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The Key Attributes for High-Quality BIM Design Model: A Review

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ABSTRACT

High-quality Building Information Modeling (BIM) design models, developed through collaborative design processes, are essential for the successful delivery of construction projects. Such models support coordination, information exchange and decision-making among project teams. However, poor model quality, including inconsistent elements, conflicting components and missing objects can introduce design errors, disrupt collaboration and delay projects. Despite growing recognition of this problem, the core attributes that define a high-quality BIM design model remain fragmented across the literature and have not been consolidated into a coherent set, which represents a clear research gap. This study addresses that gap by systematically identifying and synthesising the key attributes that characterise high-quality BIM design models in collaborative environments. A systematic literature review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. Peer-reviewed journal articles published in English between 2016 and 2025 were retrieved from the Scopus and Web of Science databases, and 65 articles satisfied the inclusion criteria. The results highlight six key attributes of high-quality BIM design models: coordinated, completeness, consistency, accuracy, synchronised and clarity. Coordinated models integrate multidisciplinary design inputs into a unified representation; completeness ensures that essential elements are included; consistency maintains data alignment across model views; accuracy supports buildability; a synchronised models enables real-time updates across disciplines; and clarity improves the interpretation of model information. By consolidating these attributes into a single structured framework, the study provides a transparent basis for evaluating and improving BIM design model quality and offers practical guidance for BIM professionals, decision-makers and policymakers.

Keywords: Building Information Modeling (BIM); collaborative design; BIM design model; design model attributes; systematic literature review

INTRODUCTION

Building Information Modeling (BIM) has become a transformative force in the construction industry. It has revolutionised the way design information is created, shared, and managed throughout the project lifecycle. By enhancing collaboration, improving workflow efficiency and increasing the precision of design documentation, BIM has elevated the quality of decision-making in construction projects. One of the most influential functions of BIM is its capacity to support collaborative design by integrating multiple stakeholders, such as architects, engineers, and other professionals, to coordinate design activities in a more synchronised and transparent manner (Shafiq 2021). This integrated approach plays a critical role in minimising fragmentation within the design process and supports improved construction performance (Aziz et al. 2024). The extent to which BIM can achieve these benefits is fundamentally dependent on the quality of the models it generates. BIM-based models support early-stage design optimisation by enabling consistent information flow, informed decision-making, and conflict mitigation, thus contributing to improved coordination and downstream project performance (Afzal et al. 2023). As such, BIM model quality is not merely a technical concern but a foundational element in achieving successful collaborative design outcomes (Lee et al. 2023).

The impact of BIM model quality extends beyond virtual environments. It plays a critical role in influencing the effectiveness and efficiency of real-world construction activities. Well-structured BIM models support the delivery of precise and consistent design information, minimising the risk of design inefficiencies (Ni et al. 2025). A structured identification of BIM model quality attributes is essential to align design intent with construction execution, strengthen interdisciplinary coordination and enhance model usability across project phases. Clearly defined benchmarks enable systematic model evaluation, support informed design decisions and reduce the likelihood of costly errors and rework (Cavka et al. 2018; Harris & Alves 2020; Lee et al. 2023). In addition, high-quality BIM models serve as a foundational asset for advanced digital applications, including digital twins, predictive analytics and performance monitoring systems. These applications facilitate early detection of design issues, enable proactive adjustments and support continuous performance improvement throughout the project lifecycle (Moretti et al. 2023; Zhou et al. 2022).

Despite the widespread recognition of BIM's advantages, persistent challenges are frequently attributed to deficiencies in model quality. These include inconsistent design elements, overlapping components, missing objects, fragmented information exchange, inadequate coordination across disciplines, outdated data and ambiguous parameter definitions (Al Hattab & Hamzeh, 2018; Alreshidi et al. 2018; Cann et al. 2022; Chowdhury et al. 2024; Liao et al. 2020; Wang et al. 2023). Consequently, these deficiencies undermine the reliability of the model and can propagate errors throughout the construction process (Martin et al. 2025). Furthermore, fragmented data environments and poorly integrated model content continue to degrade overall model quality and obstruct effective collaboration across disciplines (Doudilim et al. 2021).

Although collaborative design has become an established focus within BIM implementation, the core attributes that define a high-quality BIM design model remain inconsistently defined and are typically examined in isolation or within narrow, project-specific contexts. Few studies consolidate these dispersed quality measures into a coherent and transferable account; as a result, interdisciplinary collaboration is hindered and the reliability and utility of digital models across the project lifecycle are compromised (Cavka et al. 2018; Harris & Alves 2020). Addressing this fragmentation requires a systematic and integrated understanding of BIM model quality attributes.

Building upon this foundation, the present study addresses a central research question: what are the key attributes that define a high-quality BIM design model in collaborative design environments? To answer this question, the study systematically identifies and synthesises these attributes through a systematic literature review guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, thereby consolidating fragmented knowledge into a single coherent set.

The findings contribute to the advancement of BIM research by offering a systematically defined set of design model quality attributes that serve as practical reference points for practitioners, researchers, and policymakers. These attributes not only guide efforts to enhance model reliability and consistency within collaborative design environments but also support the development of standardised evaluation frameworks, promote best practices in model authoring, and foster a shared understanding of quality expectations across interdisciplinary teams.

This paper is structured as follows. The next section presents the background of the study, outlining the context of BIM-based collaborative design, BIM design models and the identified research gap. This is followed by a synthesis of the key attributes that define a high-quality BIM design model. The subsequent section discusses the theoretical and practical implications of these attributes. The discussion integrates the findings with existing literature to emphasise their academic and industry relevance. The paper concludes by summarising the key contributions and limitations of the study and by outlining directions for future research.

BIM-BASED COLLABORATIVE DESIGN

Design plays a pivotal role in the construction projects. It is characterised as an iterative and innovative process, continually adapted to meet the evolving demands of modern construction projects (Zhang et al. 2018). Critically, design decisions are responsible for up to 80% of a building's environmental performance and operational costs (Azari & Abbasabadi 2018). Moreover, the quality of engineering design and the standard of design management directly impact the quality of construction (Jiao & Cao 2023). As construction projects become increasingly complex and sustainability imperatives grow stronger, the design phase must integrate diverse professional expertise to deliver optimal outcomes (Lee et al. 2023). This growing complexity stems not only from the pursuit of environmentally responsible solutions but also from the pressure to deliver high-performing, cost-effective buildings within increasingly constrained timelines and budgets. Traditionally, design coordination has relied on phased workflows involving manual updates

of two-dimensional (2D) drawings, iterative revisions, and extensive deliberations among project participants (Moretti et al. 2023). However, these conventional methods have become insufficient to meet contemporary project demands, often resulting in inefficiencies, miscommunication and inconsistencies across design deliverables (Aziz et al. 2024). Consequently, there is a pressing need to transition toward advanced methodologies that enhance design accuracy, enable real-time data exchange, and ensure seamless interdisciplinary collaboration, thereby strengthening project performance and sustainability outcomes.

Consequently, collaborative design has emerged as a critical approach to address these evolving needs, providing a structured framework for integrating the expertise of multiple professionals, including architects, civil and structural engineers, and mechanical and electrical engineers, within a unified design process. Each discipline contributes its specialised knowledge: architects develop building concepts, produce detailed design documentation and visualise spatial configurations; civil and structural engineers oversee civil planning, structural analysis and design development; while mechanical and electrical engineers focus on the planning and coordination of mechanical, electrical, and plumbing (MEP) systems. This integrated approach enables multidisciplinary teams to work concurrently, fostering synergy and resulting in more efficient, accurate, and optimised building designs (Lee et al. 2023). The evolution of collaborative design has been both empirical and theoretical, with research emphasising the development of concepts, systems, and tools to support cross-disciplinary collaboration (Liu et al. 2017). In this context, advances in digital technologies have been instrumental, enabling the creation of platforms and tools that not only facilitate but also actively enhance the collaborative design process.

In light of these trends, BIM signifies a significant breakthrough, offering a dynamic, data-rich environment where multidisciplinary teams can co-create, visualise, and coordinate design solutions in real time. BIM has emerged as a transformative solution for addressing these challenges, providing a digital framework that enables seamless design integration and decision-making throughout a building's lifecycle (Doukari et al. 2023). BIM serves as a centralised knowledge repository, allowing stakeholders to collaboratively define, modify, and extract geometric and property data within a shared virtual environment (Jiao & Cao, 2023). Unlike traditional design approaches, BIM enhances visualisation, automates information exchange and enables real-time coordination among various disciplines (Zhou et al. 2022). The interoperability and interconnectivity of BIM-driven design processes mitigate conflicts and inconsistencies, reducing design errors and improving overall project efficiency (Ghaffarianhoseini et al. 2017).

Reflecting this transformation, BIM-based collaborative design represents a paradigm shift in how design activities are planned and executed in construction projects. This approach leverages BIM's capability to integrate multidisciplinary design processes into a unified digital environment, ensuring that all project stakeholders work from a single, coherent model (Abbasnejad et al. 2021). Unlike traditional fragmented workflows, BIM-based collaborative design fosters real-time coordination, reducing inconsistencies and rework while improving design quality (Wang et al. 2021). Through enhanced data interoperability, BIM facilitates seamless information sharing, allowing engineers, architects, and other professionals to detect and resolve potential clashes early in the design phase (El Mounla et al. 2023). Moreover, by integrating computational design tools and automation, BIM-based collaborative design enables advanced simulations, such as energy performance analysis, structural integrity assessments and constructability evaluations, further optimising project outcomes (Liu et al. 2023).

Thus, by integrating BIM into design workflows, the construction industry can achieve higher levels of accuracy, efficiency and sustainability, ultimately transforming traditional design paradigms into highly integrated and data-driven processes. As the complexity of construction projects continues to grow, adopting BIM-based collaborative design will be critical in ensuring that design activities remain coordinated, efficient and adaptable to the evolving demands of the industry.

BIM DESIGN MODELS

BIM design models serve as the foundation for effective decision-making in BIM-based construction projects. High-quality BIM models facilitate enhanced visualisation and collaboration during the design phase, ultimately contributing to improved project outcomes (Eastman et al. 2011; Sacks et al. 2018). However, prior research has identified significant challenges in ensuring the reliability and usability of BIM design models, particularly in relation to data quality, interoperability, and alignment with project-specific requirements (Ni et al. 2025).

A major concern in BIM design models is the inconsistency in data completeness and accuracy, which can adversely affect their effectiveness throughout the

project lifecycle (Cann et al. 2022). Errors in modelling, the presence of outdated information, and the inclusion of extraneous data can compromise the functionality of BIM models, leading to inefficiencies during construction and operation phases (Paik et al. 2022). In addition, interoperability challenges persist, as BIM design models often struggle to integrate seamlessly across diverse software platforms and among various project stakeholders (Tuval & Isaac 2022). Such interoperability issues hinder effective data sharing and collaborative workflows, ultimately diminishing the potential benefits of BIM implementation (Ren & Zhang 2021).

Research has further emphasised the need for standardised criteria to ensure the interoperability and maintainability of BIM design models. Solihin et al. (2015) laid the groundwork for defining the key attributes of a high-quality Industry Foundation Classes (IFC) model and developed automated rules to assess model completeness and accuracy. Building upon this foundation, Lee et al. (2019) proposed an evaluation method for BIM data based on varying requirements outlined in Model View Definitions (MVDs). More recently, Li et al. (2025) explored the application of data validation techniques to enhance BIM model quality, underscoring the importance of real-time feedback mechanisms. Collectively, these studies highlight the critical role of quality assurance in improving the reliability and practical utility of BIM design models. However, they tend to address individual quality concerns, such as interoperability, data validation or rule checking, in isolation rather than as part of an integrated account of model quality (Solihin et al. 2015); the attributes that jointly constitute a high-quality model therefore remain fragmented across the literature.

To address the gap in BIM model usability, researchers have proposed systematic quality control mechanisms. Elmualim and Gilder (2014) developed a framework for implementing quality assurance and control during the creation and validation of BIM models. Doukari and Motamedi (2022) further contributed by designing a quality checklist to systematically evaluate BIM models. These initiatives underscore the necessity of establishing rigorous quality control methodologies to enhance the effectiveness of BIM design models across project phases.

Overall, prior research affirms the critical role of high-quality BIM design models in achieving successful project outcomes. Ensuring the reliability, interoperability, and usability of BIM models remains essential for maximising their value within collaborative design environments. Future advancements in automated quality assessment, data validation techniques, and interoperability standards will be instrumental in addressing current challenges and expanding the practical application of BIM design models in the construction industry.

POSITIONING THIS STUDY

A review of the existing literature highlights a significant gap in the evaluation of BIM design model attributes, particularly in defining the characteristics that constitute a high-quality model. Although various studies have examined individual data quality attributes, these investigations are often limited to specific project contexts or focused on isolated technical assessments. As a result, there has been limited emphasis on a more comprehensive and integrated understanding of model attributes that contribute to overall model quality.

To bridge this gap, the present study synthesises the key attributes that define a high-quality BIM design model within collaborative design environments, conceptualising model quality not as a single property but as a multidimensional construct in which several converging attributes jointly determine the fitness of a model for collaborative use. By systematically highlighting and analysing these key attributes, the study enhances the understanding of what constitutes a robust and practically applicable BIM model. This contribution is intended to support both academic inquiry and professional practice by guiding the development of more reliable, efficient and collaboration-oriented BIM models that improve project delivery outcomes in the construction projects.

METHODOLOGY

Despite the increasing adoption of BIM in collaborative design, existing research offers limited insight into the core quality attributes that define high-performing BIM design models. To address this gap, this study employs a systematic literature review (SLR) to identify key attributes that contribute to high-quality BIM models within collaborative design processes. SLR is a well-established research method that facilitates the structured collection, evaluation and synthesis of existing literature, enabling a comprehensive and transparent analysis of the research domain (Tranfield et al. 2003). The structured and replicable nature of the SLR process enhances the reliability of findings, providing a robust foundation for future research. Moreover, SLR supports an evidence-based approach, offering valuable insights for both researchers and practitioners in developing BIM

frameworks that strengthen collaboration and model integrity (Radzi et al. 2024).

To ensure methodological rigor and transparency, this study adopts the PRISMA framework. PRISMA is widely recognised for its structured and analytical approach, enhancing the credibility and reproducibility of systematic reviews (Moher et al. 2009). Its applicability has been extensively demonstrated in built environment research, including studies in BIM adoption and digital design practices (Hellmuth, 2022; Radzi et al. 2024). As illustrated in Figure 1, the review process involved refining an initial dataset of 1400 articles to a final selection of 65 articles, ensuring a focused and high-quality synthesis of relevant literature.

DATABASE SELECTION

The selection of relevant articles was carried out using the Scopus and Web of Science (WoS) databases, which are highly regarded for encompassing influential peer-reviewed journals across various research disciplines (Chadegani et al. 2013). These databases are widely recognised and trusted within the academic community, with their use in systematic literature reviews (SLRs) being well-established and thoroughly documented (Mahmudnia et al. 2022). Utilising these sources ensures the incorporation of high-quality and impactful research throughout the review.

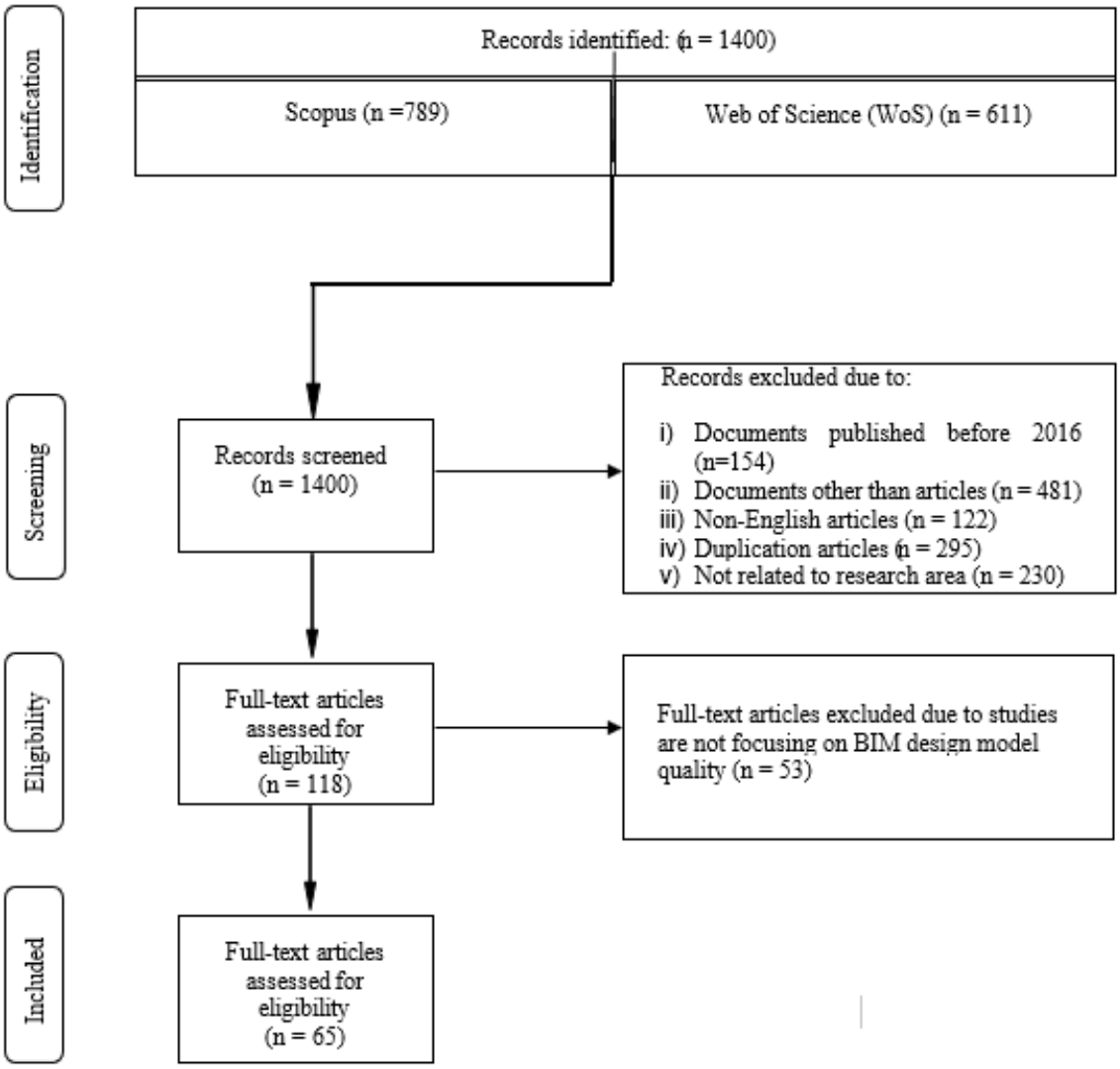


FIGURE 1. The SLR procedure in this study

KEYWORDS AND SEARCH STRING IDENTIFICATION

Following the identification of relevant keywords, a structured desktop search was conducted using the Scopus and Web of Science (WoS) databases. The initial screening revealed a large volume of studies related to BIM design models; however, few specifically addressed the key attributes influencing model quality. To bridge this gap, this study systematically reviewed the literature on collaborative BIM design environments to identify critical attributes associated with BIM design model quality. Accordingly, a combination of keywords and Boolean operators was formulated to refine the search, including terms such as:

((“Building Information Model” OR “BIM”) AND (“design model*” OR “BIM model*” OR “BIM-based model*” OR “BIM design model*”) AND (“qualit*” OR “standard*” OR “grade*” OR “level*” OR “value*”) AND (“attribute*” OR “feature*” OR “characteristic*” OR “propert*” OR “trait*” OR “factor*” OR “dimension*” OR “criterion*”))*

This search strategy ensured the retrieval of studies specifically addressing BIM design model quality within collaborative environments. The search was restricted to articles published between 2016 and 2025 to capture the evolution of BIM research in collaborative design contexts. A ten-year timeframe is commonly used in systematic reviews to reflect recent developments and research trends (Kitchenham, 2004) and is widely adopted in BIM-related reviews to analyse emerging patterns and gaps in collaborative practices (Oraee et al. 2017). Additionally, Wang, K. et al. (2024) demonstrated the relevance of this timeframe by examining a decade of BIM adoption studies, highlighting key influencing factors and contextual variations.

Furthermore, the search was limited to journal articles, as they are regarded as the most reliable and influential sources of academic knowledge (Falagas et al. 2008; Tahamtan et al. 2016). Only English-language publications were included, reflecting the dominance of English in high-impact scientific journals. This initial search yielded 789 articles from Scopus and 611 articles from WoS, which were subsequently analysed during the screening and selection stages of the review process.

SCREENING AND SELECTION

To ensure the inclusion of only relevant articles, a systematic screening and selection process was undertaken. The initial search results were refined by selecting studies that specifically aligned with the literature on BIM-based collaborative design environments. This step was critical in eliminating articles that did not meet the review’s objectives and defined scope (Page et al. 2021). The screening process involved a preliminary evaluation of titles and abstracts to identify studies relevant to the research focus. As a result, 1,282 articles were excluded, and 118 articles advanced to the next stage. Subsequently, a full-text review was conducted to further assess the studies’ alignment with the research objectives. Following the full-text review, 53 of the 118 articles were excluded for not meeting the eligibility criteria, leaving 65 articles that were identified as valid for detailed analysis. These figures reconcile with the PRISMA flow diagram in Figure 1: of the 1,400 records initially identified (789 from Scopus and 611 from Web of Science), 1,282 were excluded during title and abstract screening, and 53 of the remaining 118 full-text articles were subsequently excluded, yielding the final set of 65 included studies. The final number of included articles is consistent with similar systematic literature reviews (SLRs) employing comparable methodologies. For instance, Kharvari and Kaiser (2022) reviewed 21 articles in their SLR on the impact of extended reality on architectural education and the design process, while Mahmudnia et al. (2022) analysed 34 articles in their SLR on blockchain applications in construction management. By adopting this thorough and structured screening approach, the study ensured the selection of high-quality articles that provide valuable insights into BIM-based collaborative design environments, thereby reinforcing the robustness and reliability of the findings.

DATA EXTRACTION AND SYNTHESIS

Following the screening and selection stage, the 65 included articles underwent a structured data extraction and synthesis process. Each article was read in full, and information on the characteristics, requirements and quality of BIM design models was recorded in a standardised data-extraction form. Recurring descriptions of what constitutes a well-developed BIM design model were coded inductively, and related codes were grouped into broader categories. Through iterative comparison and refinement, these categories converged into a set of attributes characterising the quality of BIM design models, which are presented and defined in the Results and Discussion sections. The number of included studies emphasising each attribute was also recorded to indicate its relative emphasis in the literature. To enhance reliability, coding decisions were reviewed iteratively by the authors, and any disagreement over how to classify a quality concern was resolved through discussion until consensus was reached.

TABLE 1. Journal titles of the selected articles

Journal Title	Number of Articles
Automation in Construction	13
Buildings	9
Journal of Building Engineering	4
Architectural Engineering and Design Management	3
Journal of Computing in Civil Engineering	3
Journal of Construction Engineering and Management	2
Journal of Information Technology in Construction	2
Sustainability	2
Smart and Sustainable Built Environment	2
Construction Innovation	2
Applied Sciences	2
Engineering, Construction and Architectural Management	1
Construction Management and Economics	1
International Journal of Managing Projects in Business	1
Journal of Engineering and Applied Science	1
Engineering Management in Production and Services	1
Advanced Engineering Informatics	1
Journal of Cleaner Production	1
Journal of Architectural Engineering	1
International Journal of Project Management	1
Canadian Journal of Civil Engineering	1
Computer Supported Cooperative Work	1
International Journal of Construction Management	1
International Review of Applied Sciences and Engineering	1
Building and Environment	1
The Open Construction and Building Technology Journal	1
Land Use Policy	1
International Journal of System Assurance Engineering and Management	1
Facilities	1
Simulation	1
Inventions	1
Evolutionary Intelligence	1

RESULTS

ARTICLES DISTRIBUTION

Table 1 presents an overview of the journal distribution for the articles included in this review. A total of 65 articles were analysed, covering 33 distinct journals. The journal contributing the most articles is *Automation in Construction* with 13 articles, followed by *Buildings* (9 articles), *Journal of Building Engineering* (4 articles), and *Architectural Engineering and Design Management* as well as *Journal of Computing in Civil Engineering* (3 articles each). Other notable journals such as *Journal of Construction Engineering and Management*, *Journal of Information Technology in Construction*, *Sustainability*, *Smart and Sustainable Built Environment*, *Construction Innovation* and *Applied Sciences* provided two articles each. The remaining journals included in this review each contributed a single article. This distribution offers useful insights into prominent journals that actively publish research on BIM-based collaborative design, guiding researchers in identifying reputable publication avenues for future studies.

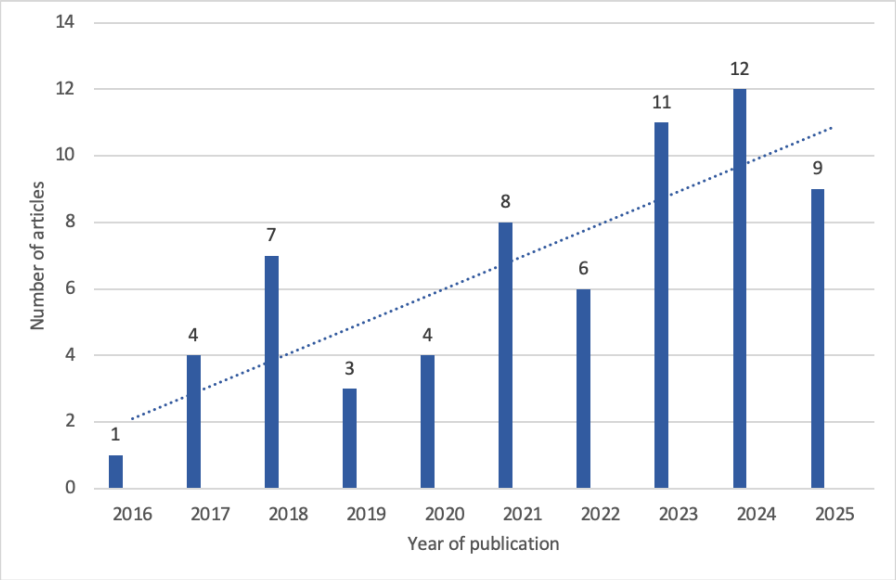


FIGURE 2. Publication year for the selected articles

ARTICLES BY YEAR

This study reviewed sixty-five peer-reviewed articles published between 2016 and early 2025 that examine the attributes of BIM model quality within BIM-based collaborative design in construction projects. As depicted in Figure 2, the publication trend demonstrates a steady increase over time, reflecting growing scholarly and professional engagement with this research area. Beginning with a single publication in 2016, the annual volume of studies increased progressively, with no fewer than three articles published each subsequent year. A notable rise in output began in 2021, culminating in a peak of 12 publications in 2024, the highest recorded during the review period. This upward trend reflects sustained scholarly efforts to define the key attributes essential for the development of high-quality BIM models within collaborative design practices. Although a slight decline was noted in early 2025, with nine articles identified, this output remains considerable given that the literature search concluded in the first quarter of the year. This growth coincides with the wider digital transformation of the construction sector and the increasing reliance on remote, model-based collaboration in recent years, which together have intensified scholarly attention to the quality of shared BIM design models. Overall, this trend is consistent with the patterns observed by Adekunle et al. (2021) and Rinchen et al. (2024) concerning the implementation of BIM within the construction industry.

CO-OCCURRENCE OF KEYWORDS

To contextualise the development of research on high-quality BIM design models, a keyword co-occurrence analysis was conducted using VOSviewer based on the selected literature. As shown in Figure 3, "building information modeling" appears as the most frequent and centrally positioned term, confirming its pivotal role in shaping the discourse.

The surrounding terms reveal several key thematic directions. Keywords such as "industry foundation classes" and "design BIM" emphasise the technical basis of BIM, particularly the role of standardised data formats in enabling seamless information exchange across platforms. Terms like "3D model", "data quality" and "digital twins" reflect growing attention to the performance and reliability of digital models. Meanwhile, "collaboration", "interoperability" and "construction" point to the organisational dimensions of BIM implementation, while "collaborative design" and "design management" highlight the importance of structured coordination in design stages.

Although these themes are well represented, the distribution of keywords indicates a fragmented approach to defining model quality. While issues of integration and collaboration are widely addressed, few studies offer a unified perspective on the attributes that constitute a high-quality BIM design model. This reinforces the need for a structured synthesis, as undertaken in this study.

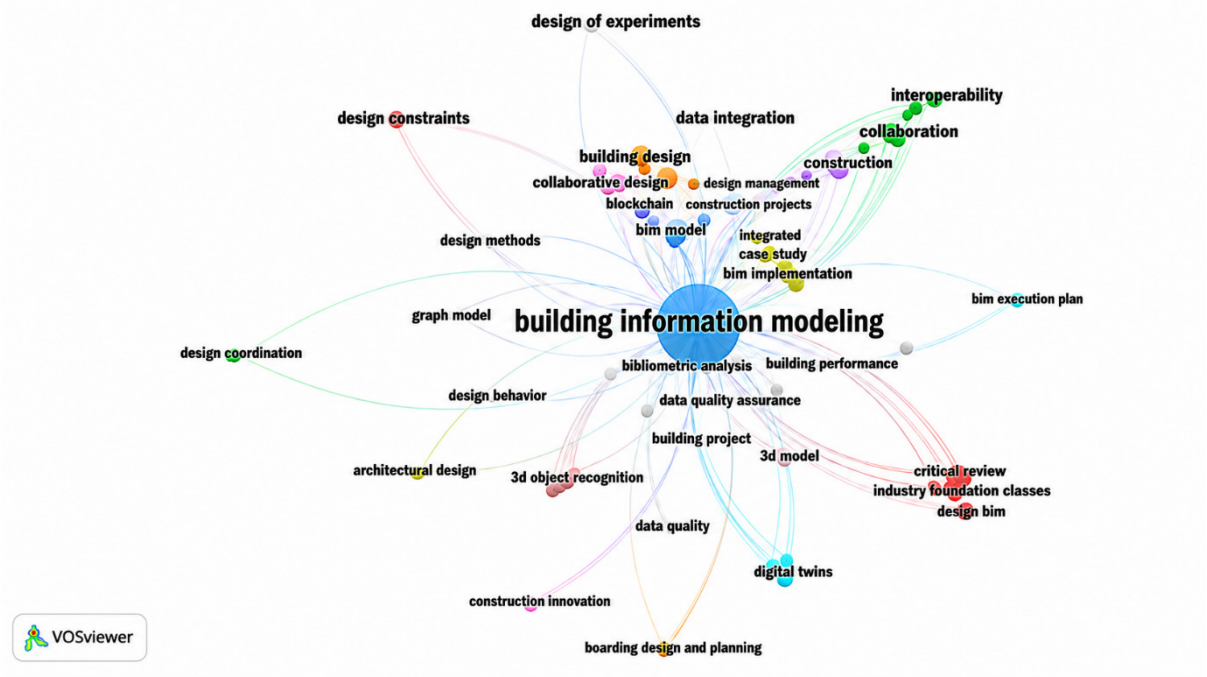


FIGURE 3. Keywords co-occurrence mapping

DISCUSSION

High-quality BIM design models are increasingly recognised as critical to collaboration, decision-making and risk reduction in construction projects. As BIM shifts from a design-centric tool to a multidisciplinary coordination platform, the robustness of digital models has become central to project success (Wang & Chen 2023). Synthesising the selected literature, this study identifies six key attributes of a high-quality BIM design model: coordinated, completeness, consistency, accuracy, synchronised and clarity (Table 2). As shown in Figure 4, coordinated is the most frequently emphasised attribute, reflecting its role in integrating multidisciplinary inputs and minimising conflicts, whereas clarity is the least mentioned yet remains essential for model readability and stakeholder collaboration. Building on this, the study presents a structured set of attributes for a high-quality BIM design model (Figure 5). These attributes provide a practical basis for assessing and improving model quality, supporting interdisciplinary collaboration and more efficient delivery of BIM-based projects. They also align with established BIM standards: coordinated, consistent and synchronised information reflects the information-management principles of ISO 19650, which emphasise structured exchange within a common data environment (ISO, 2018), while completeness and accuracy correspond to model checking and validation against open schemas such as the Industry Foundation Classes (IFC) (Solihin et al. 2015).

Table 2. Summary of key attributes identified in the selected articles

Authors	Key Attributes					
	Accuracy	Coordinated	Completeness	Synchronised	Clarity	Consistency
Zech et al. (2025)	/	/	/	/		
Ni et al. (2025)	/	/	/			/
Martin et al. (2025)	/	/	/			/
Li et al. (2025)		/	/	/		/
Zhang et al. (2025)	/	/		/	/	/
Pogorelskiy & Kocsis (2025)	/	/	/	/		/

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Zhang (2025)	/	/	/	/		/
Xia et al. (2025)	/	/	/	/		/
Zhu et al. (2025)	/	/	/		/	/
Disney et al. (2024)	/	/	/			/
Liu et al. (2024)		/	/	/		/
Rogage & Doukari (2024)	/	/	/	/		/
de Marco et al. (2024)	/	/	/	/		/
Shim et al. (2024)	/	/	/			/
Li et al. (2024)	/	/	/	/		/
Valinejadshoubi et al. (2024)		/	/	/	/	/
Xiang et al. (2024)	/	/	/	/		/
Wang, Z. et al. (2024)	/	/	/			
Chowdhury et al. (2024)	/	/	/	/		/
Aziz et al. (2024)	/	/	/	/		/
Alavi et al. (2024)	/	/	/	/		/
Zhou et al. (2023)	/	/				/
Liu et al. (2023)		/	/	/		/
El Mounla et al. (2023)		/	/		/	/
Alwee et al. (2023)		/	/	/		
Wang et al. (2023)	/	/				/
Wang & Chen (2023)	/	/	/	/		/
Lee et al. (2023)		/	/	/	/	/
Sampaio et al. (2023)	/	/				/
Sun et al. (2023)		/	/	/	/	/
Arayici et al. (2023)	/	/	/			/
Afzal et al. (2023)	/	/	/	/		/
Llatas et al. (2022	/	/	/			/
Paik et al. (2022)	/	/	/	/		/
Zahedi et al. (2022)	/	/	/	/		/
Wang et al. (2022)	/	/	/			
Cann et al. (2022)	/	/	/	/		
Xiao & Bhola (2022)	/	/	/	/		/
Jasiński (2021)		/	/	/		/
Shafiq (2021)	/	/	/	/		/
Qiu et al. (2021)	/	/	/			/
Abrishami et al. (2021)	/	/	/		/	/
Zhuang et al. (2021)	/	/	/	/		/
Tao et al. (2021)	/	/	/			/
Herrera et al. (2021)	/	/	/		/	/
He et al. (2021)		/	/	/		/
Mehrbod et al. (2020)	/	/	/	/		/
Aibinu & Papadonikolaki (2020)	/	/	/	/		
Liao et al. (2020)	/	/	/	/		
Hamidavi et al. (2020)	/	/	/	/		/

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Lai et al. (2019)	/	/	/	/		/
Paavola & Miettinen (2019)		/	/		/	/
Koseoglu et al. (2019)	/	/	/	/		/
Al Hattab & Hamzeh (2018)		/	/	/		/
Almuntaser et al. (2018)	/	/	/	/		
Mattern & König (2018)		/	/	/		/
Pärn et al. (2018)	/	/		/	/	/
Schlueter & Geyer (2018)	/	/	/		/	/
Liu et al. (2018)		/	/	/		/
Jung et al. (2018)	/	/	/			/
Li et al. (2017)		/	/	/		/
Donato (2017)	/	/	/	/		/
Sackey & Akotia (2017)	/	/	/	/		/
Liu et al. (2017)		/	/	/		/
Gledson (2016)		/	/			

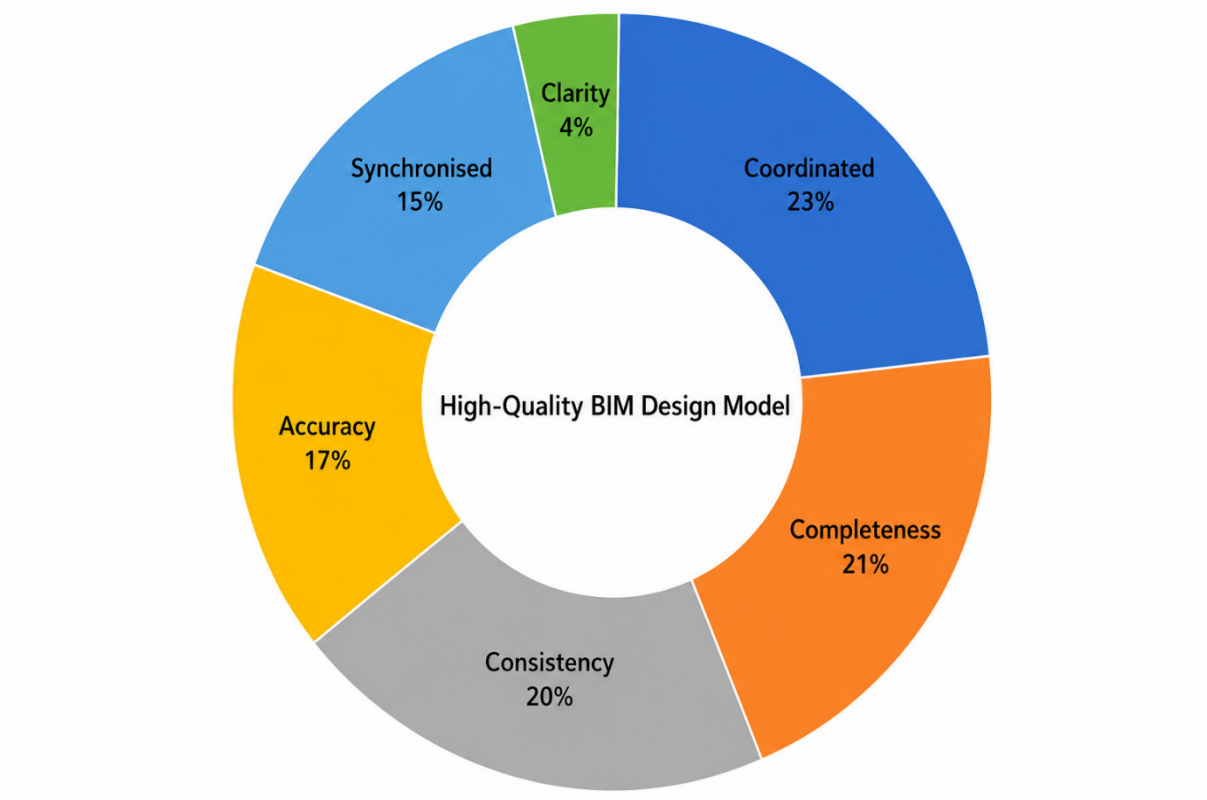


FIGURE 4. Frequency of attributes identified from the selected articles

COORDINATED

Coordinated refers to the seamless integration of architectural, structural and MEP components within a unified, conflict-free digital environment. A well-coordinated BIM model facilitates interdisciplinary collaboration, enables systematic clash detection, and improves constructability by aligning design inputs across project teams and technical domains (Aziz et al. 2024; Chowdhury et al. 2024; Shafiq, 2021; Tao et al. 2021). A coordinated model not only mitigates spatial and semantic

conflicts but also strengthens engagement among participants, enabling informed decision-making throughout design, procurement, and scheduling phases (Aibinu & Papadonikolaki 2020; Al Hattab & Hamzeh 2018; Cann et al. 2022; Disney et al. 2024).

Achieving a coordinated model typically involves federating discipline-specific models, resolving clashes through iterative detection processes, reviewing shared components, and validating geometric and data consistency (Afzal et al. 2023; Chowdhury et al. 2024; Shafiq 2021). The implementation of a Common Data Environment (CDE) supports these efforts by offering centralised access, version control, and traceability. This ensures that all disciplines work with synchronised and current information (Disney et al. 2024; Liu et al. 2023; Tao et al. 2021; Valinejadshoubi et al. 2024). In large-scale or distributed projects, CDEs are particularly valuable for minimising fragmentation and promoting digital transparency (Donato 2017; Mehrbod et al. 2020).

Despite these developments, producing a fully coordinated model remains operationally challenging. Issues such as unresolved interferences, redundant modelling, and disjointed spatial configurations frequently result from inconsistent modelling standards, communication breakdowns and a lack of interoperability enforcement among teams (Afzal et al. 2023; Aziz et al. 2024; Llatas et al. 2022). These shortcomings often lead to rework, scheduling delays, cost overruns, and reduced construction reliability (Cann et al. 2022; Hamidavi et al. 2020; Martin et al. 2025).

The role of a BIM coordinator is central to achieving a coordinated model. This individual is responsible for managing model integration, applying clash detection consistently, and harmonising modelling conventions and data structures across disciplines (Afzal et al. 2023; Liu et al. 2017; Mehrbod et al. 2020). Active engagement of consultants during review cycle further supports the coordinated development of models by bridging disciplinary gaps and preserving design intent (Llatas et al. 2022; Paik et al. 2022; Tao et al. 2021).



FIGURE 5. A structured set of key attributes for high-quality BIM design model

Technological advancements also support coordinated modelling through automation. Tools such as rule-based clash detection engines, AI-powered model validators, and model federation platforms provide real-time integration checks and enable continuous feedback across collaborative environments (Cann et al. 2022; Chowdhury et al. 2024; Valinejadshoubi et al. 2024). These systems reduce manual effort and streamline workflows among contributors (Liu et al. 2023; Zhang, 2025). In complex or lean-oriented delivery contexts, automated processes are essential for maintaining a constructible and coordinated digital model (El Mounla et al. 2023; Gledson 2016; Shafiq 2021).

Ultimately, a coordinated BIM model enhances information flow, minimises friction among disciplines, and facilitates seamless progression from design to construction. Sustained emphasis on the coordinated attribute throughout the project lifecycle contributes to improved spatial efficiency, reduced project risks and the achievement of high-quality outcomes. The coordinated nature of BIM reinforces its role as an integrative and collaborative platform for modern construction project execution (Afzal et al. 2023; Aibinu & Papadonikolaki, 2020; Aziz et al. 2024; Llatas et al. 2022; Tao et al. 2021).

COMPLETENESS

Completeness refers to the comprehensive inclusion of essential design data within a BIM model, including geometric elements, spatial relationships, material specifications, and metadata relevant to construction, operation, and maintenance (Llatas et al. 2022; Rogage & Doukari, 2024). A complete model enables coordinated decision-making, supports accurate quantity take-offs and 2D documentation, and provides a foundation for advanced applications such as simulation, digital twin integration, and facility management (Chowdhury et al. 2024; Donato 2017; Shafiq 2021).

In contrast, incomplete BIM models can impede collaboration, introduce design ambiguity, and limit their applicability for downstream processes. Common deficiencies include the absence of key elements, undefined material attributes, and omitted spatial constraints, all of which are critical for constructability, performance analysis, and regulatory compliance (Ni et al. 2025; Qiu et al. 2021). These issues frequently arise due to limited modelling expertise, ambiguous information requirements, insufficient Level of Detail (LOD), and constraints related to time or available resources during the design phase (He et al. 2021; Jasiński, 2021).

Incompleteness also undermines the effectiveness of integrated digital tools, particularly those reliant on structured data, such as AI-based systems. Missing spatial data or unassigned parameters can disrupt real-time monitoring processes and diminish the reliability of automated construction workflows (Chowdhury et al. 2024; Valinejadshoubi et al. 2024). As emphasised by Paik et al. (2022), fully populated models are essential for supporting accurate simulation and avoiding rework in later project stages.

To mitigate these challenges, the adoption of standardised modelling protocols is essential. LOD specifications, predefined data templates, and curated object libraries offer clear guidance for achieving completeness across project stages (Aziz et al. 2024; Gledson, 2016; Lai et al. 2019). Additionally, structured BIM Execution Plans (BEPs) and Model Element Tables (METs) provide formal mechanisms for defining modelling responsibilities and information requirements (Afzal et al. 2023). In practice, the use of regular audits, structured validation checklists, and point cloud comparisons has proven effective in identifying missing data prior to model finalisation (Herrera et al. 2021).

Recent technological developments further support model completeness through automation. Rule-based validation engines, machine learning algorithms, and semantic reasoning tools are increasingly used to detect and infer missing components based on established domain patterns (Li et al. 2025; Ni et al. 2025; Zahedi et al. 2022). These intelligent systems reduce the need for manual verification, expand data coverage and contribute to improved model reliability.

By reinforcing completeness through standardisation, iterative validation, and intelligent augmentation, BIM professionals can ensure that models serve as dependable sources of information across disciplines. A focus on completeness reduces ambiguity, enhances interdisciplinary coordination and supports integrated project delivery throughout the entire lifecycle.

CONSISTENCY

Consistency refers to the uniform application of data structures, modelling practices, and documentation standards throughout all phases of a project. A consistent BIM model ensures that architectural, structural, and MEP components remain properly aligned across multiple views, disciplines, and deliverables. This alignment minimises ambiguity and helps prevent errors during design coordination, construction execution, and operational handover (Ni et al. 2025; Wang & Chen 2023).

In contrast, inconsistent models pose considerable risks to project outcomes. Discrepancies in geometric representations, parameter values, and view-specific annotations may lead to misalignments between floor plans,

sections, and three-dimensional models. Such inconsistencies often result in conflicting specifications, design clashes, and execution errors during downstream phases of the project (Mehrbod et al. 2020; Zhou et al. 2023). These issues frequently arise from fragmented workflows, insufficient coordination among modelling teams, and the lack of unified digital standards (Koseoglu et al. 2019; Sackey & Akotia, 2017).

Maintaining consistency becomes increasingly challenging when project participants rely on different modelling platforms, documentation procedures, or classification systems. In the absence of a common framework, variations in object naming, attribute assignment, and semantic structuring can lead to miscommunication and workflow inefficiencies (Li et al. 2025; Liu et al. 2024; Xiao & Bhola, 2022). Moreover, when teams are geographically dispersed or operate asynchronously, unsynchronised model updates can result in fragmented datasets and further misalignment (Wang, Z. et al. 2024; Zhuang et al. 2021).

To address these challenges, the adoption of standardised modelling protocols is essential. These protocols should encompass clearly defined modelling procedures, consistent naming rules, classification schemas, and structured template frameworks. Adherence to such standards fosters uniformity in model development and facilitates effective coordination among project disciplines (Mattern & König, 2018; Shafiq, 2021). Regular quality assurance reviews are also critical for detecting and resolving inconsistencies before they propagate to subsequent project phases (Ni et al. 2025; Paik et al. 2022).

Technological advancements further support consistency through automated validation tools. AI-driven model checkers and rule-based engines enable real-time identification of discrepancies in geometry, metadata, and documentation, which allows for immediate correction and sustained model alignment (Afzal et al. 2023; Hamidavi et al. 2020; Zhang, 2025). These technologies reduce the reliance on manual auditing and improve compliance with industry standards.

Ultimately, ensuring consistency in BIM models contributes to scalable collaboration, improved interoperability, and increased confidence among project participants. A well-maintained model supports clearer communication, facilitates faster decision-making, and reduces the likelihood of rework, thereby enhancing project delivery and the quality of lifecycle data management (Al Hattab & Hamzeh 2018; Liu et al. 2017; Ni et al. 2025). By prioritising consistency, project teams can elevate the overall performance, reliability, and efficiency of digital design and construction practices

ACCURACY

Accuracy signifies the degree to which digital representations of architectural, structural, and MEP systems conform to design specifications, construction tolerances, and regulatory standards. A high level of accuracy enhances design integrity, minimises errors, and ensures alignment across project phases, thereby supporting downstream tasks such as quantity take-off, cost estimation, clash detection, and scheduling (Hamidavi et al. 2020; Wang & Chen 2023). In contrast, inaccurate models often result in misaligned components, incorrect material specifications, and unresolved system clashes. These issues can lead to costly rework, safety hazards, and project delays (Ni et al. 2025; Paik et al. 2022; Wang, Z. et al. 2024).

Achieving and maintaining model accuracy remains a critical challenge due to several interrelated factors. A key challenge involves the proficiency of design professionals in effectively using BIM tools. The accuracy of model outputs depends significantly on their modelling skills and their ability to accurately interpret and implement design intent (Abrishami et al. 2021). Ambiguous or evolving project inputs may cause repeated revisions, deletions, and inconsistent updates, contributing to data misalignment and coordination challenges (Chowdhury et al. 2024; Ni et al. 2025; Pogorelskiy & Kocsis 2025). Fragmented workflows and the absence of standardised data entry protocols across teams introduce discrepancies in geometry, metadata, and spatial configurations (Aziz et al. 2024; He et al. 2021).

Variations in modelling standards across organisations or disciplines further compound the challenges associated with maintaining model accuracy. Inconsistent practices related to LOD, naming conventions and classification systems frequently lead to miscommunication and misinterpretation (Afzal et al. 2023; Disney et al. 2024; Zech et al. 2025). An additional concern involves the misalignment between project team expectations and the appropriate level of model granularity. Requests for excessively detailed models without clear justification can increase complexity and elevate the risk of inaccuracies arising from over modelling and unnecessary parameterisation (Jasiński 2021; Paik et al. 2022).

To address these challenges, it is essential to embed structured modelling practices and robust quality control frameworks throughout the BIM process. Multi-stage validation checkpoints can be introduced across the modelling lifecycle to detect and resolve anomalies systematically (de Marco et al. 2024; Paik et al. 2022). Additionally, targeted BIM training programmes are necessary to improve practitioner competency and ensure consistent application of modelling standards (Abrishami et al. 2021). The use of AI-powered model-checking tools

and rule-based verification systems is expanding, offering automated identification of geometric discrepancies and non-compliance with modelling standards (Cann et al. 2022; Chowdhury et al. 2024; Pogorelskiy & Kocsis 2025).

Standardising modelling protocols across organisations, enforcing continuous quality assurance measures, and integrating intelligent validation technologies are critical strategies for enhancing BIM model accuracy. An accurate model not only supports interdisciplinary coordination and reliable decision-making but also establishes a strong foundation for construction planning and management (He et al. 2021; Wang & Chen, 2023). Prioritising accuracy throughout the BIM process allows project teams to reduce errors, mitigate risks, and achieve improved project outcomes.

SYNCHRONISED

Synchronised refers to the continuous and real-time alignment of BIM model data across disciplines, systems, and users, ensuring that all project participants interact with the most current, coherent, and conflict-free version of the design. A synchronised BIM model enables consistent collaboration, eliminates data silos, and enhances trust in shared digital environments by maintaining model integrity throughout the project lifecycle (Liu et al. 2023; Zech et al. 2025).

Working with unsynchronised data can lead to fragmented workflows, conflicting updates, and outdated information that disrupt design coordination and decision-making. These issues often result in design misalignments, documentation errors, and costly rework (Pogorelskiy & Kocsis 2025). Given the increasing reliance on concurrent engineering, synchronised collaboration among architects, engineers and contractors is essential for maintaining real-time model integration (Aziz et al. 2024; Donato 2017; Tao et al. 2021).

Cloud-based BIM platforms and CDEs play a critical role in supporting synchronisation by enabling real-time updates, version control, and simultaneous multi-user access to shared models across project teams (Llatas et al. 2022; Sun et al. 2023; Tao et al. 2021). Furthermore, the integration of blockchain technologies into CDEs enhances data immutability and traceability, thereby mitigating inconsistencies and strengthening accountability throughout the project lifecycle (Valinejadshoubi et al. 2024; Zech et al. 2025).

Despite technological advancements, synchronisation remains a complex task. Frequent model updates can lead to versioning conflicts without structured protocols or role-based access permissions (Li et al. 2025; Sun et al. 2023). Inadequate clarification of data ownership and update responsibilities, particularly in multidisciplinary project environments, can further impede synchronisation (Liu et al. 2023; Rogage & Doukari, 2024).

To address these challenges, it is essential for project teams to embed clearly defined synchronisation protocols within the BIM workflow, assign explicit responsibilities for data validation and control, and implement standardised procedures for model updates (Shafiq, 2021). The adoption of advanced technologies, such as AI-driven discrepancy detection tools and automated notification systems, is also expanding to support continuous validation and the early identification of model drift (Valinejadshoubi et al. 2024).

Ultimately, prioritising synchronisation promotes model coherence, enhances communication transparency, minimises rework, and facilitates more efficient decision-making across design and construction workflows. Maintaining consistent and timely model updates enables BIM to function as a reliable and centralised source of information throughout all phases of the project lifecycle.

CLARITY

Clarity directly influences the extent to which project participants can accurately interpret and apply architectural, structural, and MEP information. A well-structured model conveys spatial relationships, technical specifications, and design intent in a coherent and comprehensible manner. This allows users from various disciplines to navigate information with minimal ambiguity (Lee et al. 2023). Emphasising clarity improves interdisciplinary communication, reduces the risk of misinterpretation, and supports consistent and informed decision-making across all project stages (El Mounla et al. 2023).

In the context of BIM, clarity encompasses graphical, spatial, and semantic precision. Well-organised visual outputs, standardised naming protocols, and coherent data structures enable team members to efficiently locate, interpret, and apply relevant information throughout design and construction processes (Zhu et al. 2025). In contrast, low levels of clarity often result from inconsistent graphic styles, overloaded visual content, ambiguous object labelling, or fragmented metadata. These issues hinder comprehension, cause delays in review processes, and increase the potential for design conflicts (Pärn et al. 2018; Valinejadshoubi et al. 2024).

As BIM models integrate inputs from multiple disciplines, they frequently become visually and semantically complex. Without appropriate management, this complexity can obscure essential information and limit the model's usability. Additional challenges to clarity arise from software constraints, disconnected workflows, and variations in modelling practices across teams. These

factors disrupt visual consistency and introduce discrepancies among model elements (Paavola & Miettinen, 2019). The challenge becomes even more significant in federated models where visual interpretation is central to detecting spatial conflicts and coordinating design contributions (Pärn et al. 2018).

To improve clarity, BIM teams should apply structured modelling protocols that support graphical hierarchy, logical layer organisation, and intuitive data classification. Visual techniques such as colour coding, zone demarcation, and exploded views can improve model readability and assist communication during design coordination and client presentations (Paavola & Miettinen, 2019; Zhang et al. 2025).

Technological innovations also play an important role in improving clarity. Knowledge-based modelling and rule-based visual filtering can reduce visual complexity by tailoring outputs to specific tasks and user needs (Zhu et al. 2025). Additionally, statistical visualisation methods and simulation tools such as Design of Experiments (DoE) assist designers in analysing the relationships between clarity, model complexity, and overall performance (Schlueter & Geyer, 2018).

Despite these advancements, maintaining clarity in BIM models remains a persistent challenge. This requires continuous investment in training, the adoption of suitable technologies, and the consistent application of standardised modelling practices. Prioritising clarity from the early stages of model development can improve communication effectiveness, strengthen trust among project participants, and ensure that BIM remains a dependable platform for delivering high-quality design and construction outcomes.

IMPLICATIONS

THEORETICAL IMPLICATIONS

This study offers significant theoretical contributions by expanding the understanding of essential attributes that define high-quality BIM design model. A well-defined set of quality attributes ensures that BIM design models serve as reliable and data-rich representations throughout the project lifecycle. By identifying and highlighting these attributes, this research advances the discourse on BIM design model quality, which is essential for maximising the effectiveness of BIM during the design phase (Lee et al. 2023).

One key theoretical advancement of this study is its reinforcement of the necessity for robust BIM models to enhance interdisciplinary collaboration. BIM design models undergo continuous development throughout the design phase. Effective coordination of updates across disciplines is essential to mitigate design risks and support timely project delivery (Jin & Li, 2023). This study also aligns with prior research emphasising the importance of establishing comprehensive quality-checking mechanisms to maintain BIM model reliability, as inconsistencies in design models often translate into coordination challenges during construction (Liu et al. 2023).

Additionally, this study addresses the gap in literature by proposing a structured approach to assessing the correctness of BIM design models, offering a theoretical foundation for future research on model evaluation frameworks. The methodological approach employed in this research can also serve as a reference for scholars aiming to establish quality attributes in BIM-related studies, particularly in the domain of digital design verification and automation in model checking.

PRACTICAL AND MANAGERIAL IMPLICATIONS

From a practical perspective, this study provides valuable insights for industry practitioners aiming to enhance the quality of BIM design models. The identified attributes serve as key benchmarks for promoting the robustness of these models throughout the design and pre-construction phases. By applying these attributes, professionals can improve design reliability, strengthen interdisciplinary collaboration, and streamline decision-making processes (Ni et al. 2025).

In addition, ensuring that BIM design models are synchronised across platforms and disciplines is essential to prevent data misalignment and disruption to project workflows (Wang, Z. et al. 2024). In practical terms, project teams can achieve this by agreeing common modelling conventions and levels of development in the BIM execution plan, scheduling regular clash-detection and coordination cycles, and applying validation checklists and automated rule-based checking during quality-assurance reviews before models are issued (Sun et al. 2023). Managing models within a common data environment, supported by version control and a clear responsibility matrix for model updates and approvals, further helps to maintain the model as a single, reliable source of information throughout the project lifecycle. Collectively, these measures translate the identified attributes into routine, auditable practices rather than aspirational goals.

For policymakers, the findings underscore the importance of establishing regulatory frameworks that define quality standards for BIM design models. National or industry-wide BIM guidelines can help standardise modelling practices and ensure consistency across projects. Organisations can also leverage these insights to refine

internal workflows; form dedicated model coordination teams and invest in capacity-building initiatives to enhance the technical competency of design professionals in managing high-quality BIM models.

By integrating these attributes into BIM design practices, stakeholders across the construction industry can collectively improve model reliability, reduce design-related risks and optimise project performance. Ultimately, enhancing BIM design model quality contributes to more efficient project execution, better resource utilisation and informed decision-making across the built environment lifecycle.

CONCLUSION

The development of high-quality BIM design models is fundamental to streamlining design workflows, enabling informed decision-making across the project lifecycle and enhancing project performance. Within BIM-based collaborative environments, these models support the integration of multidisciplinary inputs and foster clear communication among stakeholders. However, existing research has predominantly emphasised the technical capabilities and application-oriented use of BIM, while paying limited attention to the underlying quality of the models themselves. This has led to persistent challenges in producing reliable, well-structured, and purpose-fit models.

To address this gap, the present study systematically identifies the key attributes that define a high-quality BIM design model. Based on a systematic review of 65 peer-reviewed articles, six core attributes are synthesised: coordinated, completeness, consistency, accuracy, synchronised and clarity. The principal theoretical contribution of the study is the reframing of BIM design model quality as a single multidimensional construct, drawing together attributes that the existing literature has largely treated in isolation. This consolidated framework provides a structured basis for evaluating and enhancing model quality and offers practical guidance for researchers and practitioners seeking to improve collaborative design outcomes and BIM implementation.

Despite its contributions, this study has certain limitations. Firstly, the research scope is confined to journal articles, which may limit the comprehensiveness of the findings. Future research could expand the review to include industry reports, conference proceedings and case-based studies to capture a broader perspective. Additionally, the study relies on a predefined set of keywords, which may not have encompassed all relevant studies; expanding the search criteria could yield further insights into BIM model development. Building on these limitations, three specific directions for future research are proposed. First, the six attributes should be validated empirically with industry experts, for example through a Delphi study, to confirm their relevance and completeness in practice. Second, future work should develop a weighted scoring instrument or assessment rubric that operationalises the attributes into measurable indicators, enabling the systematic benchmarking of BIM model quality. Third, further research should examine how the attributes can be integrated with established standards such as ISO 19650 and IFC-based automated rule checking, so that quality evaluation can be embedded directly within existing BIM workflows.

Overall, this study highlights the critical role of robust BIM model development in driving effective design outcomes. By addressing current gaps and advancing methodological approaches, future research can contribute to the maturation of BIM adoption practices, ultimately leading to enhanced project performance and better interprofessional collaboration throughout the design and construction lifecycle.

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DECLARATION OF COMPETING INTEREST

None.

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