Asian Interdisciplinary and Sustainability Review

Original Research Article

Received: 14 October 2025 **Revised:** 21 January 2026 **Accepted:** 22 January 2026

INTEGRATING DATA GOVERNANCE AND HUMAN CAPITAL FOR SUSTAINABLE BIM ADOPTION IN ASIAN MEGAPROJECTS

Kajohnsak CHAOKROMTHONG[1]

1 Faculty of Architecture, Kasem Bundit University, Thailand;
kajohnsak.cha@kbu.ac.th

Handling Editor:
Professor Dr.Muhammad HASEEB VIZJA University, Poland
(This article belongs to Theme 1: Humanities & Social Sciences for Sustainability)

Reviewers:
1) Adjunct Research Professor Dr.Shayut PAVAPANUNKUL UMSi, Indonesia
2) Associate Professor Dr.Sudawan SOMJAI DPU, Thailand
3) Assistant Professor Dr.Siriwan POLSET VRU, Thailand

Abstract

Building Information Modeling (BIM) is increasingly promoted to drive digital transformation and sustainable development in Asia's mega construction projects. Despite the widespread adoption of technical standards such as ISO 19650 and open BIM frameworks, implementation often suffers from fragmented data governance and critical gaps in workforce competencies. This study argues that treating data management and human capital as isolated domains severely limits the long-term effectiveness and sustainability of BIM adoption. Employing a comparative mixed-methods approach—comprising comprehensive policy reviews, semi-structured stakeholder interviews, and targeted professional surveys—this research evaluates institutional readiness and BIM maturity across Singapore, China, and Thailand. The findings highlight that architectural design serves as the crucial entry point for structured project information, yet practitioners often lack the essential data-oriented competencies needed to prevent downstream inefficiencies. To address these systemic challenges, the study proposes the BIM Talent Pipeline Framework, which systematically integrates data governance with human capital development. This framework spans four socio-technical stages: education, certification, industry practice, and continuous development, underpinned by a robust Education-Industry-Government partnership model. Ultimately, sustainable BIM adoption requires aligning technical mandates with institutionalized talent development strategies.

Keywords: Building Information Modeling, Data Governance, Human Capital Development, Architectural Design, Asian Mega Projects

Citation Information: Chaokromthong, K. (2026). Integrating Data Governance and Human Capital for Sustainable BIM Adoption in Asian Megaprojects. *Asian Interdisciplinary and Sustainability Review, 15*(1), Article 8. https://doi.org/10.14456/aisr.2026.8

Introduction

Mega construction projects have become critical drivers of economic development and technological transformation across Asia. Large-scale infrastructure such as high-speed rail systems, airports, ports, and smart city developments increasingly rely on digital coordination mechanisms to manage their complexity, scale, and multi-stakeholder environments. Within this context, Building Information Modeling (BIM) has emerged as a central platform for integrating design, engineering, and construction processes throughout the project lifecycle (Sacks et al., 2018). Beyond visualization, BIM functions as a shared data environment that enables structured information exchange, collaborative workflows, and data-driven decision-making.

In recent years, the adoption of BIM in Asia has been strongly influenced by the diffusion of international standards, particularly ISO 19650, which emphasizes information management principles, and open BIM frameworks such as Industry Foundation Classes (IFC), which aim to enhance interoperability across disciplines and software platforms (Utkucu & Sözer, 2020; Wang et al., 2025). Despite these advancements, empirical evidence consistently shows that BIM implementation in mega projects remains uneven. Common challenges include fragmented governance of the Common Data Environment (CDE), inconsistent data handover across project phases, and limited reuse of as-built information in operations and facility management (Seyis & Ozkan, 2024). These issues indicate that the mere presence of technical standards does not guarantee effective or sustainable BIM adoption.

Parallel to technical and governance challenges, human capital has been identified as a decisive yet underdeveloped dimension of BIM implementation. Previous studies highlight persistent mismatches between industry requirements and workforce competencies, particularly regarding data-centric workflows, information management roles, and collaborative practices (Sierra & Rodboonpha, 2023; Tan et al., 2024). In many Asian contexts, BIM education and training continue to focus on software proficiency rather than on process integration, standard compliance, and lifecycle-oriented information management. As a result, BIM adoption often stagnates at a tool-based level, limiting its systemic value in complex projects.

Architectural design occupies a particularly critical position within this landscape. As the discipline responsible for translating client intent into digital project information, architectural design initiates the data flows that shape downstream engineering, construction, and operational processes. When architectural models are developed without alignment to ISO 19650 information requirements or open BIM standards, inconsistencies and redundancies are propagated throughout the project lifecycle (Sompolgrunk et al., 2024). Conversely, when architects possess competencies in structured data management and interoperability, design models can function as reliable foundations for multidisciplinary collaboration. Despite this central role, the integration of architectural design competencies into BIM governance and workforce development strategies remains underexplored in the literature.

Comparative experiences across the region highlight that the challenges of BIM implementation in Asian megaprojects are intensified by institutional diversity, differing policy environments, and uneven workforce readiness. For instance, while Singapore has institutionalized BIM through regulatory platforms like CORENET X, China continues to face interoperability challenges despite its national standards, and Thailand remains at a fragmented, pilot stage (Sierra & Rodboonpha, 2023). These contrasts reveal that technical mandates alone are insufficient without parallel investments in structured talent development. From a sustainability perspective, this fragmentation undermines project efficiency and weakens the long-term environmental and economic performance of mega construction projects. Despite growing scholarly attention to individual countries, comparative analyses that explicitly examine the interaction between data governance and human capital across these diverse Asian contexts remain limited. Thus, sustainable BIM adoption must be understood as

a socio-technical challenge that demands integrated governance mechanisms and long-term institutional capacity building.

Against this background, a clear research gap emerges. Existing studies tend to address BIM data standards and governance on one hand, and workforce skills and training on the other, with limited effort to integrate these dimensions into a coherent framework. Moreover, the role of architectural design as the crucial entry point of structured project information has received insufficient analytical attention. To address these systemic challenges, this study aims to demonstrate how integrating data governance and human capital development can drive sustainable BIM adoption in Asian megaprojects. By proposing the BIM Talent Pipeline Framework, the research systematically links data management standards with human capital development across four socio-technical stages: Education and Training, Certification and Standards, Industry Practice, and Continuous Development. Using a comparative analysis of Singapore, China, and Thailand, this article illustrates that sustainable BIM adoption requires aligning technical mandates with institutionalized talent development strategies.

Literature Review

Building Information Modeling (BIM) has evolved from a design-oriented visualization tool into a comprehensive information management system that supports collaboration across disciplines and project phases. Central to this transformation are international standards such as ISO 19650, which establish principles for information management throughout the asset lifecycle, alongside open BIM standards like the Industry Foundation Classes (IFC), which aim to address interoperability challenges and reduce vendor lock-in (Utkucu & Sözer, 2020; Wang et al., 2025). Despite these technological advancements, empirical studies indicate that interoperability remains a persistent challenge in complex projects due to customized workflows, inconsistent parameter mappings, and fragmented data responsibilities. A recurring issue identified in the literature is the limited maturity of Common Data Environment (CDE) governance. While CDEs are widely adopted, they often serve as passive file repositories rather than as governed platforms for information validation, authorization, and lifecycle continuity (Seyis & Ozkan, 2024). This fragmentation, particularly evident during transitions from construction to operations, demonstrates that technical standards alone are insufficient without the corresponding organizational structures and competencies to enforce them.

In parallel with advancements in BIM standards, a growing body of research emphasizes human capital as a critical determinant of implementation success, encompassing not only software skills but also competencies in data governance, interdisciplinary coordination, and information management roles (Correa et al., 2025). However, multiple studies report persistent mismatches between industry demands and workforce preparedness, particularly in contexts where BIM adoption is policy-driven rather than organically embedded in professional practice. Higher education and professional training programs in many Asian countries continue to prioritize tool-based instruction, often neglecting process-oriented knowledge such as ISO-aligned workflows and collaborative decision-making. As a result, graduates may possess technical modeling skills but lack the competencies required to manage data quality and lifecycle integration, a gap further exacerbated by limited access to structured certification systems and continuous professional development (CPD), especially among small and medium-sized enterprises (SMEs). Consequently, the literature increasingly recognizes the need for competency frameworks and talent pipelines that align education, certification, and industry practice to prevent BIM from remaining an isolated technological adoption.

Within BIM-enabled workflows, architectural design occupies a unique and influential position. Architects are typically responsible for initiating digital models that encode spatial, functional, and performance-related information, which subsequently informs engineering design, construction planning, and operations. Consequently, deficiencies in architectural BIM

practices can propagate downstream, amplifying coordination problems and data inconsistencies (Sompolgrunk et al., 2024). Several studies highlight that architectural BIM practice remains predominantly tool-centric, with limited emphasis on delivering structured information and on compliance with standards. When design models are developed without alignment to ISO 19650 information requirements or open BIM schemas, they often require extensive rework by engineers or BIM coordinators, undermining efficiency and collaboration. Conversely, when architects are trained to integrate creative design intent with data governance principles, architectural models can function as robust foundations for multidisciplinary coordination. Despite this central role, the literature offers limited analytical focus on architectural design as a knowledge-management function within BIM ecosystems. Most research treats architects as end users of BIM software rather than as custodians of project information quality. This gap points to the need for frameworks that explicitly integrate architectural competencies into broader BIM governance and workforce development strategies.

Furthermore, BIM has been widely associated with sustainable development through its potential to enhance resource efficiency, reduce waste, and support lifecycle-based decision-making; for instance, BIM-enabled coordination contributes to environmental sustainability by minimizing design errors and optimizing material use (Pan et al., 2024). In the Asian context, however, BIM adoption exhibits significant heterogeneity, complicating efforts to achieve these sustainability goals. Singapore represents a mature model with standardized data governance embedded in approval processes. In contrast, China faces interoperability challenges despite national standards, and Thailand remains at an early stage characterized by fragmented guidelines and limited mandates affecting SMEs (Sierra & Rodboonpha, 2023). Comparative studies indicate that these differences reflect broader institutional and human capital conditions, demonstrating that where education, certification, and governance structures are aligned, BIM adoption tends to generate more sustainable outcomes. Despite these insights, existing literature rarely integrates sustainability considerations with analyses of workforce development and data governance in a unified framework.

In summary, while prior research has generated substantial insights into BIM standards, interoperability, and human capital, these dimensions are predominantly examined in isolation. The literature lacks integrative frameworks that explicitly link data governance standards with structured human capital development, particularly concerning the critical role of architectural design. By addressing this theoretical and practical disconnect, this study advances a systemic perspective that bridges technical, organizational, and human-dimensional objectives to support sustainable BIM adoption in Asian megaprojects.

Theoretical Framework and Analytical Approach

This study adopts the BIM Talent Pipeline Framework as its guiding theoretical model to elucidate how sustainable BIM adoption in Asian megaprojects depends on the systematic integration of data governance and human capital. The framework is grounded in the premise that BIM is not merely a technological tool, but a socio-technical system in which technical standards, organizational processes, and workforce competencies must evolve cohesively. By treating data management and human capital not as isolated domains but as an interconnected ecosystem, this framework addresses the root causes of downstream inefficiencies and fragmented project delivery.

The framework conceptualizes BIM capability development as a four-stage pipeline. The first stage, Education and Training, focuses on embedding BIM principles, open standards, and data-oriented design practices into higher education and professional training. This stage establishes foundational competencies beyond software operation, emphasizing information management and interdisciplinary collaboration. The second stage, Certification and Standards, formalizes competencies through professional certification and compliance with

standards, particularly ISO 19650 and open BIM requirements. Certification serves as a quality-assurance mechanism, ensuring that individual skills align with project-level information governance. The third stage, Industry Practice, represents the application of certified competencies within real project environments. At this stage, organizations institutionalize BIM roles, such as information managers and coordinators, and implement governed Common Data Environments (CDEs) to support standardized data workflows across disciplines and project phases. The final stage, Continuous Development, emphasizes lifelong learning and adaptive skill development in response to evolving technologies, such as digital twins and data-driven sustainability analysis. This stage ensures that BIM competencies remain relevant and resilient over time.

Across all stages, the framework positions architectural design as the entry point of structured project information. Architects translate client intent into digital models that shape downstream data flows, making architectural competencies critical to the integrity of the entire pipeline. The framework is further embedded in an Education-Industry-Government (E-I-G) partnership model, in which policy, practice, and education are aligned to support sustainable and scalable BIM adoption.

In essence, the BIM Talent Pipeline Framework provides a structured explanation of how aligning workforce development with data governance standards can enhance the effectiveness, sustainability, and long-term maturity of BIM implementation in Asian mega construction projects.

Research Methodology

This study adopts a comparative mixed-methods research design to examine the interaction between BIM data governance and human capital development in mega construction projects across Asia. The mixed-methods approach enables analysis of both institutional structures, such as policies, standards, and regulatory frameworks, and practitioners' experiences in BIM-enabled projects.

To enable a meaningful cross-country comparison, Singapore, China, and Thailand were purposefully selected as comparative cases representing distinct stages of institutional maturity, regulatory enforcement, and workforce readiness in the Asian BIM landscape. While sharing common characteristics as rapidly developing economies with extensive investments in mega construction projects, their approaches provide contrasting yet complementary insights. Singapore exemplifies a highly regulated and digitally integrated BIM environment; China reflects large-scale, state-led implementation with heterogeneous regional capabilities; and Thailand illustrates an emerging context characterized by pilot-based adoption and limited formal mandates. This targeted variation enables a robust analytical comparison of how different governance structures and human capital conditions shape BIM implementation outcomes, while maintaining contextual comparability regarding project scale, regional dynamics, and sustainability challenges.

Data were collected using three complementary methods: document and policy review, semi-structured interviews, and a targeted professional survey. The document review examined national BIM strategies, regulatory frameworks, and standards related to ISO 19650 adoption, Common Data Environment (CDE) requirements, and workforce development initiatives. This provided a baseline understanding of formal data governance structures in each context. Semi-structured interviews were conducted with academic experts, government representatives, and industry practitioners, including architects, engineers, BIM coordinators, and project managers. Participants were selected through purposive sampling based on their professional roles and experience with BIM-enabled projects, and the interviews explored data management practices, competency requirements, organizational challenges, and perceptions of BIM readiness. Finally, a targeted survey was administered to professionals involved in ongoing or

recent mega construction projects. The survey addressed two main dimensions: BIM data governance practices and human capital development, including training, certification, and access to continuous professional development. Survey results were used to complement interview findings and provide descriptive insights into perceived BIM maturity across contexts.

Qualitative data from documents and interviews were analyzed using thematic analysis to identify recurring patterns related to data governance, human capital development, and organizational practices. Survey data were analyzed descriptively, focusing on frequency distributions and comparative trends rather than inferential statistics. The mixed-methods design enabled triangulation of data sources to strengthen the robustness of cross-country comparisons.

Findings from the three data sources informed the development of the BIM Talent Pipeline Framework through an iterative process that linked empirical observations to concepts identified in the literature review. Four interrelated stages Education and Training, Certification and Standards, Industry Practice, and Continuous Development were identified as critical components of BIM capability development. Architectural design was positioned as the entry point of the pipeline due to its role in initiating structured project information and influencing downstream processes.

To enhance analytical rigor, this study employed a systematic process for integrating data from qualitative and quantitative sources. Findings from document and policy reviews were first used to establish institutional and regulatory baselines for each country. These insights informed the development of interview protocols and survey instruments, ensuring conceptual alignment across data sources. Interview findings were then analyzed thematically and compared with survey results to identify convergent and divergent patterns related to BIM data governance and human capital development.

This integrative approach enabled cross-validation of key observations and reduced the risk of overreliance on a single data source. By triangulating policy documents, practitioner perspectives, and survey responses, the study strengthened the internal consistency and credibility of the comparative analysis. In addition, iterative comparison across cases allowed emerging themes to be refined and contextualized within each national setting, while maintaining analytical coherence across the three countries. This process supported the development of the BIM Talent Pipeline Framework as an empirically grounded and transferable analytical model for examining BIM implementation in complex construction environments.

The study involved human participants through interviews and surveys. Ethical safeguards were implemented, including voluntary participation, informed consent, anonymity, and confidentiality. No personal identifiers were collected, and participants were informed of the study's academic purpose and their right to withdraw at any time. As a comparative study, the limitations include the size of the interview and survey samples and the reliance on self-reported perceptions. To mitigate these constraints, multiple data sources and triangulation were employed to enhance the credibility of the findings.

Research Results

The findings reveal consistent patterns in the interaction between BIM data governance and human capital development across the three Asian megaproject contexts: Singapore, China, and Thailand. Despite varying levels of BIM maturity and institutional readiness, empirical evidence shows that technical mandates and workforce capabilities are fundamentally interdependent drivers of implementation success, not isolated factors. When evaluated through a socio-technical lens, it becomes evident that improvements in data governance structures cannot be sustained without parallel investments in human capital.

Singapore exhibits the highest level of institutional maturity in BIM data governance. Regulatory mechanisms embed BIM requirements into approval and submission processes, resulting in standardized information deliverables and consistent use of governed Common Data Environments (CDEs). Data structures, validation procedures, and information responsibilities are relatively well defined. However, sustaining workforce competencies remains challenging, particularly for small and medium-sized firms with limited access to continuous professional development.

China shows widespread adoption of BIM in public infrastructure projects, driven by national standards and implementation by large state-owned enterprises. Nevertheless, data workflows remain fragmented at interfaces between design, construction, and operation phases. As-built information is frequently incomplete or inconsistently structured, limiting its reuse for facility management. Skill disparities between large urban firms and smaller regional contractors further contribute to uneven implementation outcomes.

Thailand remains at an early stage of BIM institutionalization. The absence of binding national mandates results in project-specific, largely informal BIM practices. CDE usage is primarily limited to file sharing rather than structured information governance, and information requirements vary widely across projects. These conditions result in inconsistent data quality and weak lifecycle integration, particularly in projects involving multiple stakeholders and SMEs.

Across all three contexts, human capital readiness plays a decisive role in shaping BIM implementation outcomes. Workforce competencies are unevenly distributed, and strong technical skills are often not accompanied by adequate understanding of data governance principles, standards compliance, or interdisciplinary coordination. While Singapore offers more structured training and certification pathways, participation varies across organizational scales. In China, large firms benefit from internal training systems, whereas smaller firms lack comparable resources. In Thailand, BIM education and training remain predominantly software-oriented, with limited exposure to ISO aligned workflows and lifecycle-based information management.

A key finding concerns the role of architectural design as the entry point of structured project information. Architects are typically responsible for initiating digital models that inform downstream engineering and construction activities. However, architectural BIM practices frequently prioritize visualization over the delivery of structured data. Where competencies in information requirements, interoperability standards, and data governance are limited, design models often require rework or reinterpretation by other disciplines, reducing coordination efficiency. Projects demonstrating stronger alignment between architectural practice and information standards exhibit smoother interdisciplinary collaboration and higher data reliability.

Comparative analysis highlights several cross-cutting patterns. Technical challenges, including fragmented CDE use, interoperability issues, and inconsistent data handover, are present in all three countries, albeit to varying degrees. These challenges consistently coincide with gaps in workforce competencies, certification uptake, and role definition. The results confirm that improvements in data governance are unlikely to be sustained without parallel investment in human capital development, while training initiatives alone are insufficient without standardized governance frameworks.

The empirical findings directly inform the BIM Talent Pipeline Framework. The four stages Education and Training, Certification and Standards, Industry Practice, and Continuous Development- reflect recurring gaps and alignment points observed across the three cases. Contexts exhibiting stronger alignment across these stages demonstrate higher levels of BIM maturity, data reliability, and collaborative efficiency. Importantly, the pipeline operates as a cyclical process in which feedback from industry practice informs education and training, and

evolving standards necessitate continuous skill development. Architectural design emerges as the critical entry point of this cycle, reinforcing its strategic role in sustaining data quality and long-term BIM effectiveness.

Conclusion and Discussion

Theoretical Implications

This study reinforces the view that sustainable Building Information Modeling (BIM) adoption in mega construction projects operates as a socio-technical system, in which technological standards, organizational structures, and human capabilities are inextricably linked. While prior studies have traditionally treated data governance—such as CDE protocols and interoperability—as technical enablers (Utkucu & Sözer, 2020; Seyis & Ozkan, 2024) separate from workforce competencies, the proposed BIM Talent Pipeline Framework bridges this theoretical divide. By explicitly integrating data governance with human capital development, this perspective aligns with and extends existing conceptualizations of BIM maturity, emphasizing that performance evolves through coordinated organizational progress rather than isolated technological investments (Succar et al., 2012; Succar & Kassem, 2015). Furthermore, by conceptualizing architectural design as a critical knowledge management function rather than mere software execution, the study complements goal-driven perspectives on BIM success (Won & Lee, 2016) and addresses a significant gap in the literature regarding how early-stage data creation dictates lifecycle performance, ensuring that design disciplines are no longer under-theorized.

From a sustainability perspective, the framework also contributes to theoretical discussions on sustainable digital transformation in construction. Previous research has linked BIM adoption to improvements in environmental and lifecycle performance (Pan et al., 2024; Olawumi & Chan, 2019) yet has paid limited attention to the sustainability of organizational capabilities and skills over time. The present findings suggest that sustainable BIM adoption depends not only on data quality and standards, but also on the long-term renewal of human capital. In this sense, the BIM Talent Pipeline Framework bridges BIM adoption theory with sustainability theory by emphasizing capability continuity as a condition for enduring performance gains.

Practical and Policy Implications

At the practical level, the findings indicate that institutionalized roles and governed practices must accompany investments in BIM platforms and standards to generate consistent project outcomes. Organizations that rely on software acquisition without embedding standardized workflows, information responsibilities, and competency requirements are unlikely to achieve meaningful BIM maturity, an observation consistent with goal-driven governance structures (Won & Lee, 2016). Consequently, for educational institutions and professional bodies, the results underscore an urgent need to move beyond software-oriented training toward curricula that emphasize information management, interoperability, and lifecycle thinking. Integrating ISO 19650 principles and open BIM concepts into architectural and engineering education can help align graduate competencies with industry requirements. At the same time, Continuous Professional Development (CPD) must be recognized as an essential component for preparing professionals for emerging domains such as digital twins and data-driven asset management (Sacks et al., 2020).

From a policy perspective, the comparative analysis highlights the importance of coordinated governance frameworks that link regulation, education, and industry practice. Experiences from countries with more mature BIM ecosystems suggest that mandates alone are insufficient without parallel investments in workforce development and institutional capacity. Comparative approaches to assessing national BIM maturity further support the need for policy instruments that align capability development across stakeholders (Patacas et al., 2015). Incentive mechanisms, training subsidies, and public-private partnerships can play a critical role in

enabling SMEs to participate effectively in BIM-enabled project environments. Ultimately, these implications align BIM adoption with broader sustainable development objectives—encompassing environmental efficiency, social capacity building, and economic resilience—demonstrating that embedding BIM within an Education-Industry-Government partnership model provides a practical governance structure for advancing sustainable construction practices in Asia.

Limitations and Directions for Future Research

Several limitations should be acknowledged. First, the empirical data are derived from a limited number of interviews and survey responses across three national contexts. While triangulation was employed to enhance credibility, the findings may not capture the full diversity of BIM practices within each country. Second, reliance on self-reported perceptions introduces the possibility of respondent bias. Further research should extend the proposed BIM Talent Pipeline Framework by examining its applicability within emerging digital construction environments. As BIM increasingly serves as a foundational data platform for Digital Twin systems, data analytics, and artificial intelligence, new competency requirements will emerge for architects and other built environment professionals. Longitudinal studies would be particularly valuable for assessing how sustained investment in education, certification, and governance influences BIM maturity and organizational learning over time. In addition, comparative research involving a broader range of regional and institutional contexts could refine the framework and enhance its transferability beyond the Asian setting. Such research would contribute to a deeper understanding of how integrated data governance and human capital development can support resilient, scalable, and sustainability-oriented construction practices.

Conclusion

This study demonstrates that effective and sustainable BIM adoption in Asian megaprojects fundamentally depends on integrating data governance with human capital development. The proposed BIM Talent Pipeline Framework provides a structured, socio-technical explanation of how aligning education, certification, industry practice, and continuous development can bridge persistent competency gaps and enhance long-term BIM maturity. By positioning architectural design as the crucial entry point of structured project information and embedding the framework within a robust Education-Industry-Government partnership, the study offers both theoretical advancement and actionable policy guidance. Ultimately, the findings suggest that treating data management and human capital as interdependent domains is essential; BIM must be viewed not merely as a digital toolset, but as a strategic, sustainability-oriented capability sustained through people, processes, and robust governance.



Figure 1 The BIM Talent Pipeline Framework: Aligning data governance and human capital through an Education-Industry-Government (E-I-G) partnership model.

References

Correa, S., Turk, Ž., & Dujc, J. (2025). BIM integration in higher education: a global assessment. *Journal of Information Technology in Construction, 30*, 1059-1079.

Olawumi, T., & Chan, D. (2019). Critical success factors for implementing building information modeling and sustainability practices in construction projects: A Delphi survey. *Sustainable Development, 27*(4), 587-602.

Pan, X., Khan, A., Eldin, S., Aslam, F., Rehman, S., & Jameel, M. (2024). BIM adoption in sustainability, energy modelling and implementing using ISO 19650: A review. *Ain Shams Engineering Journal, 15*(1), 102252.

Patacas, J., Dawood, N., Vukovic, V., & Kassem, M. (2015). BIM for facilities management: Evaluating BIM standards in asset register creation and service life planning. *Journal of Information Technology in Construction, 20*, 313-331.

Sacks, R., Brilakis, I., Pikas, E., Xie, H., & Girolami, M. (2020). Construction with digital twin information systems. *Data-Centric Engineering, 1*, e14.

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers* (3rd ed.). New Jersey: John Wiley & Sons.

Seyis, S., & Ozkan, S. (2024). Benefits and challenges of implementing the common data environments in the construction phase of BIM-based projects. *Journal of Construction Engineering and Management, 150*(8). https://doi.org/10.1061/JCEMD4.COENG-14133

Sierra, F., & Rodboonpha, C. (2023). Building information modelling implementation models in Thailand: Drivers, benefits, barriers and lessons learned. *Journal of Construction in Developing Countries, 28*(2), 37-55.

Sompolgrunk, A., Banihashemi, S., Golzad, H., & Nguyen, K. (2024). Strategic alignment of BIM and big data through systematic analysis and model development. *Automation in Construction, 168*(A), 105801.

Succar, B., & Kassem, M. (2015). Macro-BIM adoption: Conceptual structures. *Automation in Construction, 57*, 64-79.

Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. *Architectural Engineering and Design Management, 8*(2), 120-142.

Tan, T., Mills, G., Ma, X., & Papadonikolaki, E. (2024). Adoption challenges of building information modelling (BIM) and off-site construction (OSC) in healthcare construction: are they fellow sufferers?. *Engineering, Construction and Architectural Management, 31*(13), 390-410.

Utkucu, D., & Sözer, H. (2020). Interoperability and data exchange within BIM platform to evaluate building energy performance and indoor comfort. *Automation in Construction, 116*, 103225.

Wang, J., Ma, Y., Li, R., & Zhang, S. (2025). Applications of Building Information Modeling (BIM) and BIM-Related Technologies for Sustainable Risk and Disaster Management in Buildings: A Meta-Analysis (2014-2024). *Buildings, 15*(13), 2289.

Won, J., & Lee, G. (2016). How to tell if a BIM project is successful: A goal-driven approach. *Automation in Construction, 69*, 34-43.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or a claim that its manufacturer may make, is not guaranteed or endorsed by the publisher.

Copyright: © 2026 by the authors. This is a fully open-access article distributed under the terms of the Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0).