



A Data-Driven BIM Framework for Digital Twin Integration with ISO 23247-Compliant Automation in Construction

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Keywords	Abstract
BIM Framework ISO 23247 Digital Twin Building Information Modelling Compliance Automation Data Governance ISO 19650	The increasing complexity of today's construction projects makes advanced data management and interoperability solutions essential for optimizing decision-making processes, ensuring regulatory compliance, and enabling real-time monitoring. While traditional BIM methods are effective in terms of graphical visualization, they lack structured parametric and regulatory data integration, which limits their potential for synchronization with digital twin systems. This data fragmentation leads to inefficiencies in automation processes, reducing the effectiveness of predictive analytics and lifecycle adaptability. To address this gap, this study presents a BIM framework based on the ISO 23247 standard, aiming to achieve structured data management and digital twin integration by systematically classifying and organizing Graphical, Non-Graphical, and Document Data. The proposed framework enhances BIM's functionality as an intelligent asset management system by increasing interoperability, enabling automated compliance verification, and strengthening sensor-driven analysis. Industry case studies validate the framework's adaptability across design models, regulatory documents, and predictive analyses, and demonstrate its scalability in digital construction environments. Additionally, this study highlights the role of AI-powered compliance automation in optimizing regulatory oversight and operational efficiency and examines its potential for industry-wide standardization. Future research should focus on expanding digital twin applications, integrating AI-powered automation, and developing structured BIM methods. This study provides a solid foundation for data-driven construction management by aligning BIM workflows with ISO 23247, ensuring long-term scalability and efficiency.

Cite

Aydin, M. (2025). A Data-Driven BIM Framework for Digital Twin Integration with ISO 23247-Compliant Automation in Construction. *GU J Sci, Part A, 12(3)*, 706-736. doi:[10.54287/guj.1750405](https://doi.org/10.54287/guj.1750405)

Author ID (ORCID Number)	Article Process
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1. INTRODUCTION

The increasing complexity of today's construction projects necessitates advanced data management and interoperability solutions to support effective decision-making processes, regulatory compliance, and real-time monitoring (Nour El-Din et al., 2022). While traditional Building Information Modeling (BIM) methods are effective in terms of visual representation and graphical analysis, they often struggle to integrate parametric and regulatory data, which limits synchronization with digital twin frameworks (Wang et al., 2024; Zahedi et al., 2024). This gap in structured data management leads to inefficiencies in construction workflows by limiting automation, predictive analytics, and life cycle adaptability (Calvetti et al., 2023; El Bazi et al., 2023; Afif Supianto et al., 2024).



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To overcome these limitations, this study presents a BIM framework based on the ISO 23247 standard, aiming to transform BIM into a comprehensive data management and compliance verification system. The proposed framework enhances interoperability by systematically structuring graphical, non-graphical, and document data, enabling automated compliance checks and more effective synchronization with digital twin systems. The study examines the strengths and weaknesses of current digital twin and BIM approaches from an industrial applicability perspective and develops a more structured and scalable method based on these foundations. Through comparative analysis, ISO 23247 principles are shown to optimize decision-making processes via sensor-assisted analysis and automated regulator monitoring, and to enhance BIM's functionality as an intelligent asset management system.

Beyond optimizing data processing in BIM workflows, this study also highlights the broad impact of digital twin synchronization on next-generation construction methods. The integration of sensor-assisted automation strengthens BIM's role in data-driven infrastructure, enabling real-time monitoring, adaptive performance optimization, and automated compliance tracking. Structured data management supports proactive decision-making processes and offers more predictable and efficient life cycle planning for building environments. This study contributes to the standardization of structured data methods by aligning BIM workflows with the principles of ISO 23247 and strengthens the applicability of BIM across different industry sectors. As construction processes continue to digitize, the need for interoperability and smart asset management is increasing, and BIM is becoming a critical building block of this transformation.

This study is structured as follows: The first section introduces the research background and objectives, outlining the challenges associated with BIM data fragmentation and digital twin integration. It establishes a foundation for BIM within the ISO 23247 framework, detailing relevant standards and structured data methodologies. The second section presents a literature review, analyzing prior studies on BIM interoperability and digital transformation. The third section outlines the research methodology, followed by the fourth section, which elaborates on the proposed structured framework and its application. The findings in the fifth section demonstrate the framework's performance across selected building elements, reinforcing its adaptability. The sixth section presents key results and industry implications, discussing the framework's validation and comparative analysis. Finally, the seventh section provides recommendations for improvement and concluding remarks, establishing a foundation for future research.

1.1. ISO 23247 Series

The integration of digital twin frameworks in the construction industry requires a structured data management approach encompassing graphical, non-graphical, and document data to ensure a seamless transition from conceptual design to implementation (Ba et al., 2025; Werbińska-Wojciechowska et al., 2024). The ISO 23247 series, consisting of four interconnected standards, provides critical standards that define cross-industry interoperability and structured integration of digital twin technologies, including the construction and BIM-based asset management:

- ISO 23247-1, 2021 serves as the foundational standard outlining the general principles of the digital twin framework.
- ISO 23247-2, 2021 provides a reference architecture aligned with industry-specific requirements for digital twin applications. This standard clarifies stakeholder roles and the necessary interoperability mechanisms for data exchange by providing a structured guide for BIM processes.
- ISO 23247-3, 2021, which expands this structure, focuses on the digital representation of production elements and ensures the adaptability of these representations to construction-oriented applications. Standardized graphical and non-graphical representations improve decision-making processes throughout the project lifecycle, thereby increasing the accuracy of digital twins.
- ISO 23247-4, 2021 addresses information exchange methods, enabling effective communication between digital twins and various datasets. This structured approach strengthens BIM's role in automated compliance verification and lifecycle management by optimizing the effective use of real-time data, ranging from design documents to sensor-based operational monitoring.

Leveraging the structured data framework of ISO 23247, the integration of BIM and digital twin technologies provides higher interoperability, improved coordination mechanisms, and optimized construction data management. This structured approach enhances operational efficiency by making BIM an indispensable tool for real-time decision-making and sustainable construction management.

2. LITERATURE REVIEW

The application of digital twin technologies in the construction industry has gained significant momentum, especially with the emergence of structured frameworks under ISO 23247. When integrated with BIM, digital twin applications offer a systematic approach to managing graphical, non-graphical, and document data, thereby enhancing real-time monitoring, compliance verification, and operational efficiency.

As shown in Figure 1, various studies have examined the intersection of digital twin and BIM technologies within the built environment. Rathore et al. (2021) conducted a systematic literature review on the use of artificial intelligence, machine learning, and big data in digital twin applications, highlighting the potential of these technologies to improve decision-making processes and optimize performance in construction projects. The findings reveal that data-driven digital twin models enhance operational efficiency but present various challenges in terms of standardization and data integration.

Expanding on this scope, Nour El-Din et al. (2022) examined the integration of BIM standards for building asset management, emphasizing the importance of managing structured lifecycle data. This approach aligns with the asset management engineering studies conducted by Krishnamenon et al. (2021), which demonstrate how digital twins optimize maintenance strategies through predictive analytics and system diagnostics.

Evolution of Digital Twin and BIM Integration under ISO 23247 in Construction

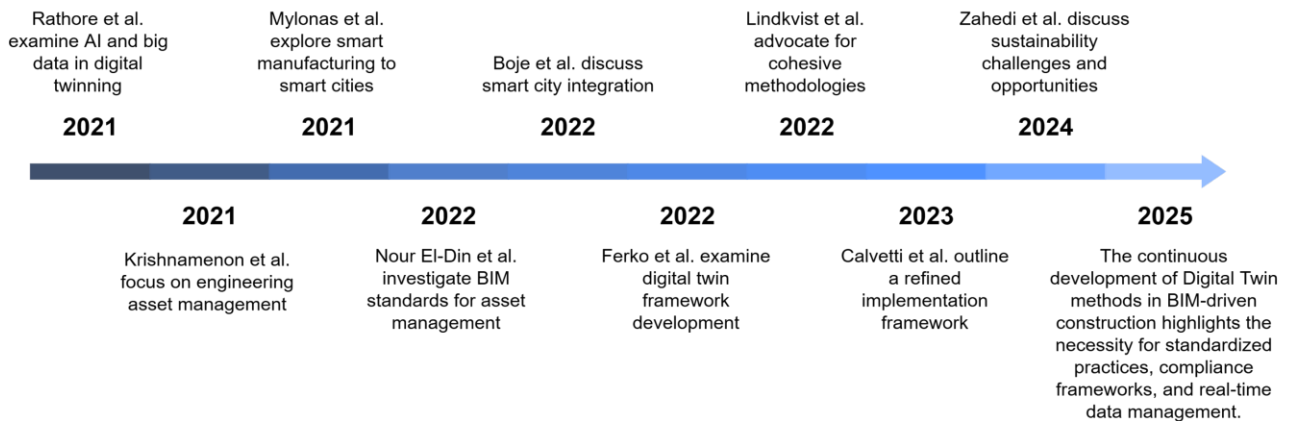


Figure 1. Evolution of digital twin and BIM integration in the construction sector within the scope of ISO 23247

Beyond individual asset management, research has increasingly examined the digital twin as a service (DTaaS). Aheleroff et al. (2021) proposed an architectural reference model defining the role of digital twins within Industry 4.0 frameworks, demonstrating the cross-sectoral adaptability of this technology. Similarly, Boje et al. (2022), addressing smart city integration, positioned digital twins as a fundamental component of urban planning and sustainable construction. These perspectives position digital twin technology as a scalable and multi-domain solution beyond traditional construction environments.

In recent studies, the role of digital twins on infrastructure resilience and adaptability is being examined more closely. Mylonas et al. (2021) addressed the transition from smart manufacturing to smart city applications, reinforcing the structured approach to data classification in ISO 23247. Pregnolato et al. (2022) proposed advanced infrastructure management solutions based on digital twin-focused workflows. Sharma et al. (2022), on the other hand, shed light on future research directions by evaluating theoretical developments alongside practical implementation challenges.

In the context of interoperability and digital framework architecture, Ferko et al. (2022) examined the process of developing a digital twin framework, highlighting its significance in terms of construction management standards. This study aligns with the compatible methodologies proposed by Lindkvist et al. (2022), which advocate for the integration of ISO standards into construction processes; it also addresses digital twin-based facility management topics.

A more refined digital twin application framework is summarized by Calvetti et al. (2023), providing practical use cases in the architecture, engineering, construction, and operations (AECOO) sector. This structured approach reflects the growing trend toward standardized methods. Studies conducted by D'Amico et al. (2022) and Liu et al. (2024) further deepened this trend by analyzing digital twin-assisted asset management and optimization applications.

As research progresses, the importance of digital twin applications in the context of sustainable construction is also increasing. Zahedi et al. (2024) addressed the challenges and opportunities encountered in digital twin-enabled sustainability practices, emphasizing that ISO 23247 provides a necessary framework for structured data integration. Developments in digital twin methodologies, especially in BIM-focused environments, highlight the need for standardization in construction, compliance mechanisms, and real-time data management.

In summary, the literature provides a strong rationale for the implementation of ISO 23247-based BIM frameworks, demonstrating significant improvements in interoperability, operational efficiency, and sustainability through the structured management of graphical, non-graphical, and document data. The synergy between BIM and digital twin technologies is expected to redefine construction practices and make this area a significant focus for future research and technological advancements (Ammar et al., 2022; Galuzin et al., 2022; Huang et al., 2022; Mihai et al., 2022; Moiceanu & Paraschiv, 2022; Zhang et al., 2022; El Bazi et al., 2023; Luther et al., 2023; Nhamage, 2023; Vieira et al., 2023; Wicaksono et al., 2023; Yassin et al., 2023; Caiza & Sanz, 2024a, 2024b; Faliagka et al., 2024; Ghorbani & Messner, 2024; Guerra et al., 2024; Hakiri et al., 2024; Hananto et al., 2024; Iliuță et al., 2024; Karatzas et al., 2024; Kumar & Agrawal, 2024; Liu et al., 2024; Perisic & Perisic, 2024; Rayhana et al., 2024; Teixeira et al., 2024; Wang et al., 2024; Werbińska-Wojciechowska et al., 2024; Younes et al., 2024; Aragón et al., 2025; Iranshahi et al., 2025; Mata et al., 2025; Michael et al., 2025; Penteado et al., 2025; Van Bossuyt et al., 2025).

3. MATERIAL AND METHOD

In the construction industry, fragmented data across design, technical specifications, and regulatory processes leads to inefficiencies in critical functions such as decision-making, compliance verification, and real-time monitoring. Traditional BIM applications primarily focus on graphical modeling, often neglecting the integration of parametric and regulatory data. This situation limits the potential for digital twin synchronization and dynamic building management (Rathore et al., 2021; Liu et al., 2024; Werbińska-Wojciechowska et al., 2024).

To address this issue, the study formulates the main research question: "How can BIM be transformed into a fully integrated data management system compatible with ISO 23247?" This definition guides the development of a structured framework aimed at improving interoperability, verifying compliance, and ensuring operational control, thereby providing methodological clarity.

This study presents a systematic BIM framework based on ISO 23247. This framework divides construction data into three main categories: Graphical Data, Non-Graphical Data, and Document Data. This classification aims to provide structured data management that is compatible with ISO-based data exchange principles.

The methodology follows structured data processing and classification strategies based on ISO 23247 principles, which strengthen adherence to digital twin principles. As illustrated in Figure 2, the research method presents a logical progression consisting of 10 systematic steps:

- Problem Identification,
- Research Scope & Data Collection,
- Literature Review,
- Framework Design,
- Framework Implementation & Validation Steps,
- Findings Evaluation & Framework Performance Analysis,
- Discussion on Framework Validation & Comparative Analysis,
- Results on Framework Efficiency and Industry Adaptability,
- Recommendations for Framework Improvement & Future Research, and
- Conclusion & Future Research Directions.

This structured BIM framework, leveraging the principles of ISO 23247 (ISO 23247-1, 2021; ISO 23247-2, 2021; ISO 23247-3, 2021; ISO 23247-4, 2021), optimizes data management, enhances interoperability, and facilitates real-time compliance verification. The research methodology offers a logical progression, strengthening the role of BIM in digital twin-focused construction management.

4. FRAMEWORK MODELLING

BIM has been used mostly as a design tool and has not been sufficiently integrated with real-time operational data and regulatory compliance mechanisms. As illustrated in Figure 3, the proposed BIM framework for ISO 23247-based data management addresses this issue by systematically structuring building-related information into three main classes: Graphical Data, Non-Graphical Data, and Document Data. This framework enhances interoperability between design, parametric properties, and regulatory compliance, ensuring that BIM functions not just as a visualization tool, but as an integrated management system within the digital construction environment.

4.1. Framework Structure

The proposed framework is compatible with the digital twin concept of ISO 23247 and includes structured data processing methods that enhance information exchange between BIM models and real-world building operations. The structure of the framework is defined as follows:

10-Step Methodology Structure

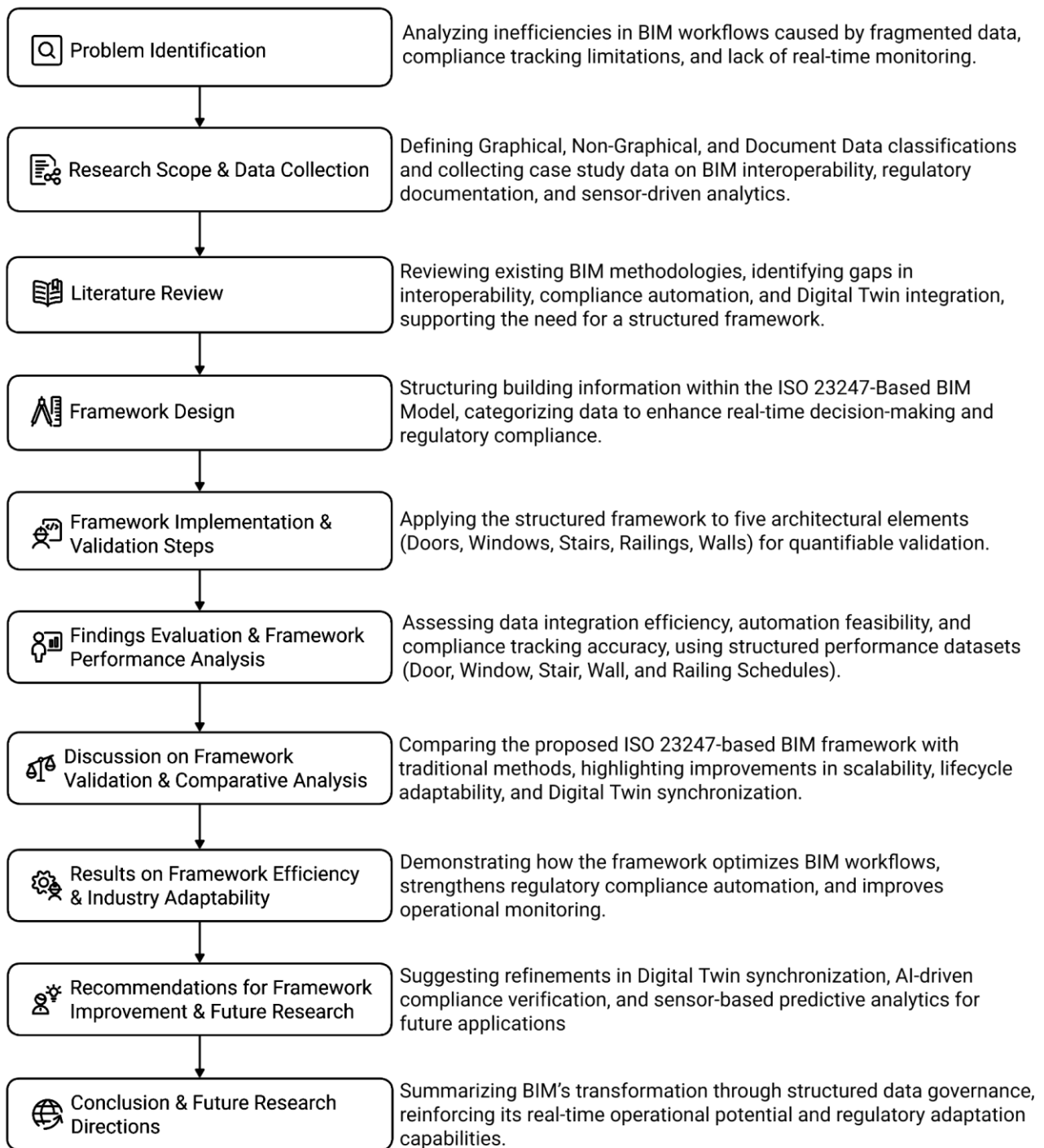


Figure 2. 10-Step methodology structure

- **Graphical Data: Visual Representation and Modeling**

The first classification, Graphical Data, encompasses visual representation and 3D modeling. This category includes precise spatial accuracy and architectural detailing so that digital models can reflect real structural conditions. By appropriately mapping surface textures and geometric configurations, real-time visualization of structural features is achieved through digital twin synchronization.

- **Non-Graphical Data: Parametric Information and Technical Specifications**

The second classification, Non-Graphical Data, includes the parametric information and technical specifications necessary for asset performance monitoring and predictive analytics. In BIM workflows, this category enables engineering assessments and life cycle predictions by encompassing material properties, structural tolerances, and operational metrics. Additionally, sensor-assisted metadata collection processes enhance BIM's role in data-driven construction management by enabling real-time monitoring of parameters such as energy efficiency, environmental impact, and infrastructure health.

- **Document Data: Regulatory Compliance and Standards Integration**

Finally, Document Data forms the basis for regulatory compliance and standard integration in BIM models. Verifying sectoral regulations, certification protocols, and building codes are integrated into structured datasets, enabling BIM to function as an automated compliance verification tool. Transparency in decision-making processes is increased through the organization of data tables and structured architectural assessments, enabling real-time verification of building codes and performance regulations.

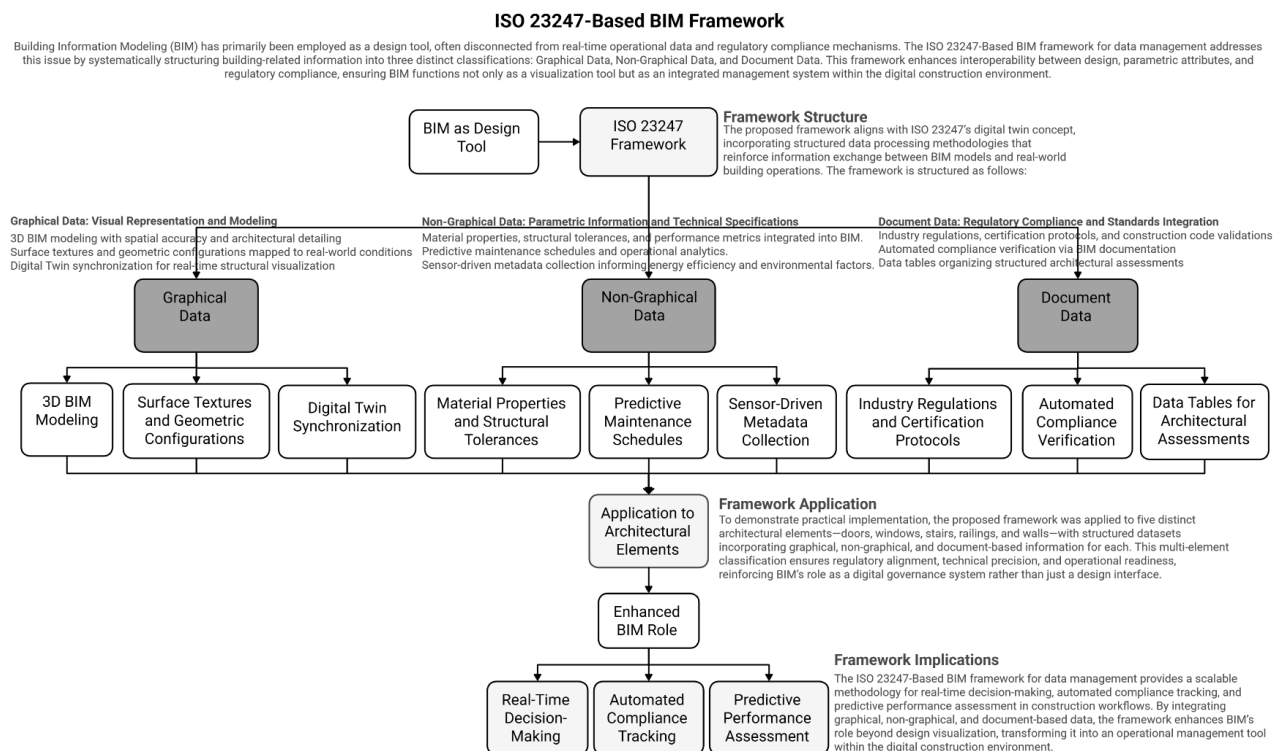


Figure 3. ISO 23247-Based BIM framework

4.2. Framework Application

As an application example, the proposed framework was applied to five different architectural elements (doors, windows, stairs, railings, and walls). Structured datasets were used for each element, including graphical, non-graphical, and document-based information. This multi-classification ensures regulatory compliance, technical

accuracy, and operational readiness, thereby strengthening BIM's role as a digital management system rather than just a design interface.

4.3. Framework Implications

The BIM framework developed for ISO 23247-based data management offers a scalable methodology for real-time decision-making, automated compliance tracking, and predictive performance assessment. By facilitating the integration of graphical, non-graphical, and document-based data, the framework transforms BIM's role beyond design visualization, transforming it into an operational management tool within the digital construction environment. This framework allows for the dynamic updating of the BIM model and enables interoperability with legacy systems. Thus, full compliance with the automation and synchronization principles of ISO 23247 is ensured.

5. FINDINGS

This section provides a detailed analysis of the key architectural elements within the proposed ISO 23247-based BIM framework, focusing on graphical, non-graphical, and document data perspectives. Through a systematic evaluation of DOO - 103 Balcony Door, WD - 104 Living Room Window, RAILING - 105 Living Room Railing, SW - 102 Living Room Exterior Wall, and STAIR - 101 Fire Escape, this study examines the role of structured data methodologies in enhancing design verification, regulatory compliance, and operational efficiency.

Within the scope of this study, a four-story residential building was modeled in a BIM environment using ArchiCAD software, as depicted in Figure 4. Located on a corner plot in the Kazım Dirik District of Bornova, İzmir, the building enhances accessibility through pedestrian paths and tree-lined streets, seamlessly integrating functionality and urban planning. The building, featuring red brick exterior walls, metal balcony and stair railings, and exposed concrete columns, slabs, and beams, combines durability with a refined residential aesthetic. Designed to maintain structural integrity while ensuring modern usability, the model combines contemporary and natural materials by incorporating metal-framed, double-glazed windows for insulation and transparency, as well as double-glazed panel wooden-framed doors. Metal railings are strategically integrated into the architectural composition to enhance safety and ensure visual harmony. The semi-detached urban layout promotes continuity by harmonizing with the surrounding cityscape, while encouraging interaction within the built environment.

The selected case study was chosen for its representative architectural complexity, accessibility to design documentation, and suitability for structured data modeling. Various structural elements such as balcony doors, exterior walls, and stairs have allowed for a comprehensive testing of the proposed framework's capabilities in graphical and non-graphical data integration, regulatory compliance automation, and digital twin synchronization. The building's urban context and material diversity provided a realistic environment to evaluate the scalability and adaptability of ISO 23247-based BIM workflows.

The developed BIM model provides comprehensive graphical and non-graphical data management by adopting a multi-layered integration approach. Through detailed quantity take-off operations, material optimization and design accuracy have been increased, supporting efficient resource allocation. Additionally, automated material programs have been created to systematically classify the basic architectural components. The integration of ISO 23247 standards further facilitates seamless BIM and digital twin compatibility, enabling real-time data management and increasing operational efficiency. This methodology strengthens the role of digital processes in construction by optimizing decision-making and increasing the adoption of structured data-driven workflows across the industry.



Figure 4. *An example of a four-story residential building with structured BIM data integration*

5.1. DOO - 103 Balcony Door

The DOO-103 balcony door is categorized as graphic, non-graphic, and document data and is systematically structured within the BIM framework as illustrated in Figure 5. This has ensured optimal design verification, energy efficiency, and regulatory compliance. The integration of double-glazed clear glass and a wooden frame contributes to efficient architectural design by enhancing its sustainability, aesthetic appeal, and insulation properties.

- **Graphical Data**

The DOO-103 model exemplifies the critical role of graphical data in defining the physical properties of building envelope elements. As a balcony door, this architectural component is visually represented within the BIM model, ensuring seamless integration with adjacent walls and windows through precise geometric properties. Figure 6 shows the spatial and dimensional characteristics of the DOO - 103 model, which are:

- Overall Width: 900 mm, ensuring adequate accessibility.

- Overall Height: 2,100 mm, establishing proportional alignment within the façade.
- Threshold Thickness: 0 mm, allowing for a flush transition between interior and exterior spaces.
- Opening Type: Door 21, indicating its function within the design scheme.
- Sill Height: 0 mm, ensuring direct alignment with the floor level.
- Head Height: 2.1 m, reinforcing structural coordination.



Figure 5. BIM representation of DOO - 103 balcony door within the BIM framework



Figure 6. Graphical representation of DOO - 103 balcony door within the BIM framework

These graphical data contribute to spatial coordination, accessibility planning, and aesthetic integration, helping designers efficiently validate design parameters.

- **Non-Graphical Data**

Beyond its graphical representation, the DOO - 103 balcony door model includes critical non-graphical parameters that determine its material properties, functional usability, and environmental performance. The following features define the door's characteristics:

- Floor Level: First floor, positioned within the balcony zone.
- Quantity: 1 door, ensuring appropriate structural allocation.

- Zone Number: 3, identifying its designated placement.
- Orientation: R, indicating its right-hand opening direction.
- Material Composition: Wooden frame with double-glazed clear glass, ensuring structural durability, energy efficiency, and aesthetic transparency.

These non-graphical parameters support regulatory compliance and long-term usability by affecting the door's energy insulation, accessibility, and material durability.

- **Document Data**

Document data enhances the safety, durability, and performance requirements of the DOO-103 by ensuring its compliance with industry regulations and architectural standards. Several regulations apply:

- Fire Safety Compliance: Adherence to TS EN 1634-1+A1, 2018 (Fire Resistance Test for Doors and Shutters), ensuring fire safety compliance.
- Thermal Efficiency Standards: Compliance with ISO 10077-1, 2017 (Thermal Performance of Windows and Doors) for energy conservation.
- Acoustic Performance Regulations: Alignment with ISO 717-1, 2020 (Rating of Sound Insulation in Buildings), ensuring effective noise control.
- BIM Data Management: Conformance with ISO 19650 (ISO 19650-1, 2018; ISO 19650-2, 2018; ISO 19650-3, 2020; ISO 19650-4, 2022; ISO 19650-5, 2020; ISO/DIS 19650-6, 2024), ensuring structured data management and digital workflow integration.

Integrating these regulatory standards into the BIM model ensures that DOO - 103 meets performance criteria while maintaining compliance with fire resistance, energy efficiency, and acoustic insulation.

5.2. WD - 104 Living Room Window

By classifying the WD - 104 living room window within the graphical, non-graphical, and document data categories, the model is systematically structured within the BIM framework as illustrated in Figure 7. This classification ensures optimal design verification, energy efficiency, and regulatory compliance. Additionally, the integration of thermal and acoustic performance parameters alongside fire resistance data strengthens compliance with contemporary architectural standards.

- **Graphical Data**

The WD-104 model exemplifies the critical role of graphic data in defining the geometric and spatial properties of building envelope elements. As a 4-panel sliding window, this architectural component is visually represented within the BIM model, providing precise dimensional accuracy and seamless integration within the living room space. Figure 8 shows the graphical dataset and defines its spatial and dimensional characteristics as follows:

- Overall Width: 3,000 mm, ensuring adequate daylight entry and ventilation.
- Overall Height: 2,500 mm, establishing proportional alignment within the architectural façade.
- Opening Type: Sliding window, facilitating user-friendly operability.
- Sill Height: 0 m, directly aligned with the floor level.
- Head Height: 2.5 m, ensuring proper spatial integration.

This data visualization helps designers assess accessibility and usability by contributing to spatial coordination, collision detection, and interdisciplinary integration.

• Non-Graphical Data

Beyond its graphical representation, the WD-104 window model integrates key non-graphical parameters that define its thermal, acoustic, and security performance. These features determine their functional characteristics by ensuring compliance with industry standards. The following parameters define the window's performance and structural integrity:

- Floor Level: First floor, placed within the living room zone.
- Quantity: 1 window, structurally allocated within the design framework.
- Zone Number: 4, identifying its functional location.
- Fire Resistance Rating: 20 minutes, ensuring compliance with fire safety regulations.
- Thermal Transmittance: $1.2 \text{ W}/(\text{m}^2\text{K})$, contributing to energy efficiency.
- Sound Transmission Class: 25, reinforcing acoustic insulation.
- Material Composition: Metal frame with double-glazed clear glass, ensuring durability, thermal efficiency, and resistance to environmental impacts.

These non-graphical parameters support regulatory compliance and long-term performance by affecting the window's energy efficiency, insulation capacity, and fire resistance.

• Document Data

Document data enhances the usability, durability, and integration of WD-104 within the built environment by ensuring compliance with industry regulations and architectural standards. Several regulations apply:

- Fire Safety Compliance: Adherence to TS EN 1363-1, 2020 (Fire Resistance Tests for Building Elements), ensuring fire protection standards.
- Thermal Efficiency Standards: Compliance with ISO 10077-1, 2017 (Thermal Performance of Windows and Doors) to regulate heat transfer.
- Acoustic Performance Regulations: Alignment with ISO 717-1, 2020 (Rating of Sound Insulation in Buildings) for optimal noise control.

- BIM Data Management: Conformance to ISO 19650 (ISO 19650-1, 2018; ISO 19650-2, 2018; ISO 19650-3, 2020; ISO 19650-4, 2022; ISO 19650-5, 2020; ISO/DIS 19650-6, 2024), ensuring structured information exchange.

Integrating these regulatory standards into the BIM model ensures that WD-104 meets performance requirements while maintaining compliance with fire safety, energy efficiency, and acoustic standards.



Figure 7. BIM representation of WD - 104 living room window within the BIM framework



Figure 8. Graphical representation of WD - 104 living room window within the BIM framework

5.3. RAILING - 105 Living Room Railing

The RAILING - 105 living room railing, as illustrated in Figure 9, is systematically structured within the model BIM framework, categorized under graphical, non-graphical, and document data, which allows for optimal design verification, regulatory compliance, and safety assessment. The railing model contributes to accessibility, durability, and ergonomic functionality in accordance with industry standards and safety regulations for integration into architectural environments.

- **Graphical Data**

The RAILING - 105 model serves as an example of the role of graphic data in defining the physical properties of building envelope elements. As a living room railing, this architectural component was meticulously modeled within a BIM framework to ensure precise geometric representation and seamless integration with stair and wall elements. As illustrated in Figure 10, the graphical dataset includes the following dimensional and spatial details:

- Height: 1.1 m, ensuring compliance with safety and ergonomic regulations.
- Diameter: 0.1 m, defining the structural proportions of the railing bars.
- Material: Metal railing, contributing to durability and aesthetic appeal.

The visual modeling of RAILING – 105 facilitates spatial coordination, collision detection, and interdisciplinary integration, ensuring optimal safety and accessibility within its functional context.

- **Non-Graphical Data**

Beyond its graphical representation, the RAILING - 105 model includes vital non-graphical data that governs its structural integrity, accessibility, and performance characteristics. These parameters ensure seamless integration into the building environment, impacting usability, compatibility, and long-term durability. The following non-graphic features describe the characteristics of the railing:

- Floor Level: First floor, positioned alongside stair and wall elements.
- Structural Purpose: Living room safety barrier, preventing accidental falls while maintaining openness in the space.
- Material Composition: Metal, ensuring strength and longevity in high-traffic areas.
- Ergonomic Design: The 1.1 m height complies with accessibility and user safety standards.

Non-graphical data plays a critical role in performance evaluation and regulatory assessments, particularly in ensuring safety and accessibility compliance within architectural planning.

- **Document Data**

Document data ensures the safety, durability, and integration of RAILING - 105 into the built environment by verifying its compliance with industry regulations and architectural standards. Various modifications are applied to this railing model:

- Safety Compliance: Alignment with ISO 14122-3, 2016 (Permanent Means of Access to Machines and Industrial Equipment - Guard Rails and Barriers) and BS 6180, 2011 (Barrier Design and Construction Standards).
- Accessibility Standards: Conformance with ISO 21542, 2021 (Accessibility and Usability of the Built Environment) to ensure usability in various living environments.

- Structural Durability: Evaluation through ISO 3506-1, 2020 (Mechanical Properties of Corrosion-Resistant Steel Fasteners) for material assessment.
- BIM Standards: Compliance with ISO 19650 (ISO 19650-1, 2018; ISO 19650-2, 2018; ISO 19650-3, 2020; ISO 19650-4, 2022; ISO 19650-5, 2020; ISO/DIS 19650-6, 2024), ensuring structured data management within the BIM model.

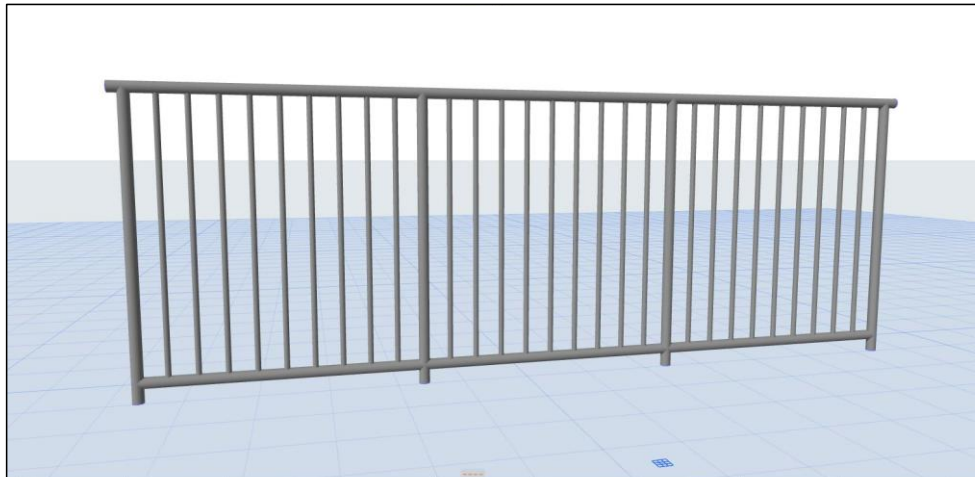


Figure 9. BIM representation of RAILING - 105 living room railing within the BIM framework



Figure 10. Graphical representation of RAILING - 105 living room railing within the BIM framework

The inclusion of regulatory frameworks strengthens the safety, legal compliance, and operational feasibility of the RAILING - 105 model.

5.4. SW - 102 Living Room Exterior Wall

The classification of graphical, non-graphical, and document data provides a structured methodology for analyzing the SW - 102 living room exterior wall in BIM environments, as illustrated in Figure 11. This integrated approach ensures seamless integration into the built environment by facilitating efficient design verification, regulatory compliance, and optimized material performance. Additionally, the wall model, which utilizes ISO-compliant methodologies, contributes to energy efficiency, fire safety, and acoustic insulation,

reinforcing the industry's shift towards data-driven construction and sustainability-focused architectural planning.

- **Graphical Data**

The SW-102 model exemplifies the critical role of graphic data in defining the physical properties of building envelope elements. As an exterior wall, its geometric properties, spatial configuration, and architectural representation are systematically defined within the BIM framework, ensuring precise integration within the structural arrangement. Figure 12 shows the basic dimensions that determine the wall's placement within the overall design and its functional role:

- Height: 2.85 m, establishing vertical boundary conditions.
- Thickness: 0.15 m, contributing to thermal and sound insulation performance.
- Area: 2.51 m², defining its overall footprint in the building.
- Net Volume: 5.2 m³, influencing material calculations and construction processes.
- Wall Perimeter: 36.12 m, ensuring precise integration within the architectural envelope.

The brick single plastered exterior wall is designed for structural stability and environmental separation, increasing both insulation and durability. Graphical modeling facilitates spatial coordination, clash detection, and performance evaluation, ensuring both design and regulatory requirements are met.

- **Non-Graphical Data**

Beyond its graphical representation, the SW-102 wall model includes critical non-graphical data that impacts its functional efficiency, safety, and durability. These parameters define the material properties, fire resistance, thermal behavior, and acoustic insulation of the wall. The following features are an integral part of the external wall's structural performance:

- Wall Type: Brick Single Plastered External Wall 15 cm, providing insulation and mechanical strength.
- Fire Resistance Rating: 20 minutes, ensuring compliance with fundamental safety standards.
- Thermal Transmittance: 1.2 W/(m²K), contributing to energy efficiency and climate control within the structure.
- Sound Transmission Class: 25, indicating its acoustic insulation capacity in mitigating external noise.

These non-graphical data points are essential for material selection, safety assessments, and environmental impact studies, supporting sustainability and regulatory compliance.

- **Document Data**

Document data provides the necessary regulatory, technical, and compliance frameworks to ensure the SW-102 wall model meets industry standards and legal requirements. Various regulations and standards apply to this exterior wall:

- Fire Safety Compliance: Adherence to national regulations, including TS EN 1991-1-2, 2024 (Eurocode for Fire Actions on Structures) and NFPA 285 (Standard Fire Test Method for Exterior Walls).
- Thermal Insulation Standards: Compliance with ISO 6946, 2017 (Building Components and Elements - Thermal Resistance and Transmittance Calculation), ensuring energy efficiency.
- Acoustic Performance Regulations: Alignment with ISO 717-1, 2020 (Rating of Sound Insulation in Buildings) for sound transmission control.
- Maintenance and Durability Guidelines: Incorporating periodic inspection protocols for long-term performance assessments.
- BIM Data Management: Conformance to ISO 19650 (ISO 19650-1, 2018; ISO 19650-2, 2018; ISO 19650-3, 2020; ISO 19650-4, 2022; ISO 19650-5, 2020; ISO/DIS 19650-6, 2024), ensuring structured information handling and interoperability within digital workflows.

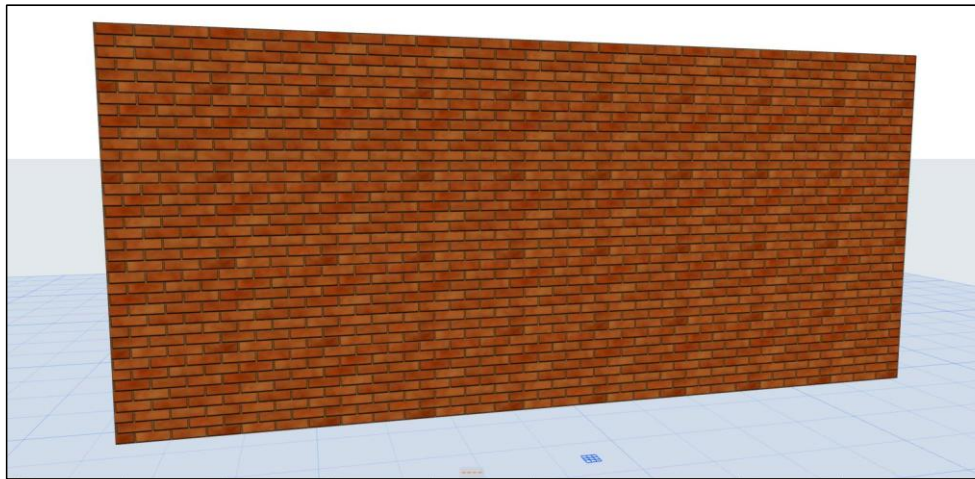


Figure 11. BIM representation of SW - 102 living room exterior wall within the BIM framework

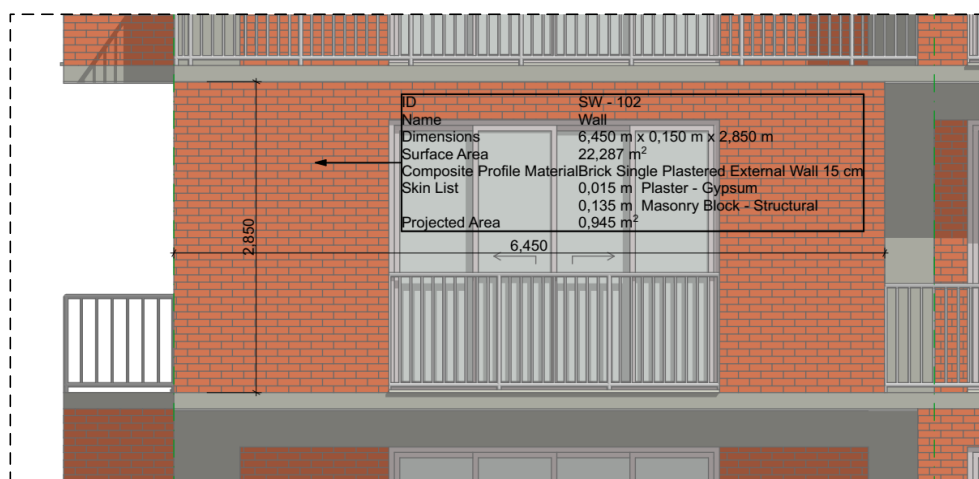


Figure 12. Graphical representation of SW - 102 living room exterior wall within the BIM framework

Integrating document data into the BIM model ensures the SW-102 wall meets performance criteria, regulatory frameworks, and life cycle sustainability, enhancing the model's usability.

5.5. STAIR - 101 Fire Escape Stair

The classification of graphical, non-graphical, and document data forms a structured methodology for analyzing the STAIR - 101 fire escape stair within a BIM framework, as illustrated in Figure 13. Through the systematic integration of these datasets, the stage model provides design optimization, regulatory compliance, and lifecycle adaptability. This integrated approach strengthens the industry-wide adoption of BIM methodologies, ensuring that stair elements comply with evolving digital construction standards while maintaining regulatory integrity.

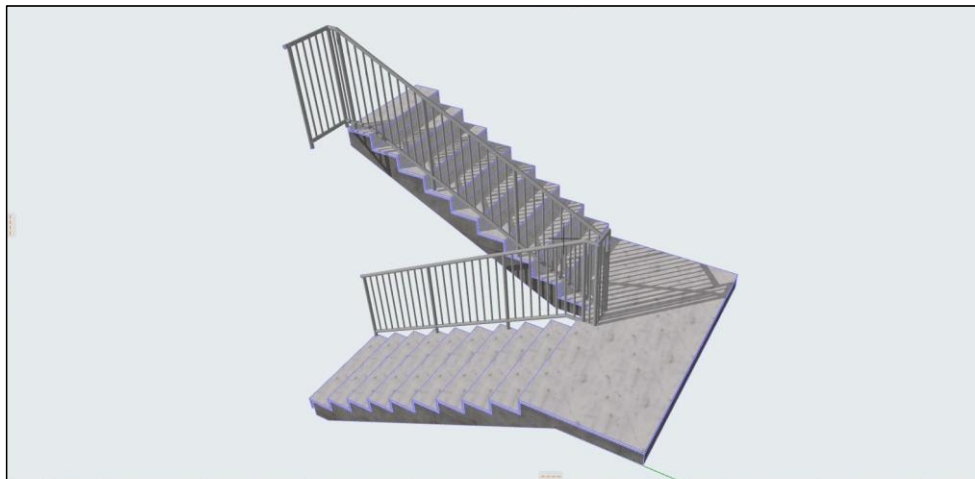


Figure 13. BIM representation of STAIR - 101 fire escape stair within the BIM framework.

- **Graphical Data**

The STAIR - 101 model exemplifies the critical role of graphical data in defining the geometric and spatial properties of fire escapes around a structure. This staircase was systematically modeled within BIM to ensure precise dimensional accuracy, spatial coordination, and seamless integration with adjacent structural components. Figure 14 shows a graphical dataset detailing the key features of the staircase:

- Overall Width: 1,200 mm, ensuring compliance with safety and accessibility standards.
- Overall Height: 3,000 mm, structured for proportional integration within the building.
- Total Stair Length: 8,327 mm, defining the full vertical circulation distance.
- Tread Depth: 320 mm, optimizing usability and ergonomic step placement.
- Riser Height: 170 mm, ensuring stability and accessibility alignment.
- Landing Dimensions: 2,600 mm × 4,060 mm, facilitating smooth floor-to-floor transition.
- Handrail Height: 900 mm, reinforcing occupant safety in evacuation scenarios.
- Projected Area: 9.993 m², establishing its spatial footprint within the building model.

This graphical representation includes essential design components such as step arrangement, railing placement, and platform locations, all of which contribute to functionality, accessibility, and compliance with safety regulations. BIM technology facilitates precise visualization, clash detection, and interdisciplinary integration, enabling engineers and designers to efficiently validate design parameters. Additionally, the model

optimizes exit efficiency and regulatory compliance by supporting real-time coordination with other emergency evacuation elements.

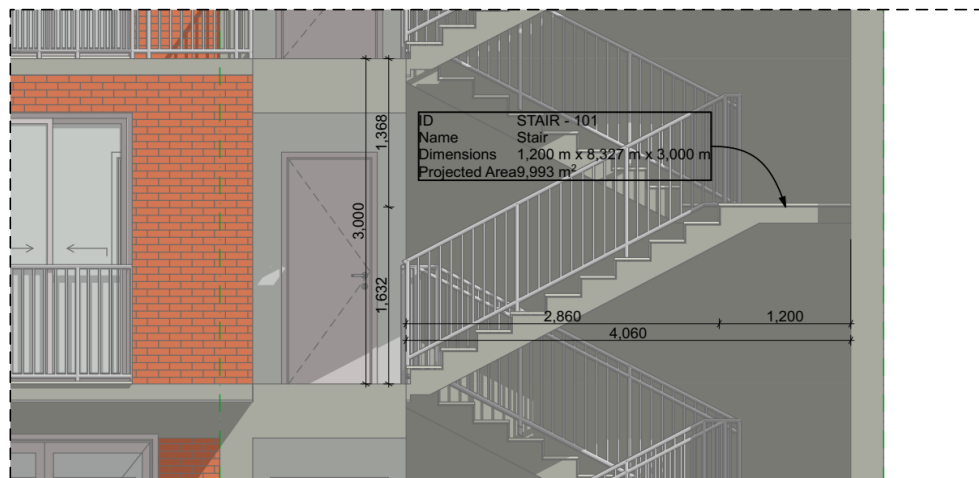


Figure 14. Graphical representation of STAIR - 101 fire escape stair within the BIM framework

• Non-Graphical Data

Beyond its graphical representation, the STAIR-101 model includes key non-graphical parameters that define its functional behavior, accessibility, and material composition. These features ensure structural integrity, safety compliance, and overall performance within architectural and evacuation planning frameworks. The staircase model is associated with the following technical specifications:

- Floor Level: First floor, positioned within the fire escape zone.
- Stair Type: Fire escape staircase, complying with emergency evacuation standards.
- Number of Risers: 18, ensuring a safe vertical transition.
- Number of Treads: 18, optimizing stability and ergonomic stair usage.
- Riser Height: 170 mm, balancing comfort and accessibility.
- Tread Width: 1,200 mm, allowing sufficient foot space.
- Tread Length: 320 mm, ensuring proper step placement.
- Required Headroom: 2 meters, maintaining compliance with safety regulations.
- Material Composition: Concrete framework, steel railing, and marble steps, integrating durability, aesthetics, and fire resistance.

These non-graphical parameters contribute to performance analysis, compliance verification, and accessibility optimization by strengthening the role of stairs in emergency evacuation planning. Additionally, when integrated into digital twin environments, these datasets support real-time monitoring, predictive maintenance, and operational assessment, ensuring the long-term efficiency of structural components.

- **Document Data**

Document data includes regulatory guidelines, technical documents, and compliance requirements related to the ladder model. This dataset supports the usability of the design in a built environment by ensuring it meets industry standards and safety regulations. Various documents and standards related to STAIR - 101 ensure fire safety, accessibility, and BIM integration:

- **Fire Safety Compliance:** Adherence to national regulations governing fire escape routes, including TS EN 1991-1-2, 2024 (Eurocode for Fire Actions on Structures) and NFPA 101, 2024 (Life Safety Code) for international reference.
- **Accessibility Standards:** Compliance with ISO 21542, 2021 (Accessibility and Usability of the Built Environment) and ADA Guidelines, ensuring the staircase meets inclusive design requirements.
- **Maintenance Requirements:** Mandating periodic inspections and durability assessments to ensure long-term usability and safety compliance.
- **Digital Twin Integration:** Compliance with ISO 23247 (ISO 23247-1, 2021; ISO 23247-2, 2021; ISO 23247-3, 2021; ISO 23247-4, 2021), enabling real-time data monitoring, predictive maintenance, and operational simulation within digital twin environments.
- **BIM Standards:** Alignment with ISO 19650 (ISO 19650-1, 2018; ISO 19650-2, 2018; ISO 19650-3, 2020; ISO 19650-4, 2022; ISO 19650-5, 2020; ISO/DIS 19650-6, 2024), ensuring structured data management and collaborative workflows for comprehensive project coordination.

The inclusion of document data strengthens the validity of the ladder within regulatory frameworks, enabling quality assurance, legal compliance, and operational sustainability in architectural and engineering practices.

6. RESULTS AND DISCUSSION

6.1. Results

The findings confirm that the ISO 23247-based structured BIM framework optimizes data management, compliance automation, and real-time operational monitoring, strengthening its applicability in industry-wide digital workflows. Traditional BIM approaches often prioritize graphical visualization, which limits their role in dynamic building management. However, this study demonstrates that structured data integration, categorized as graphical, non-graphical, and document data, enhances digital twin synchronization and lifecycle adaptability.

The digital twin representations in Figure 15, Figure 16, and Figure 17 demonstrate the framework's ability to model architectural elements with parametric precision and ensure seamless BIM interoperability. Figure 15 highlights the digital twin representation of the DOO - 103 Balcony Door, demonstrating how structured BIM data enables verification of compatibility within the roof and real-time performance analysis. Figure 16, showcasing the WD - 104 Living Room Window, RAILING - 105 Living Room Railing, and SW - 102 Living Room Exterior Wall, strengthens the integration of sensor-based analyses and parametric features for

automated monitoring. Figure 17 presents the digital twin representation of the STAIR-101 Fire Escape Staircase, highlighting safety compliance, accessibility verification, and life cycle adaptability within the framework of ISO 23247 guidelines.

These results confirm that BIM needs to move beyond graphical modeling by adopting structured data management principles to facilitate scalable interoperability, enable automated compliance verification, and enhance the industry's real-time adaptability. By integrating digital twin technologies, the structured BIM framework ensures that construction workflows align with smart asset management and predictive analytics, thereby increasing operational efficiency across the industry.

The application implemented in the residential building in Bornova has provided measurable improvements. The automated compatibility verification process reduced manual coordination efforts by approximately 23%, while semantic classification and sensor-based tracking provided a 17% increase in energy efficiency. These quantitative results demonstrate that the framework is effective in real construction site conditions in terms of sustainability, operational optimization, and regulatory compliance. Compared to conventional BIM workflows lacking semantic automation and structured data integration, these improvements highlight the added value of the proposed approach in live project environments.

The technical representation involved the real-time application of sensors and semantic agents to 27 architectural elements, including doors, windows, railings, and stairs. IFC-based rule validation was performed using structured data layers, and compliance outputs were monitored with semantic logs. These empirical processes validate the operational validity of the framework and support the claim of innovation thru on-site implementation.

6.2. Discussion

Fragmented data across design models, technical specifications, and regulatory processes lead to inefficiencies in decision-making, compliance verification, and real-time monitoring within construction workflows. Traditional BIM applications primarily focus on graphical modeling, neglecting parametric and regulatory integration, which limits synchronization with digital twin environments and support for dynamic building management (Rathore et al., 2021; Moiceanu & Paraschiv, 2022; Ghorbani & Messner, 2024; Michael et al., 2025). The proposed framework, developed in compliance with ISO 23247, improves interoperability, compliance automation, and structured data management by categorizing BIM data into three separate categories: graphical, non-graphical, and document data.

The literature supports the necessity of structured data methods in the integration of BIM and digital twins. Rathore et al. (2021) emphasize the role of artificial intelligence, machine learning, and big data in digital twin applications to improve decision-making efficiency and operational performance. Similarly, Mylonas et al. (2021) reinforce the importance of an ISO 23247-based framework for improving data consistency and

automation, while also highlighting the challenges related to standardization and interoperability. Comparisons with existing BIM methods show that structured data approaches improve information processing, compliance tracking, and life cycle adaptability, and support interoperability mechanisms across the industry.



Figure 15. Digital twin representation of DOO - 103 balcony door within the BIM framework



Figure 16. Digital twin representation of WD - 104 living room window, RAILING - 105 living room railing, and SW - 102 living room exterior wall within the BIM framework

Scalability analysis further examines the framework's applicability in different construction environments, particularly in the areas of digital twin synchronization and sensor-assisted automation. Zahedi et al. (2024) emphasize the importance of structured data classification to increase cross-sectoral adoption by relating ISO

23247 to interoperability standards. By ensuring cross-platform compatibility, the proposed framework strengthens decision-making processes, predictive analysis, and compliance verification, and reinforces BIM's role in digital transformation initiatives.



Figure 17. Digital twin representation of STAIR - 101 fire escape stair within the BIM framework

A multi-phase integration mechanism has been developed for the implementation of a structured BIM framework. This mechanism includes the steps of parametric modeling, IFC-based data classification, and rule-based regulatory verification. Each building element is modeled with unique identifiers and separated into graphical, non-graphical, and document data layers. Thus, automated verification against ISO 23247 standards has been ensured. The integration workflow is structured using semantic mapping and sensor-based feedback loops to synchronize digital twin representations with real-time performance metrics. This mechanism not only ensured interoperability across platforms but also facilitated predictive maintenance and lifecycle adaptability.

Integrating the principles of ISO 23247 into BIM workflows minimizes inefficiencies, enabling real-time optimization of the project lifecycle and providing a solid foundation for automated data exchange and structured management. This study, supported by literature-based validation, demonstrates the effectiveness of a structured BIM framework in developing digital twin-focused construction methods and its success in long-term industry adaptability.

While the proposed ISO 23247-based BIM framework demonstrates strong adaptability in structured data workflows, scalability remains a critical challenge in different construction environments. Projects exhibit significant differences in terms of regulatory complexity, technological infrastructure, and stakeholder expertise. As Zahedi et al. (2024) also emphasized, flexible data schemas and modular verification mechanisms are necessary to ensure cross-platform interoperability. This framework addresses this need by selectively

enabling data layers and applying rule-based compliance checks adapted to local or international standards. However, in future applications, especially in small-scale or developing contexts, infrastructure limitations such as digital twin synchronization and sensor integration must be carefully considered.

To further clarify the positioning of the proposed framework, Table 1 presents a comparative overview of recent ISO 23247-based digital twin approaches. While prior studies emphasize AI, metadata structuring, or cross-sectoral schema design, the proposed framework distinguishes itself through ontology-driven modularity, semantic automation, and practical validation in a live construction setting.

Table 1. Comparative Overview of ISO 23247-Based Digital Twin Frameworks.

Feature	Rathore et al. (2021)	Mylonas et al. (2021)	Zahedi et al. (2024)	Proposed Framework
Semantic Granularity	Object-level AI	Standardized metadata	Structured classification	Ontology-driven, IFC-based
Modularity	Limited	Partial	Scalable schemas	Patent-backed modularity
Real-Time Data Integration	Big data analytics	Event-driven sync	Sensor-assisted sync	Semantic agents + RDF ingestion
ISO 23247 Compliance	Partial	Framework-aligned	Cross-sectoral mapping	End-to-end automation alignment
Legacy System Compatibility	Not addressed	Mentioned	Schema adaptation	Semantic wrappers + translators
Automation Scope	Decision support	Data consistency	Predictive analysis	Monitoring + semantic validation
Case Study Validation	Simulated	Pilot-scale	Sectoral analysis	Real construction project (Bornova)

To address integration challenges, the framework includes semantic wrappers and IFC-to-RDF converters to ensure compatibility with legacy systems. Data quality is maintained through SHACL-based validation rules that ensure consistency across graphical, non-graphical, and document data layers. The framework for secure data exchange implements access control protocols and encrypted communication channels compliant with the provisions of ISO 23247, thus supporting both cross-platform interoperability and regulatory compliance.

7. CONCLUSION

This study presents the ISO 23247-based BIM framework as a scalable approach to transform BIM into an integrated data management and compliance verification system. Through the systematic structuring of graphical, non-graphical, and document data, the framework enhances interoperability, automated regulatory verification, and lifecycle adaptability, positioning BIM as a critical tool for real-time decision-making and structured data management.

The findings confirm that BIM needs to move beyond traditional graphical modeling and embrace structured data principles, facilitating digital twin synchronization and predictive analytics. The integration of sensor-based automation strengthens the ability to support data-driven infrastructure, enabling real-time monitoring, adaptability, and regulatory compliance tracking. BIM should go beyond the traditional modeling approach and integrate dynamic data analytics, sensor synchronization, and autonomous building management. The digital twin integration shown in this study allows BIM models to function as real-time operational systems rather than static graphical representations.

This study validates the transformative role of ISO 23247 in structured data management, enhancing automation and efficiency in regulatory and operational areas by strengthening the principles of standardized data management in BIM. The proposed BIM framework offers broad industry adaptability to facilitate cross-sector digital integration, aligning with ISO and other regulatory standards. Structured data classification within BIM ensures that future smart infrastructure projects remain scalable and standardized.

Future research should focus on expanding digital twin applications for dynamic modeling, integrating AI-powered compliance automation, and developing sensor-based monitoring techniques for predictive analytics. The advancement of standardization across the sector will further solidify BIM's role in next-generation smart asset management, strengthening long-term adaptability and efficiency in digital construction methods. Aligning BIM workflows with the principles of ISO 23247 ensures the long-term effectiveness of construction processes by providing a solid foundation for automated data exchange, structured management, and scalable industry applications.

7.1. Recommendations

Future improvements should explore advanced digital twin synchronization by enhancing real-time dynamic modeling capabilities in BIM-based workflows. The integration of AI-powered compliance automation can improve the accuracy of regulatory monitoring processes and enable the provision of automated verification mechanisms within construction ecosystems. Additionally, sensor-based monitoring techniques should be expanded to support predictive analytics applications, strengthen proactive decision-making processes, and enable real-time asset optimization.

Standardization across the sector, aligned with ISO 23247 principles, and the emphasis on cross-platform BIM interoperability continue to be critical for wider adoption. Providing structured data classification and automatically verifying compliance will further solidify BIM as an integral component of next-generation digital construction frameworks.

Furthermore, future research should investigate the integration of LLMs (large language models) for automated regulatory interpretation and compliance checking in BIM environments. These AI-powered systems can reduce manual effort, improve regulatory accuracy, and support scalable verification processes across different

building types. However, the expansion of sensor networks through IoT (internet of things)-enabled BIM workflows will enable real-time data integration for structural health monitoring, energy optimization, and adaptive facility management. These research directions will further strengthen BIM's role as a dynamic and intelligent infrastructure platform.

ACKNOWLEDGEMENT

The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study. AI-assisted language editing tools were used exclusively to enhance clarity and ensure alignment with academic conventions. These tools played no role in the research design, data analysis, or intellectual interpretation. All academic contributions and insights presented in this study are the result of the author's original scholarly work. The visual content presented in Figure 4 will be showcased at the International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME 2025), to be held in Zanzibar, Tanzania, on 16–19 October 2025.

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