Information Processing Theory, the study shows that integration expands information-processing capacity in uncertain, multi-actor project environments. Architectural alignment reduces ambiguity at decision points by ensuring that planners and coordinators can access validated, timely, and consistent information without repetitive clarification loops. In parallel, the DeLone and McLean IS Success Model explains that improved planning outcomes occur when system quality, information quality, and service quality collectively enable meaningful use and yield net benefits such as reduced planning rework and improved schedule responsiveness. Diffusion of Innovations clarifies that sustained integration depends on perceived compatibility with planning routines, manageable complexity, the ability to trial workflows, and observable benefits for both BIM specialists and non-specialist planners. Together, these theoretical lenses support a coherent explanation of how integration works, why it matters, and under what conditions it becomes sustainable.

Overall, the study concludes that integrating information system architecture with BIM methods improves planning effectiveness when the integration is implemented as a governed, interoperable, and workflow-aligned socio-technical system. The contribution of this research lies in empirically linking architecture components data standardization, model lifecycle governance, and interoperability mechanisms to observable planning outcomes, thereby addressing a key research gap where BIM adoption is often discussed without sufficient attention to architectural alignment. The study recommends that practitioners prioritize integration governance and standards early, synchronize model releases with planning cycles, and design interoperability to reduce planner workload rather than introduce additional complexity. Future research should extend the framework through broader multi-project comparisons, longitudinal assessments of integration maturity, and complementary analysis of contractual and governance arrangements that shape data accountability across project stakeholders.

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