RESEARCH IN MANAGEMENT OF TECHNOLOGY AND BUSINESS
e-ISSN: 2773-5044

RMTB

Vol. 6 No. 2 (2025) 906-914
https://publisher.uthm.edu.my/periodicals/index.php/rmtb

Building Information Modelling (BIM) Standardisation for Optimal Urban Infrastructure Asset Management (AM)

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DOI: https://doi.org/10.30880/rmtb.2025.06.02.070

Article Info

Received: 30 September 2025
Accepted: 1 November 2025
Available online: 1 December 2025

Keywords

Building Information Modelling (BIM), Asset Management (AM), Urban infrastructure

Abstract

Building Information Modelling (BIM) has emerged as a revolutionary technology in architecture, engineering, and construction (AEC). It facilitates the creation and management of digital representations of physical and functional characteristics of built environments. BIM has transformed traditional approaches to project design, construction, and maintenance by enabling multi-disciplinary collaboration and fostering efficient decision-making. Particularly in urban infrastructure, which involves complex networks of interconnected systems, BIM offers unparalleled potential for streamlining workflows and optimising resource utilisation. However, the actual value of BIM extends beyond the construction phase; it plays a pivotal role in Asset Management (AM). This involves managing the life cycle of assets, from handover to operation and maintenance, where the quality and structure of BIM data are critical. Despite its immense promise, the integration of BIM into AM has faced challenges, mainly due to inconsistencies in data classification and the lack of standardisation across projects. These issues hinder the effective use of BIM in AM and highlight the pressing need for a standardised information and parameter management framework.

1. Introduction

Urban infrastructure projects, such as transportation networks, utilities, and public buildings, pose unique challenges and opportunities for BIM-AM integration. These projects typically involve numerous stakeholders, large datasets, and dynamic operational requirements, necessitating precise and consistent information management. However, current practices often reveal significant gaps in how BIM data is classified and standardised for AM purposes. Parameters such as asset identification, condition monitoring, and maintenance schedules are frequently defined differently across projects, creating fragmentation in data systems. This lack of uniformity leads to inefficiencies in AM processes as stakeholders struggle to interpret and utilise data effectively. Moreover, the absence of standardised BIM parameters complicates data integration with AM software and systems, limiting the ability to achieve optimal outcomes. Addressing these challenges requires a systematic approach to standardising BIM information and parameters tailored to the needs of urban infrastructure projects.

The growing adoption of international standards such as ISO 19650 further underscores the importance of standardising BIM information. This standard emphasises the need for a Common Data Environment (CDE) to enable collaborative workflows and ensure consistency in data management throughout a project's life cycle. Project teams can improve data interoperability, minimise errors, and enhance decision-making processes by adopting standardised frameworks. In the context of AM, this means establishing clear and consistent parameter definitions that facilitate asset tracking, performance analysis, and lifecycle cost management. For urban infrastructure, the benefits of such standardisation are amplified, as it enables city-wide integration of data, improves operational efficiency, and supports the implementation of smart city initiatives. Furthermore, standardised BIM data can enhance sustainability outcomes by providing accurate and accessible information for energy management, waste reduction, and other environmental objectives.

This research focuses on urban infrastructure as a case study to explore the significance of BIM information standardisation in optimising AM processes. This research aims to identify the benefits of emphasising the standardised BIM information, review the current approach to optimise AM processes, and evaluate its impact on construction phases, including operation and maintenance. In doing so, the research addresses critical questions about bridging the gap between BIM and AM, particularly in complex urban environments. For example, it examines how detailed and standardised BIM information can improve the AM processes by reducing data silos and enabling predictive operation and maintenance strategies. These insights are expected to have far-reaching implications for urban infrastructure projects and the broader adoption of BIM in AM across different sectors.

2. Building Information Modelling for Asset Management (BIM-AM)

BIM has significantly transformed AEC industries by providing comprehensive digital representations of buildings throughout their life cycle. When integrated with AM, BIM extends its utility beyond design and construction into the operational phase, enhancing asset management, maintenance, and space utilisation. This integration, known as BIM-AM, enables stakeholders to access accurate and comprehensive building information, facilitating informed decision-making and efficient facility operations. The integration of BIM into AM offers numerous benefits. By incorporating BIM data into AM processes, asset managers can access detailed information about building components, systems, and spaces, leading to more effective maintenance strategies and resource allocation. This comprehensive data access facilitates proactive maintenance, reducing downtime and extending the lifespan of building assets.

Despite these advantages, the adoption of BIM-AM integration faces several challenges. Dixit et al. (2019) identified 16 issues impeding BIM-AM integration, categorised into four groups: BIM-execution and information management, technological, cost-based, and legal and contractual issues. The study highlighted that the most crucial issue is the lack of AM involvement in project phases when BIM evolves. This lack of early involvement can lead to misaligned objectives and under utilisation of BIM capabilities in AM.

Technological challenges also play a significant role. Hilal et al. (2019) noted that the research hypotheses must be tested for validation. Future works include surveys, and experts' interviews were required for model validation. This indicates a need for further research to develop and validate models that can effectively guide BIM adoption in AM.

Organisational factors, such as resistance to change and lack of training, further complicate BIM-AM integration. A study by Ariffin et al. (2023) emphasised that organisational, process, and technological factors influence the early adoption of BIM-AM integration in the Malaysian construction industry. Addressing these challenges requires a comprehensive approach that includes stakeholder engagement, process re-engineering, and investment in training and development.

In conclusion, while BIM-AM integration is promising to enhance asset management through improved information access and collaboration, several challenges must be addressed to realise its full potential. Early involvement of AM professionals in BIM processes, technological advancements, and organisational change management are critical factors for successful integration. As the industry evolves, ongoing research and practical case studies will be essential to develop effective strategies for overcoming these challenges and maximising the benefits of BIM-AM integration.

2.1 Existing Standards for BIM-AM

The adoption of BIM is governed by a series of standards and protocols designed to promote standardisation, collaborative workflows, and efficient information exchange within a Common Data Environment (CDE) among project stakeholders. The Construction Industry Council (CIC) introduced the initial BIM Protocol in 2013, which was revised in 2018 to support the implementation of BIM Level 2, mandated for all centrally procured projects since 2016 (Gledson & Greenwood, 2017).

The Publicly Available Specifications (PAS) 1192 series was developed to define requirements for levels of detail, information, model definitions, and information exchange protocols in preparation for the government enforcement of BIM implementation. This suite addresses the collaborative production of AEC information. Specifically, PAS 1192-2:2013 and PAS 1192-3:2014 focus on the construction (CAPEX) and operational (OPEX) phases, respectively, outlining Level 2 maturity requirements at each stage. PAS 1192-2:2014 provides a code of practice for the collaborative generation of information to meet employers' information requirements. Similarly, countries like Canada and the USA have developed their AEC protocols and Level of Development (LOD) specifications (Chen & Jupp, 2019). The PAS 1192 standards have since evolved into the international BS EN ISO 19650 series. Parts 1 and 2 have already been published, and additional parts will be forthcoming.

A critical practice for adhering to the ISO 19650 standards and ensuring effective collaboration among project participants is compliance with file naming conventions. While these naming conventions aim to streamline information management, their repetitive nature and the requirement for precise sequences of letters and numbers can render the process complex, time-consuming, and prone to errors. Recent studies have identified significant barriers to BIM adoption, including the steep learning curve, substantial financial investments required for implementation and correct naming in compliance with the standards (Bew and Underwood, 2010; Eadie et al., 2014; Chan et al., 2019; Crowther and Ajayi, 2019). Munianday et al. (2023) highlight that the most significant impediments to BIM adoption are the appraisal of time and finances and the tolerance of changes in approach. Additionally, the high costs associated with BIM software and hardware have been noted as primary challenges in the Malaysian construction industry (Tahir et al., 2017). These challenges underscore the need for comprehensive training and education to facilitate effective BIM implementation.

2.2 Crucial Role of BIM-AM Integration in Urban Areas

An urban area, such as a city or town, functions as a system of systems comprising multiple interconnected subsystems. A *"system of systems"* describes a network of interdependent components that operate collectively to achieve a broader goal while maintaining their functions. These subsystems include land use, transportation, waste management, water resources, energy, infrastructure, and various social, economic, and environmental processes (Walport & Wilson, 2016; Javed et al., 2022). Infrastructure, the backbone of urban functionality, consists of physical and organisational structures necessary for a city, country, or organisation to function efficiently. It is typically categorised based on service provisions, such as transportation (roads, rail, air), energy (electricity, gas, solar, wind), water and waste management (drinking water, wastewater, solid waste), information and communication technologies, and social and cultural services (schools, hospitals, museums, etc.) (Du et al., 2023). As these infrastructure systems support nearly all aspects of daily life, their efficient and sustainable management is critical to mitigating potential risks associated with infrastructure failures, ensuring resilience against social, economic, and environmental disruptions.

One of the key challenges in managing urban infrastructure is its increasing complexity and inter-dependencies (Rinaldi et al., 2001; Buldyrev et al., 2010). Since infrastructure components are highly interconnected, a failure in one system can trigger a cascading effect, leading to widespread disruptions (Buldyrev et al., 2010). Even minor defects or temporary malfunctions might cause significant financial and operational losses. To address these growing challenges, governments worldwide have advocated adopting BIM for efficient infrastructure management. BIM provides a digital framework for representing, storing, managing, and sharing urban assets' physical and functional characteristics in a collaborative environment (Eastman et al., 2011). This data-driven approach enhances decision-making, improves infrastructure resilience, and fosters sustainable urban development.

BIM-AM integration is a comprehensive approach to managing the complexities of urban infrastructures, ensuring efficiency, sustainability, and resilience. Urban environments often deal with space constraints. BIM-AM integration offers precise spatial data, allowing efficient space planning and utilisation. This capability ensures that every square meter is used effectively, accommodating the diverse needs of urban populations. Moreover, this integration can provide a holistic view of a building's lifecycle, accurately forecast operational expenses and facilitate cost-effective maintenance strategies. It makes sense because understanding the total cost of ownership is essential for sustainable urban development. This comprehensive perspective will aid in budget allocation and financial planning, ensuring the long-term viability of urban projects.

Therefore, the integration of BIM with AM is indispensable for the effective management of urban infrastructures. This integration will enhance data centralisation, promote proactive maintenance, optimise space and asset utilisation, manage lifecycle costs, and foster stakeholder collaboration. While challenges exist, strategic planning and investment in training can pave the way for successful implementation. Embracing BIM-AM integration is a critical step toward creating resilient, efficient, and sustainable urban environments.

2.3 Current Approaches to Optimise BIM-AM

Current approaches to optimise BIM-AM include early AM involvement, lean principles, and addressing organisational and technological challenges. Studies highlight the importance of structured implementation, standardised data management, and advanced interoperability solutions. Overcoming adoption barriers through training and process improvement ensures seamless integration. This section explores key strategies for optimising BIM-AM, highlighting research findings and case studies to enhance its efficiency and performance.

Ariffin et al. (2023) emphasise that integrating BIM-AM in the early phase of the BIM project will increase performance, improve collaboration and communication, increase AM business values, and reduce costs and time. By engaging AM professionals from the outset, the BIM model can be tailored to include relevant data and functionalities that support long-term facility operations. This proactive approach ensures that the information necessary for effective AM is embedded during design and construction, facilitating a smoother transition to the operational phase. Therefore, incorporating AM input during the early stages of BIM projects is crucial for successful integration.

Integrating lean concepts into BIM-AM processes aims to enhance efficiency by minimising waste and optimising workflows. In 2013, Codinhoto et al. conducted an exploratory investigation. They found that guidance is necessary for the establishment of the essential steps for the implementation of BIM for AM purposes, such as the identification of key deliverables, the establishment of the level of integration, the definition of the maturity level and the standard BIM protocols. This underscores the importance of a structured implementation plan that defines clear objectives, integration levels, and standardised procedures to guide the BIM-AM integration process. Practical insights from case studies further illustrate effective strategies for BIM-AM optimisation.

A study by Terreno et al. (2019) suggests that BIM-AM implementation can be improved by applying lean concepts in two ways. The first suggestion is through tactical implementation and detailed monitoring and tracking. The second suggestion is to utilise collated information for strategic planning. Implementing lean techniques involves establishing robust information management policies, conducting periodic audits to ensure data quality, and fostering continuous improvement. This structured approach helps in managing the vast amount of data generated. It provides seamless information flow across different stages of a building's lifecycle. As BIM-AM integration continues to evolve, future research should focus on developing quantitative metrics to assess the effectiveness of integration strategies. Terreno et al. (2019) also highlight the need for in-depth examination of sample cases, focusing on organisational strategy, process documentation, established performance measures and process improvement initiatives. Such studies can provide valuable data to inform best practices and drive continuous improvement in BIM-AM processes.

Despite the benefits, several challenges hinder the optimisation of BIM-AM integration. Significant barriers include organisational resistance to change, lack of standardised processes, and technological limitations. Ariffin et al. (2023) suggest that to overcome these challenges, organisations should invest in training and development to build BIM competencies among AM professionals. Establishing clear protocols and standards for data management ensures consistency and reliability. Additionally, leveraging advanced technologies and ensuring the interoperability of BIM and AM systems can facilitate smoother integration.

In conclusion, optimising BIM-AM integration requires a multifaceted approach that includes the early involvement of AM professionals, the application of lean principles, and addressing organisational, process, and technological challenges. By adopting these strategies, stakeholders can enhance collaboration, improve information management, and achieve more efficient asset operations. Ongoing research and practical case studies will be essential to refine these approaches and fully realise the potential of BIM-AM integration.

3. Statement of Issues

This section explains the critical issues underscoring the necessity for BIM information standardisation in AM, drawing insights from recent scholarly literature. As previously mentioned, when integrated with AM, BIM offers significant potential to enhance the efficiency and effectiveness of asset operations. However, BIM's lack of standardised information poses substantial challenges to its seamless integration into AM practices.

One of the primary challenges in integrating BIM with AM is the inconsistency in data formats and structures. Without standardised information protocols, data generated during the design and construction phases may not align with the requirements of AM systems, leading to inefficiencies and potential data loss. Muhammad and Mustapa (2020) highlight that the lack of accurate transmission of building information from the earlier stages of a building project to AM professionals leads to a significant loss in the quality of building information for operational needs. Effective asset management requires comprehensive data that spans the entire lifecycle of a building. Muhammad and Mustapa (2020) also emphasise that information management is a major threat facing AM practice, where multi-disciplinary activities demand extensive information requirements. Nguyen et al. (2024) highlight that, in current BIM project practice, complicated and/or detailed information is often neglected, leading to future problems during the AM phase. Stride et al., (2020) state that the lack of complete and accurate data was the main issue faced by AM professionals, including quantity surveyors (QSs). This was supported by Nguyen et al. (2021), who observed that data extracted directly from the BIM model are insufficient or not detailed enough to facilitate a BIM-based quantity take-off (QTO). Standardising BIM information ensures that data collected during the design and construction phases is structured to support long-term AM needs, enabling more effective lifecycle data management and contributing to the sustainability and efficiency of asset operations.

The absence of standardised BIM information exacerbates the interoperability issues between various software platforms used in AM. Dixit et al. (2019) note that the most crucial issue is the lack of AM involvement in project phases when BIM is evolving, often resulting in data incompatibility. Standardisation efforts, such as adopting the Construction Operations Building Information Exchange (COBie) standard, aim to bridge this gap by providing a consistent framework for data exchange between BIM and AM systems. Implementing such standards enhances interoperability, allowing for seamless data flow and reducing the need for manual data re-entry, which can be time-consuming and error-prone. However, Kelly et al. (2013) stated that COBie does not provide details on what information should be provided.

Without standardised information protocols or guidelines during the early phase of the construction project, there is a heightened risk of data redundancy and inaccuracies within BIM models. Ariffin et al. (2023) emphasise that inconsistent data entry practices and varying levels of detail can lead to duplicated or outdated information, complicating AM tasks such as maintenance scheduling and asset tracking. Standardisation establishes clear data input and maintenance guidelines, ensuring that all stakeholders adhere to the same protocols, thereby enhancing data accuracy and reliability. In 2018, Ngo emphasised that incompatibility with national construction regulations, standard codes and practices leads to BIM-based solution errors and time-consuming operationalisation. This statement is supported by Nguyen et al. (2020c) in their observation. In 2016, Smith stated that a lack of consistent modelling standards would lead to QSs conforming to several approaches. This will have a negative impact, resulting in inconsistencies and inaccuracies during operation and maintenance cost estimation. Luu and Nguyen (2020) highlight a difference between the existing object classifications integrated into BIM platforms and the construction component categorisation used in the measurement method.

When all parties adhere to standardised information protocols, everyone has access to the same accurate and up-to-date data, reducing misunderstandings and facilitating more effective decision-making throughout the building's lifecycle. In 2022, Samsuddin and Zaini have developed a conceptual framework emphasising the importance of standardised information exchange processes. They identified key moderators, including the AM information that needs to be tracked, stakeholders' responsibilities for data provision, equipment information export in COBie format, and import assets data from the COBie spreadsheet into AM systems. Standardising these processes ensures that critical information is accurately captured and transmitted, facilitating more efficient AM practices. Their work justifies that effective information exchange between BIM and AM systems is crucial for successfully implementing BIM in asset operations.

The integration of BIM into AM is often hindered by several challenges, many of which stem from a lack of standardised information. Azmi et al. (2024), in their study, discussed the adoption and impact of BIM towards AM in Malaysia, noting that management and information technology (IT) system improvements are required for the adoption of this technology. Without standardised information, AM professionals may face difficulties in utilising BIM data effectively, leading to underperformance and resistance to adoption. Establishing standardised information protocols can mitigate these challenges by providing a clear framework for data management and utilisation.

The standardisation of BIM information is crucial for effectively integrating BIM into AM. It addresses data inconsistency, interoperability, redundancy, and inaccuracies while enhancing collaboration, lifecycle data management, and technological integration. By establishing and adhering to standardised information protocols, stakeholders can ensure that BIM is a valuable tool in optimising asset operations, improving efficiency, reducing costs, and enhancing asset performance throughout its lifecycle.

4. Research Significance

This research is pivotal for bridging the knowledge gap in BIM-AM integration and fostering improved industry practices. From an academic perspective, the standardisation of BIM information provides a foundation for further research on digital transformation in AM. By establishing clear guidelines, this research enriches the academic discourse by offering a structured approach to BIM-AM integration, addressing gaps in data modelling, exchange protocols, and information retrieval. Also, establishing standardised BIM information enables comparative studies across different regions and industries.

The practical implications of BIM standardisation in AM are far-reaching, impacting asset operations, asset management, and sustainability. One of the most immediate benefits is improved data interoperability. The lack of standardised data formats has been a persistent challenge, leading to inefficiencies in AM systems. This research proposes standardised protocols that enable seamless data exchange between BIM and AM software, reducing reliance on manual data re-entry and minimising errors. Furthermore, standardised BIM information enhances predictive maintenance and operational efficiency. Asset managers often struggle with disorganised data, leading to reactive maintenance approaches rather than proactive strategies. By ensuring structured and accessible data, this research supports implementing predictive maintenance systems, optimising resource allocation and reducing long-term operational costs.

Finally, it also could aid in policy development and industry standardisation. Governments and regulatory bodies increasingly recognise the need for BIM standardisation to ensure consistent data practices across construction and AM sectors. By providing empirical evidence on the benefits of standardised information, this study supports creating policies that drive industry-wide adoption, ultimately improving long-term asset performance.

5. Research Methodology

This research employs qualitative methods as the most suitable approach, as opposed to quantitative and mixed methods. As defined by Ugwu & Eze (2023), qualitative method examines the nature of real-life situations, focusing on their quality, context, or the perspectives from which the date is obtained. The purpose of the qualitative method is to gain a thorough understanding of real-life moments in their natural environment. This research approach relies on the direct experiences of QSs and asset management professionals involved in urban infrastructure AM.

In this research, a qualitative method is employed to identify the asset information required for optimal asset management processes and their impact on operations and maintenance. Based on the research objectives, two types of variables are considered: independent variables and dependent variables. The independent variable refers to the internal and external information required for optimal urban AM, while the dependent variables represent the impact of this information on AM performance.

The expected outcomes from the data collection through interviews and focus group instrumentation are a comprehensive understanding of the specific BIM information requirements necessary for effective urban infrastructure AM. This includes identifying key data attributes such as asset type, location, condition status, maintenance history, and lifecycle stage that stakeholders consider essential for managing infrastructure assets efficiently. The discussions are also expected to reveal common challenges, gaps, and inconsistencies in current BIM practices, as well as suggestions for improving data standardization and interoperability. From these insights, a preliminary list of standardized BIM parameters can be formulated, reflecting stakeholder consensus on what information should be consistently included in BIM models. Additionally, the data will provide contextual understanding of how different roles use BIM data in practice, supporting the development of a user-oriented BIM framework tailored to urban infrastructure needs. Ultimately, these outcomes will guide the creation of a validated, practical, and standardized BIM data structure.

6. Conclusion

Establishing standardised BIM information is a critical research area with substantial contributions to academic knowledge and industry practices. This research advances digital AM methodologies and interdisciplinary studies by addressing theoretical gaps in data standardisation and interoperability. In practice, it enhances operational efficiency, facilitates predictive maintenance, supports sustainability efforts, and informs policy development. Ultimately, this research fosters a more structured, data-driven approach to AM, ensuring that BIM realises its full potential in optimising building lifecycle management.

Acknowledgement

This research study was supported by Sarawak Premier Seat Grant Scheme RJ130000.7352.1R021 and RJ130000.7352.1R034, Universiti Technologi Malaysia (UTM).

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nurul Nasuha Mohd Nor and Norhazren Izatie Mohd;* ***draft manuscript preparation:*** *Nurul Nasuha Mohd Nor and Norhazren Izatie Mohd. All authors reviewed the results and approved the final version of the manuscript.*

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