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(Research Article)

# Application of end-to-end testing methods to verify compliance of BIM models and as-built documentation in digital platforms

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## Abstract

The paper examines one of the main problems of the modern construction industry - the discrepancy between the parameters embedded in building information models (BIM) and the actual data reflected in the executive documentation. The purpose of the study is to substantiate an end-to-end approach to testing that allows automating the verification of compliance of design models with the actual state of objects in digital construction management platforms. The methodological basis is a system analysis of existing studies in the field of quality control in construction and adaptation of software testing principles, in particular the behavior-driven development (BDD) methodology, which made it possible to widely explore the topic. As a result, a conceptual framework is proposed that integrates the collection of field data (laser scanning, photogrammetric survey), their spatial semantic comparison with the BIM model and automated generation of reports on the identified discrepancies. The scientific novelty lies in the unification of heterogeneous sources of information (BIM models, executive schemes) in a single continuous verification cycle, similar to the CI/CD pipeline, which increases the accuracy, efficiency and objectivity of construction work control. The results obtained will be of interest to construction site managers, quality engineers, BIM managers and developers of digital platforms for the construction industry.

**Keywords:** Building Information Modeling; BIM; End-To-End Testing; Executive Documentation; Data Verification; Digital Platforms; Construction Control; Automation; Project Compliance; Quality Management

## 1. Introduction

The digital revolution in the construction industry represents an irreversible and large-scale process aimed at improving efficiency, transparency, and safety at all stages of the project life cycle. At its core lies the implementation of Building Information Modeling (BIM), a technology that enables the creation and maintenance of a unified, interconnected, and up-to-date database about a structure and its characteristics. According to analysts' estimates, the global BIM market will grow from USD 9.12 billion in 2025 to USD 22.08 billion by 2032, with an average annual growth rate of 13.5 % during the forecast period [1]. In addition, the construction sector increasingly benefits from the use of artificial intelligence (AI) and machine learning (ML) to automate and prioritize tests. The effectiveness of these technologies has been proven: their implementation reduces regression testing time by 45 % and decreases the number of missed defects by 32 % when ML algorithms are integrated into QA processes of distributed systems [13]. Besides, the use of graph neural networks for test prioritization increases the APFD metric to 84.2 % compared with traditional approaches [14]. These results confirm the potential of AI methods in optimizing end-to-end testing and supporting decision-making under limited resource conditions. The drivers of this transformation include not only growing regulatory requirements across jurisdictions but also the industry's intention to leverage advanced technologies to reduce design-stage conflicts, optimize logistics and scheduling, and lay the foundation for developing a digital twin of the built asset.

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However, a significant gap remains between the theoretical BIM model ("as designed") and the actual implementation ("as built"). This discrepancy is reflected in the as-built documentation - a set of textual and graphical materials capturing the physical realization of design decisions. Existing approaches to comparing BIM data with as-built documentation remain mostly manual, fragmented, and vulnerable to human error, resulting in delayed defect detection, increased correction costs, and conflicts between project participants. Statistics show that up to 30 % of construction costs are associated with rework and error correction, many of which could have been prevented through timely and accurate quality control [3, 4]. Therefore, the problem of data verification is not only technical but also economic, as it directly affects project profitability.

Based on the above, a research gap is identified: despite the availability of advanced tools for generating design (BIM) models and collecting real-world data (laser scanning, photogrammetry), there is still no unified, systematic methodology for their automated comparison in near-real-time mode. Existing studies mainly address partial tasks, such as detecting collisions within a BIM model itself, but do not propose an integrated solution that covers the entire business process of verification within a single digital platform.

The purpose of the study is to substantiate an end-to-end approach to testing that allows automating the verification of compliance of design models with the actual state of objects in digital construction management platforms.

The scientific novelty lies in combining heterogeneous sources of information (BIM models and as-built drawings) within a single continuous verification cycle analogous to a CI/CD pipeline.

The author’s hypothesis is that the proposed methodology can accelerate and improve the accuracy of discrepancy detection, transforming quality control from a discrete reactive process into a continuous proactive one - similar to Continuous Integration / Continuous Delivery (CI/CD) practices in the IT industry. As demonstrated by related domains, such as complex IT ecosystems for the financial sector or government infrastructure, this approach provides the foundation for ensuring the reliability and stability of the final product.

## 2. Materials and Methods

In recent years, the development of BIM technologies has shown a clear trend toward deeper specialization and the integration of related digital tools. For instance, the report by Fortune Business Insights systematizes the BIM market by components and functionality - 3D modeling, clash detection, cost and time estimation, energy efficiency analysis, and more - and forecasts growth in AI-driven, AR/VR-integrated, and IoT-enabled solutions by 2032 [1]. In parallel, the systematic review conducted by Nikologianni A., Mayouf M., and Gullino S. [9] to assess the impact of BIM on the landscape environment identifies several bottlenecks in technology application, such as a low level of semantic interoperability, data fragmentation, and a lack of tools for evaluating environmental and socio-spatial effects.

The methodology of scientific reviews described by Huang S. et al. [2] demonstrates that scientometric analysis (including co-authorship mapping, keyword clustering, and topic evolution tracking) can effectively identify gaps in the research field and reveal the evolution of end-to-end testing approaches for BIM models.

In the domain of semantic enrichment and point cloud processing, two main directions can be observed. First, the ontological approach proposed by Dinis F. M. et al. [4] extends BIM models by converting IFC structures into OWL representations using RDF and SPARQL queries, which allows semantic interpretation of elements and attributes of construction objects. Second, deep learning-based semantic segmentation of 3D scans - where architectures such as PointNet, PointCNN, and their graph-convolutional derivatives - demonstra tes high classification accuracy for structural elements in both heritage and construction sites [5, 12].

Automation of code-based compliance checks has evolved through the design of rule sets linked to BIM parameters. In Malaysia, Ismail A. S. et al. [3] developed a user-friendly system for verifying fire safety regulations, where IFC attribute values are mapped to regulatory parameters, and a C#-based engine automatically generates discrepancy reports. Guo D., Onstein E., La Rosa A. D. [7] advanced the semantic vector approach by formalizing building codes as OWL ontologies and employing SPARQL queries to detect conflicts between the model and the code. Additionally, Santos S. et al. [11] adapted behavior-driven development (BDD) for non-functional requirements in the BIM environment by defining Gherkin scenarios and integrating them into a CI/CD pipeline for end-to-end data quality testing.

The integration of BIM into digital platforms is evolving in two major areas. Zitiello E. P. et al. [6] proposed a new paradigm of digital procurement, in which BIM metadata are automatically transmitted to e-procurement systems through REST APIs and semantic mappings, ensuring supply chain transparency and accelerating procurement processes. Similarly, Asare K. A. B., Liu R., Anumba C. J. [10] demonstrated the use of BIM for airport facility management: the digital twin links model elements to maintenance schedules, allowing real-time comparison of the actual equipment condition with planned documentation.

To verify the compliance of as-built documentation and BIM models, visualization and inspection methods are increasingly employed. Choi Y. et al. [8] describe a smart bridge application where photogrammetry and UAV scanning generate point clouds aligned with the original BIM model. Feature extraction algorithms are then used to identify defects and measure deformations, ensuring end-to-end structural verification.

Sources [13] and [14] were also applied in this research to demonstrate the potential of AI methods in optimizing end-to-end testing and supporting decision-making under limited resource conditions.

It can thus be observed that the literature is divided into two dominant approaches: the semantic–ontological and the data-driven testing paradigms based on deep learning algorithms. However, no unified framework currently exists to combine these two methods into an integrated, end-to-end pipeline architecture. Market forecasts emphasize the significance of AI and IoT, yet the existing research does not provide seamless integration with real-time data streams from sensors and devices. Moreover, there remains a disconnect between high-level analytical reports, which identify trends and industry needs, and applied case studies, which focus on localized problems without scalable solutions. Limited attention has been given to the quantitative evaluation of verification methods, with no unified benchmarks or test datasets available. The interaction between human operators and automated systems on construction sites, as well as the economic assessment of implementing end-to-end testing in design and operation workflows, also remains underexplored.

## 3. Results and Discussion

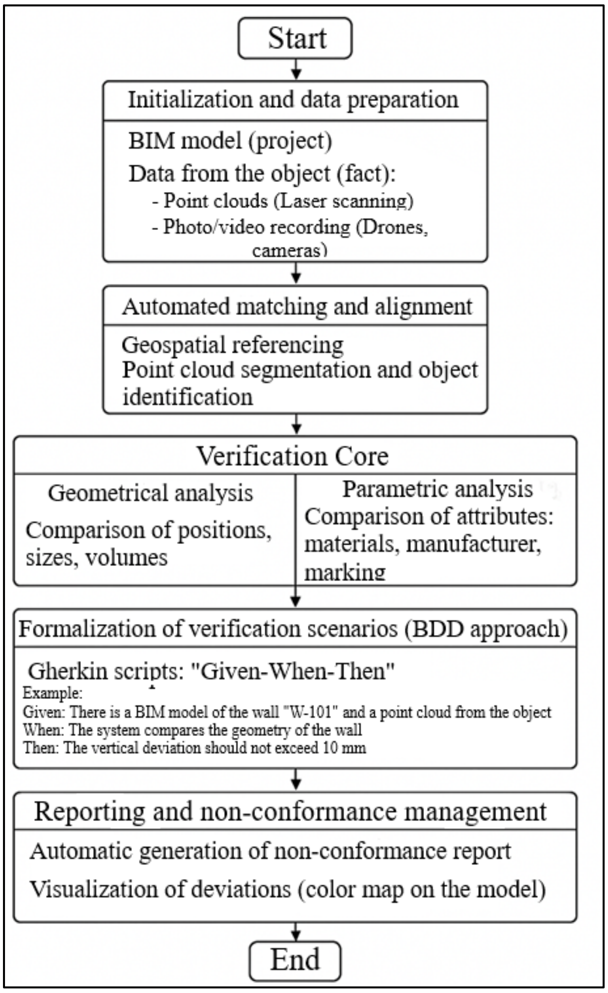


**Figure 1** Conceptual framework for end-to-end verification of BIM and ID (compiled by the author based on [2, 7, 9]

Based on the conducted analysis and in order to overcome the limitations identified in existing studies, a conceptual end-to-end testing framework is proposed for verifying the compliance of BIM models and as-built documentation (hereinafter referred to as the Framework). Its distinguishing feature lies in treating the verification process as a single, continuous scenario seamlessly integrated into the digital construction management platform. Structurally, the Framework consists of a sequence of stages that are logically arranged yet iteratively interconnected, as schematically illustrated in Figure 1.

The stages shown in Figure 1 are described in more detail below. The first stage involves initialization and data preparation. At this step, two main data streams enter the system.

- Design data – a BIM model in its native design format (e.g., RVT) and/or in the open IFC format, containing detailed three-dimensional and attribute information about structures and engineering systems.
- Actual data – heterogeneous sources such as point clouds obtained through laser scanning, photogrammetric models constructed from drone imagery, and digital as-built documentation (for instance, weld maps or hidden work inspection reports).

It is critically important to ensure a unified geospatial alignment for all incoming data. Only with guaranteed coordinate precision can subsequent data fusion and analysis be performed correctly [2, 9].

The second stage focuses on automated comparison and alignment. The system automatically aligns the point cloud with the BIM model using predefined reference points. Then, with the help of modern machine learning architectures such as Point Net++ or RandLA-Net, semantic segmentation of the point cloud is performed - identifyi ng individual structural elements (walls, columns, slabs, pipelines, etc.). Each segment is then linked to the corresponding BIM object based on its unique identifier (GUID) [4, 5].

The third stage represents the verification core of the Framework. This central module performs comprehensive data comparison along three analytical dimensions:

- Geometric analysis – calculating positional deviations, dimensions, slopes, and volumetric characteristics of elements between the "as-designed" and "as-built" models, visualizing the results as heat maps of deviations.

Parametric analysis – comparing non-spatial attributes; for instance, OCR modules recognize pipeline markings from photographs and match them to materials specified in the BIM object attributes (see Figure 2).

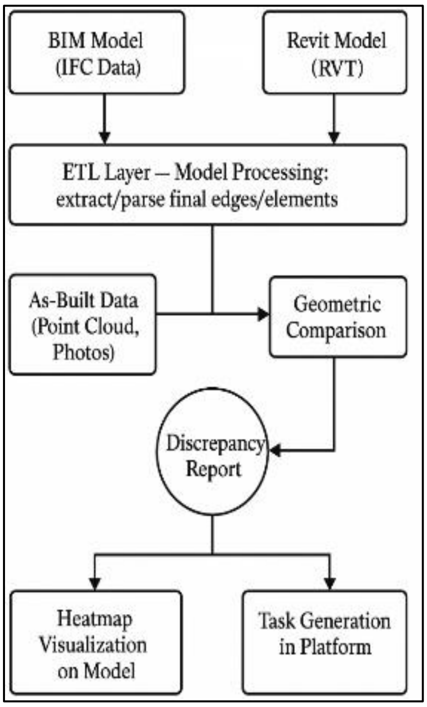


**Figure 2** Data flow diagram and visualization of deviations (compiled by the author based on [4, 5, 9, 11]

The fourth stage focuses on formalizing verification scenarios using the BDD approach. To ensure maximum transparency and consistency of verification across all stakeholders (quality engineers, designers, and site managers), the Behavior-Driven Development methodology is implemented. Control criteria are described in structured natural language using Gherkin syntax and Given–When–Then templates.

Example of a Gherkin scenario for wall verticality verification

- Feature: Wall verticality check
- Scenario: Evaluation of wall deviation from the vertical axis
- Given: The BIM model of the 5th floor and the point cloud
- When: The system identifies the wall with ID Wall-Exterior-05-A1 and analyzes its actual geometry
- Then: The maximum surface deviation from the vertical plane must not exceed 15 mm along the full height of the floor
- And: A report is generated indicating the maximum deviation and its location

Such scenarios serve simultaneously as human-readable specifications and machine-interpretable test cases that the verification core can automatically execute. This fully aligns with the BDD concept, where test examples function as "living documentation" of the system [6, 7].

At the fifth stage, the Framework introduces a nonconformity management process. When a deviation exceeding the specified threshold is detected, the system automatically generates a nonconformity report containing

- a visualization of the issue (a model screenshot with a heat map overlay),
- the exact coordinates of the inspected area,
- deviation values,
- a reference to the corresponding regulatory document or specific BDD scenario.

Next, the platform's task management module automatically creates an incident assigned to a responsible performer (for example, the site supervisor). After correcting the defect, the assignee updates the incident status in the system and attaches confirmation materials. This action triggers a re-verification cycle (e.g., a follow-up scan of the area) to confirm successful correction. Such a closed loop of "detection – assignment – correction – validation" represents a practical implementation of continuous control principles, conceptually similar to the CI/CD (Continuous Integration / Continuous Delivery) approach in the IT industry, where every system component is constantly validated and integrated into the whole [10, 11].

The effectiveness of the proposed Framework is evaluated using several key performance indicators compared with traditional manual control methods. Comparative results are presented in Table 1 [5, 8, 12].

**Table 1** Comparative efficiency of verification methods (compiled by the author based on [5, 8, 12])

| Metric | Traditional Manual Control | Automated Verification (Framework) | Justification |
|---|---|---|---|
| Verification time per 1000 $m^2$ | 16–24 person-hours | 2–4 machine-hours | Automation of data collection and processing reduces time by a factor of 5–8. |
| Accuracy of deviation detection | 60-75% | > 95% | Elimination of human error; high scanner precision (2–5 mm). |
| Cost per detected defect | High (due to labor costs) | Low (after implementation) | Main expenses relate to equipment depreciation and software. |
| Inspection coverage | Selective (control points) | Complete (100 % of surfaces) | Laser scanning ensures data collection across the entire visible area. |
| Report generation time | 24-72 hours | 0.5-2 hours | Automated reporting immediately after data processing. |

The metrics presented in Table 1 translate directly into measurable economic benefits. Reduced verification and reporting time accelerates decision-making and minimizes downtime. Increased accuracy and coverage enable early-stage defect detection when correction costs are lowest, dramatically reducing the share of rework expenditures mentioned in the Introduction. Consequently, the technological efficiency of the Framework forms the basis for improving both economic performance and project manageability.

Analysis of the results highlights that this Framework goes beyond merely automating established procedures - it fundamentally transforms the approach to construction quality control. Instead of the traditional reactive model of "detect and fix," it implements a proactive strategy of "prevent and continuously validate." Integration with a digital platform creates a unified, transparent information space for all project stakeholders, where every deviation is logged, tracked, and verified until full resolution. This approach not only minimizes the risk of schedule delays and cost overruns but also enhances the overall quality and safety of the constructed asset. The success of large-scale and mission-critical projects - from skyscraper construction to national digital infrastructure - depends on a culture of quality shared by all participants and embedded in the architecture of processes.

Despite the clear advantages, implementing such a solution entails certain challenges: significant upfront investment in scanning equipment and software, in-depth personnel training, and complex tasks related to the semantic interpretation of collected data. Nevertheless, the experience of digitalization in related industries demonstrates that the long-term benefits - improved reliability, risk reduction, and the creation of a fully functional digital twin - greatly outweigh the initial costs.

## 4. Conclusion

A comprehensive review of the relevant literature confirmed the high relevance of the research topic and revealed a significant scientific gap in the field of integrated automation of construction quality control processes.

The proposed Framework is based on the adaptation of end-to-end (E2E) testing and behavior-driven development (BDD) principles, originally developed in software engineering, and represents a holistic system that combines BIM technology, laser scanning, and machine learning into a single continuously operating workflow. The core of the methodology is the verification module, which performs a multi-dimensional analysis - geometric, parametric, and regulatory - while the use of formalized verification scenarios ensures maximum transparency and engagement of all project participants.

Comparative analysis shows that implementation of the proposed approach can potentially reduce time expenditures, increase defect detection accuracy, and provide complete inspection coverage of all surfaces instead of selective sampling. Therefore, the author's hypothesis that construction quality control can evolve from a reactive process into a proactive strategy is theoretically confirmed.

The scientific novelty of the study lies in the formation of an integrated "CI/CD for construction" concept, where verification ceases to be an isolated stage and becomes a continuous component of the project life cycle. The practical significance of the research is that the proposed Framework can serve as a conceptual foundation for construction companies and developers of digital platforms in creating next-generation quality management systems. Future research should focus on pilot testing of the Framework to quantitatively assess its effectiveness under real construction site conditions and to identify specific industry constraints.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

## References

[1] Building Information Modeling (BIM) Market Size, Share & Industry Analysis, By Component (Software & Services), By Functionality (3D Modeling, Visualization, Clash Detection, Conflict Resolution, Cost Estimation, Time Scheduling & Sequencing, Sustainability & Energy Analysis), By Enterprise Type (Large Enterprises, SMEs), By Technology (AI-Driven BIM Solutions, AR/VR-Integrated BIM, IoT-Enabled BIM), By End-user (Architect and Engineers, Facility or Construction Managers), Regional forecast, 2032. [electronic resource]. – Access mode:

https://www.fortunebusinessinsights.com/building-information-modelling-software-market-102986 (date of request: 07/20/2025).

[2] Huang S. et al. Plastic waste management strategies and their environmental aspects: a scientific analysis and comprehensive review //International Journal of Environmental Research and Public Health. – 2022. – Vol. 19. – No. 8. – pp. 1-31. https://doi.org/10.3390/ijerph19084556 .

[3] Ismail A. S. et al. BIM-Based Automated Code Compliance Checking System in Malaysian Fire Safety Regulations: A User-Friendly Approach //Buildings. – 2023. – Vol. 13. - No. 6. – pp. 1-25. https://doi.org/10.3390/buildings13061404 .

[4] Dinis F. M. et al. BIM and semantic enrichment methods and applications: A review of recent developments //Archives of Computational Methods in Engineering. – 2022. – Vol. 29. - No. 2. – pp. 879-895.

[5] Rauch L., Braml T. Semantic point cloud segmentation with deep-learning-based approaches for the construction industry: A survey //Applied Sciences. – 2023. – Vol. 13. - No. 16. – pp. 1-8. https://doi.org/10.3390/app13169146 .

[6] Zitiello E. P. et al. Synergy Between BIM and e-Procurement: A New Paradigm for Digital Procurement Management //International Conference on Computational Science and Its Applications. – Cham: Springer Nature Switzerland, 2025. – pp. 63-77.

[7] Guo D., Onstein E., La Rosa A. D. A semantic approach for automated rule compliance checking in the construction industry //IEEE Access. – 2021. – Vol. 9. – pp. 129648-129660.

[8] Choi Y. et al. Utilization and verification of imaging technology in smart bridge inspection system: an application study //Sustainability. – 2023. – Vol. 15. - No. 2. – pp. 1-31. https://doi.org/10.3390/su15021509 .

[9] Nikologianni A., Mayouf M., Gullino S. Building Information Modeling (BIM) and the impact on landscape: A systematic review of evolutions, shortfalls and future opportunities //Cleaner Production Letters. – 2022. – Vol. 3. – pp. 1-10. https://doi.org/10.1016/j.clpl.2022.100016 .

[10] Asare K. A. B., Liu R., Anumba C. J. Building information modelling for airport facility management: the case of a US airport //Infrastructure Asset Management. – 2023. – Vol. 11. -No. 1. – pp. 3-14.

[11] Santos S. et al. Using behavior-driven development (bdd) for non-functional requirements //Software. – 2024. – Vol. 3. - No. 3. – pp. 271-283. https://doi.org/10.3390/software3030014 .

[12] Yang S., Hou M., Li S. Three-dimensional point cloud semantic segmentation for cultural heritage: a comprehensive review //Remote Sensing. – 2023. – Vol. 15. - No. 3. – pp. 1-8. https://doi.org/10.3390/rs15030548 .

[13] Husakovskyi A. Enhancing Automation in QA Engineering with Advanced AI Techniques in Complex Distributed Systems //Asian Journal of Research in Computer Science. – 2025. – Vol. 18. – No. 4. – pp. 410-415. https://doi.org/10.9734/ajrcos/2025/v18i4628 .

[14] Husakovskyi A. Harnessing Graph Neural Networks (Gnn) For Automated Test Case Prioritization: Challenges and Opportunities in Qa Automation //The American Journal of Engineering and Technology. – 2025. – Vol. 7. – No. 4. – pp. 7-15. https://doi.org/10.37547/tajet/Volume07Issue04-02 .