A BIM-Integrated Digital Inspection Framework for Improving Construction Quality Management and Cost Control

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ABSTRACT

The construction industry continues to encounter challenges in maintaining construction quality and controlling project costs due to fragmented inspection processes, paper-based documentation, and inefficient information management. Conventional quality inspection practices are often associated with delayed reporting, limited traceability, human error, and ineffective communication among project stakeholders, leading to rework, schedule delays, and increased project costs. This study proposes a BIM-integrated Digital Inspection and Testing System to improve construction quality management through the integration of Building Information Modelling (BIM), Novade, and business intelligence platforms (Microsoft Power BI and Google Data Studio). The study adopted the System Development Life Cycle (SDLC) methodology to analyse the existing inspection workflow, identify its limitations, and develop a conceptual digital framework that supports real-time inspection, centralized information management, BIM-based quality tracking, and analytical reporting. The proposed system establishes an end-to-end digital workflow that integrates field data collection, cloud-based information storage, BIM-enabled traceability, and interactive dashboards to enhance inspection efficiency, stakeholder collaboration, and data-driven decision-making. Unlike existing studies that examine BIM, mobile inspection, or analytics independently, this framework integrates these technologies into a unified quality management ecosystem. Although the framework has not yet been implemented or empirically validated, it provides a practical foundation for future prototype development and industry application. The proposed system has the potential to reduce documentation redundancy, improve quality traceability, minimize rework, and strengthen construction cost control, thereby supporting the digital transformation of construction quality management.

Keywords: Construction Quality Management; Building Information Modelling (BIM); Digital Inspection; Novade; Power BI; Google Data Studio; System Development Life Cycle (SDLC); Cost Control.

INTRODUCTION

The construction industry plays a pivotal role in supporting economic growth through the development of buildings, infrastructure, and public facilities. The success of construction projects is commonly assessed based on three interrelated performance dimensions: quality, cost, and time. Among these, quality management has become increasingly important because it directly influences project performance, client satisfaction, regulatory compliance, and the long-term functionality of constructed assets (Toakley and Marosszeky, 2003; Samsudin et al., 2012). Effective Construction Quality Management (CQM) is therefore essential to ensure that construction activities conform to design specifications, contractual obligations, and industry standards throughout the project lifecycle (Ren and He, 2013; Cajzek and Klanšek, 2014).

Despite significant technological advancements in the Architecture, Engineering, Construction, and Operations (AECO) industry, maintaining consistent construction quality remains a persistent challenge. Conventional inspection and testing practices continue to rely heavily on paper-based documentation, manual checklists, spreadsheets, and sequential approval processes. These traditional methods are often characterised by fragmented information management, delayed reporting, inconsistent documentation, and human error, which reduce the efficiency and reliability of quality control activities (Wendebaum and Fliedner, 2005; Acikara, Kazaz and Ulubeyli, 2017). Consequently, quality deficiencies are frequently identified only after construction work has progressed, leading to rework, schedule delays, material wastage, contractual disputes, and increased project costs (Toakley and Marosszeky, 2003; Samsudin et al., 2012).

The digital transformation of the construction industry has introduced new opportunities to improve quality management through the integration of advanced information technologies. Among these technologies, Building Information Modelling (BIM) has emerged as a key enabler for digital construction by providing a collaborative platform that integrates project information throughout the design, construction, and operational phases (Cheng, 2018; Marcellino, Castelblanco and De Marco, 2023). Unlike conventional documentation systems, BIM enables quality inspection records to be linked directly with digital building components, thereby improving information traceability, coordination, and communication among project stakeholders (Chen and Luo, 2014; Jiang, 2025). Furthermore, BIM supports lifecycle information management by providing a centralized environment for project visualization, clash detection, quality documentation, and decision-making (Hasnain, 2024).

Complementing BIM, mobile inspection applications have transformed field inspection activities by enabling inspectors to capture quality data, photographs, defect records, and inspection checklists directly from construction sites using mobile devices. Digital inspection platforms reduce reliance on paper-based reporting while facilitating real-time information sharing and standardized inspection procedures (Alomari, Gambatese and Anderson, 2017; Jiang, 2025). The availability of cloud-based information management further enhances collaboration by allowing contractors, consultants, and clients to access updated inspection records from a common digital environment.

In addition to digital inspection, business intelligence technologies such as Microsoft Power BI and Google Data Studio have expanded the capability of construction organisations to analyse quality performance using interactive dashboards and real-time visualisation. These analytical platforms convert raw inspection data into meaningful performance indicators, enabling project managers to monitor defect trends, evaluate inspection progress, identify quality risks, and support evidence-based decision-making (Alasadi, 2024; Marcellino, Castelblanco and De Marco, 2023). The integration of BIM, digital inspection systems, and data analytics therefore provides a comprehensive digital ecosystem capable of improving both construction quality and project cost performance.

Although numerous studies have investigated BIM implementation, digital quality management, mobile inspection technologies, and cost management independently, limited research has focused on integrating these technologies into a unified framework for construction quality inspection and testing. Existing studies predominantly examine the individual capabilities of BIM, digital inspection platforms, or business intelligence tools without establishing a comprehensive workflow that connects on-site inspection, centralized information management, BIM visualization, and real-time analytical reporting (Chen and Luo, 2014; Cheng, 2018; Marcellino, Castelblanco and De Marco, 2023). This fragmented approach limits the ability of construction organisations to fully leverage digital technologies for proactive quality management and cost control.

Problem Statement

The construction industry continues to experience persistent challenges in maintaining high standards of quality while simultaneously achieving cost and schedule objectives. Despite the widespread implementation of quality management systems, construction defects, rework, project delays, and budget overruns remain common issues that adversely affect project performance and stakeholder satisfaction (Toakley and Marosszeky, 2003; Samsudin et al., 2012; Ren and He, 2013). These challenges indicate that existing quality management practices are often insufficient to address the increasing complexity of modern construction projects, particularly those involving multiple stakeholders, large volumes of project information, and stringent regulatory requirements.

One of the primary causes of ineffective quality management is the continued reliance on conventional inspection and testing procedures. Many construction projects still depend on paper-based inspection forms, manual documentation, spreadsheets, and email communication to record inspection activities and quality test results. Such approaches are inherently fragmented and susceptible to human error, incomplete documentation, inconsistent reporting, and delays in information exchange (Wendebaum and Fliedner, 2005; Acikara, Kazaz and Ulubeyli, 2017). The existing inspection process examined in this study similarly demonstrates that multiple manual approval stages, separate documentation systems, and repetitive administrative activities reduce inspection efficiency and hinder timely corrective action.

The limitations of manual inspection processes also reduce the traceability and accessibility of quality information. Inspection reports, photographs, laboratory test results, and approval records are typically stored in different physical or digital locations, making it difficult to retrieve historical information or monitor quality performance throughout the project lifecycle. Consequently, project managers often lack timely and accurate information to identify recurring quality issues, evaluate contractor performance, or implement preventive measures before defects escalate into costly rework. This fragmented information management contributes to inefficient decision-making and weakens overall project governance (Cajzek and Klanšek, 2014; Samsudin et al., 2012).

Although Building Information Modelling (BIM) has emerged as a transformative technology for digital construction, its implementation in construction quality management remains relatively limited. Most BIM applications focus on design coordination, clash detection, visualization, and project planning rather than integrating quality inspection records with digital building components (Cheng, 2018; Marcellino, Castelblanco and De Marco, 2023). Similarly, digital inspection platforms and mobile applications have demonstrated significant potential for improving on-site data collection and reporting; however, these technologies are frequently implemented independently without seamless integration with BIM and business intelligence systems (Alomari, Gambatese and Anderson, 2017; Jiang, 2025). As a result, construction organisations continue to operate separate digital platforms that restrict information sharing, reduce interoperability, and limit the benefits of digital transformation.

Another significant limitation is the underutilisation of construction data for strategic decision-making. Modern construction projects generate substantial quantities of inspection records, defect reports, laboratory test results, and progress updates. However, much of these data remain stored in isolated databases or static reports with limited analytical capability. Without integrated data analytics, project managers are unable to monitor quality performance in real time, identify recurring defect patterns, evaluate inspection efficiency, or predict quality-related risks. Consequently, quality management remains largely reactive, where corrective actions are implemented only after defects have occurred rather than through proactive monitoring and early intervention (Alasadi, 2024; Hasnain, 2024).

The deficiencies in current quality management practices also have direct financial implications. Poor quality control contributes to repeated inspections, increased labour costs, material wastage, project delays, and contractual claims, all of which reduce project profitability. Previous studies have consistently demonstrated that early detection of construction defects through digital technologies can significantly reduce rework and improve cost performance by enabling timely corrective action and better resource management (Chen and Luo, 2014; Alasadi, 2024; Gerber, Becerik-Gerber and Kunz, 2010). Nevertheless, many construction organisations have yet to establish an integrated digital quality management system capable of simultaneously supporting inspection, information management, and cost control.

Although previous research has investigated construction quality management, Building Information Modelling (BIM), mobile inspection technologies, and digital cost management, these technologies have largely been examined as separate solutions. There remains a significant gap in developing an integrated framework that combines BIM, digital inspection platforms such as Novade, and business intelligence tools including Microsoft Power BI and Google Data Studio into a centralized quality management ecosystem. Existing studies provide limited evidence on how these technologies can operate collectively to improve inspection efficiency, information traceability, stakeholder collaboration, and data-driven decision-making across the construction project lifecycle.

Therefore, this study addresses this research gap by proposing a BIM-integrated Digital Inspection and Testing System that consolidates digital inspection, BIM, centralized information management, and business intelligence analytics into a unified quality management framework. The proposed system is intended to replace fragmented manual inspection practices with an integrated digital workflow capable of supporting real-time inspection, automated reporting, centralized data management, and analytical visualization. By improving the accuracy, accessibility, and traceability of quality information, the proposed framework aims to enhance construction quality management, reduce quality-related rework, strengthen cost control, and support the digital transformation of the construction industry.

LITERATURE REVIEW

Construction quality management has evolved from conventional inspection-based control towards integrated and data-driven quality assurance. Earlier studies emphasised that effective quality management requires systematic coordination across the project lifecycle rather than relying solely on final inspection activities (Toakley and Marosszeky, 2003; Samsudin et al., 2012). Structured quality management can improve efficiency, reduce defects and enhance customer satisfaction; however, implementation remains constrained by fragmented responsibilities, resource limitations and inconsistent organisational commitment (Cajzek and Klanšek, 2014; Acikara, Kazaz and Ulubeyli, 2017). These limitations are particularly significant where quality management remains dependent on manual documentation and subjective inspection practices.

Digitalisation provides a mechanism for addressing several weaknesses associated with conventional quality control. Digital inspection systems enable electronic recording, centralized information storage and faster communication between project stakeholders. In contrast to paper-based inspection, digital workflows potentially improve data accessibility, traceability and consistency. Nevertheless, the reviewed literature provides relatively limited evidence specifically evaluating end-to-end digital inspection systems. Much of the existing research discusses digital inspection indirectly through BIM and broader construction information management applications. This indicates that the technological capability for digital inspection is established, but its integration into comprehensive construction quality workflows remains insufficiently examined.

Building Information Modelling (BIM) represents the most extensively investigated digital technology within the reviewed literature. BIM facilitates visualization, information integration, coordination and lifecycle management, allowing quality information to be connected with individual construction elements (Cheng, 2018; Chen and Luo, 2014). Chen and Luo (2014), in particular, demonstrated the applicability of BIM for construction quality management by linking quality information to the digital model. More recent research continues to position BIM as an enabling platform for improving construction engineering quality and information management (Jiang, 2025). BIM can also facilitate early identification of design conflicts, thereby reducing the likelihood of downstream construction errors and rework (Shewale et al., 2023).

However, BIM should not be regarded as an independent solution to construction quality problems. Its effectiveness depends on information quality, interoperability, technical competency and organisational adoption. Challenges relating to implementation capability, technology acceptance and integration with established construction processes continue to restrict BIM utilisation (Ngoc et al., 2024; Hasnain, 2024). Consequently, the literature suggests a transition from examining BIM merely as a modelling technology towards considering it as part of a wider interconnected digital information ecosystem.

Mobile applications complement BIM by bringing digital quality management directly to the construction site. Mobile inspection applications enable field personnel to capture checklists, photographs, observations and defect information at the location where construction activities occur. Their primary contribution is therefore not simply replacing paper forms, but reducing the temporal gap between inspection, documentation, communication and corrective action. However, within the reviewed studies, mobile inspection applications remain less extensively investigated than BIM. The evidence is therefore insufficient to conclude that mobile applications alone improve construction quality or reduce project costs. Their value is more plausibly realised when field data are connected to centralized project information systems and subsequent analytical processes.

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Data analytics represents another important development in digital construction management. As construction organisations increasingly generate digital inspection and project data, analytical platforms can transform raw information into performance indicators, trends and management insights. BIM-based information systems provide the foundation for organizing project information, while analytical applications allow decision-makers

to interpret this information more effectively (Marcellino, Castelblanco and De Marco, 2023; Jiang, 2025). Nevertheless, the reviewed literature concentrates substantially more on BIM implementation than on business intelligence applications specifically for construction quality management. Therefore, the contribution of platforms such as Power BI or Google Data Studio to quality-control performance remains an underdeveloped area within the selected literature.

Table 1: Critical Analysis of Literature on Digital Construction Quality Management

Research Area	Key Literature	Main Contribution	Critical Limitation	Implication for This Study
Construction Quality Management	Toakley and Marosszeky (2003); Samsudin et al. (2012); Ren and He (2013); Cajzek and Klanšek (2014); Acikara et al. (2017)	Establishes quality management as a lifecycle and organisational process associated with efficiency, compliance and customer satisfaction	Predominantly focuses on management practices rather than integrated digital quality-control mechanisms	Demonstrates the need to digitalise conventional quality management processes
Digital Inspection	Wendebaum and Fliedner (2005); Jiang (2025)	Indicates potential for automated documentation and digital monitoring of quality activities	Limited research on complete construction inspection workflows and cross-platform integration	Supports development of a centralized digital inspection workflow
BIM for Quality Control	Chen and Luo (2014); Cheng (2018); Shewale et al. (2023); Jiang (2025)	Enables quality-data integration, visualization, coordination, traceability and early problem identification	BIM applications are frequently isolated from field inspection and analytical platforms	Positions BIM as the information backbone of the proposed system
BIM Implementation	Marcellino et al. (2023); Ngoc et al. (2024); Hasnain (2024)	Demonstrates BIM's wider potential for integrated construction information management	Interoperability, competency, adoption and organisational barriers remain	Integration must consider practical workflow and information accessibility rather than technology alone
Mobile Inspection Applications	Alomari et al. (2017); related BIM literature	Enables field-based digital data capture and faster	Limited direct empirical evidence on quality and cost outcomes from	Mobile technology is proposed as the field-data acquisition layer

		information transfer	mobile inspection applications	rather than a standalone solution
Data Analytics	Jiang (2025); Marcellino et al. (2023); Alasadi (2024)	Supports monitoring, visualization and data-informed construction decision-making	Limited focus on inspection-specific analytics and business intelligence dashboards	Justifies integration of Power BI/Google Data Studio with inspection information
Digital Cost Control	Gerber et al. (2010); Chen and Luo (2014); Alasadi (2024)	Digital information and BIM can improve coordination, reduce waste and support cost management	Direct causal evidence linking digital inspection to measurable cost savings remains limited	Cost improvement should be treated as an anticipated outcome of reduced rework and improved information management
Overall Research Gap	Synthesis of reviewed studies	Digital technologies individually demonstrate strong potential for improving construction management	Existing literature remains fragmented across BIM, inspection, analytics and cost control, with limited end-to-end integration	Provides justification for an integrated BIM–mobile inspection–analytics quality management framework

Digitalisation is also closely related to construction cost control because quality failures generate financial consequences through rework, wasted materials, additional labour and schedule disruption. BIM can enhance cost management by improving information accuracy, coordination and change management (Alasadi, 2024). Furthermore, BIM and Lean Construction have complementary capabilities in reducing waste and improving process efficiency (Gerber, Becerik-Gerber and Kunz, 2010). However, the relationship between digital quality inspection and cost performance is frequently inferred rather than directly measured. Although earlier defect detection is expected to reduce rework expenditure, stronger empirical evidence is required to demonstrate the magnitude of cost benefits generated by integrated digital quality systems.

Collectively, the literature demonstrates considerable progress from conventional quality management towards BIM-enabled and digitally supported construction processes. However, the existing knowledge remains technologically fragmented. BIM, quality management, mobile inspection, analytics and cost management are predominantly investigated as separate research domains. Limited attention has been directed towards an end-to-end digital quality management framework that connects field inspection, BIM-based information integration, centralized records and analytical visualization. This integration gap provides the basis for the proposed BIM-integrated Digital Inspection and Testing System in this study.

The analysis Table 1 indicates that BIM is relatively mature within the literature, whereas the integration of mobile inspection and business intelligence analytics with BIM-based quality management remains comparatively underdeveloped. Accordingly, the contribution of the present study lies not in proposing BIM, mobile inspection or analytics as new technologies individually, but in integrating them into a coherent workflow in which Novade supports field data acquisition, BIM provides component-level information and

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traceability, and Power BI/Google Data Studio supports quality monitoring and managerial analysis. This integration directly addresses the technological fragmentation identified across the reviewed literature

Review of the Current Approach

The current construction quality inspection process remains predominantly manual and document-centred, involving multiple project participants such as contractors, site engineers, clerks of works, QA/QC personnel, consultants, and clients. Typically, the contractor initiates a Request for Inspection (RFI) after completing a construction activity, followed by inspection, verification, approval, or rejection by the responsible parties. Where non-compliance is identified, corrective work is undertaken before the activity is submitted for re-inspection. Although this workflow provides formal control and accountability, its effectiveness is constrained by repetitive documentation, sequential approvals, and fragmented information exchange.

A major weakness of the current approach is its reliance on paper-based forms, spreadsheets, physical files, and informal communication channels. Inspection findings and quality-test results, including concrete cube test records, may be stored separately, increasing the risk of missing information and making historical data retrieval difficult. This fragmentation prevents the establishment of a single, reliable source of quality information and reduces the ability of stakeholders to monitor inspection status consistently. From an information-management perspective, the problem is therefore not merely the use of paper, but the absence of an integrated mechanism for capturing, updating, retrieving, and analysing quality information.

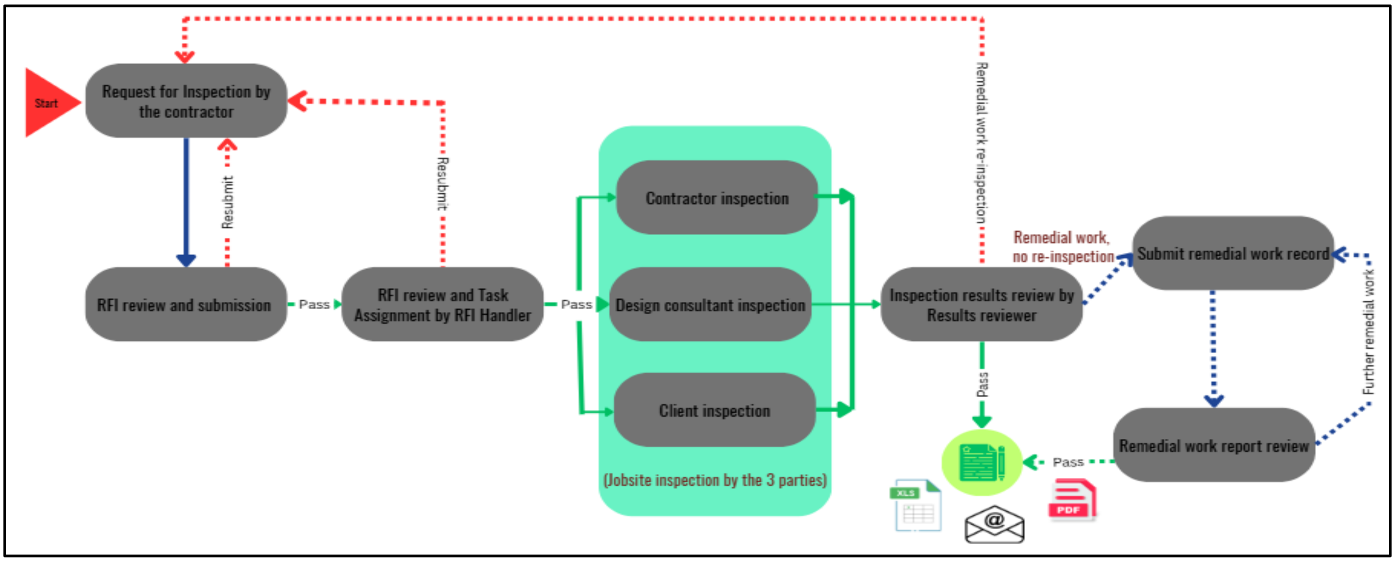

Figure 1: Workflow Diagram of the Current Work Inspection Process

The existing approach is also strongly dependent on individual inspectors. Visual inspection outcomes may be influenced by professional experience, knowledge, interpretation, and judgement, creating potential variation in defect identification and reporting. The manuscript identifies this subjectivity as a contributor to incomplete or inaccurate inspection information. Consequently, conventional quality inspection is largely reactive: non-conformances are identified during or after inspection and subsequently corrected through rework and re-inspection rather than systematically anticipated through continuous information monitoring.

Another critical limitation concerns communication and approval. The conventional workflow requires information to move sequentially from contractors to consultants and clients. Where documents are submitted manually or exchanged through disconnected communication channels, the time between inspection, review, corrective action, and approval can increase. The manuscript further notes that manual communication can delay the sharing of critical information and consequently postpone defect identification and corrective action. Such delays are particularly problematic for activities that must be inspected before subsequent work proceeds, as unresolved inspection issues can affect downstream construction activities.

The technological environment supporting the existing process is similarly fragmented. Paper forms, spreadsheets, and manual reporting tools provide basic documentation functions but operate independently and provide limited synchronization. Although these tools may be adequate for recording individual transactions, they provide limited support for real-time monitoring, cross-project analysis, automated reporting, or integration with BIM. The resulting information silos restrict the ability of project managers to identify recurring defects, monitor inspection turnaround times, assess quality trends, or establish relationships between quality deficiencies and project cost.

Cost implications arise principally through the delayed identification and resolution of quality problems. Repeated inspections, corrective works, additional labour, wasted materials, and disruption to subsequent activities can increase project expenditure. Previous BIM-based quality research indicates that improving information integration and identifying quality issues earlier can contribute to reduced rework and improved construction management (Chen and Luo, 2014; Cheng, 2018). Therefore, while the current process fulfils the basic requirement for inspection and approval, it provides insufficient integration, responsiveness, and analytical capability for contemporary data-driven construction quality management.

Overall, the review indicates that the principal weakness of the existing approach is fragmentation rather than the inspection procedure itself. The conventional RFI–inspection–approval process establishes necessary quality control checkpoints; however, the information supporting these checkpoints is dispersed across manual forms, spreadsheets, files, and communication channels. The required improvement is therefore not to remove established inspection governance, but to digitally integrate the existing process. A suitable solution should preserve inspection responsibilities and approval authority while introducing real-time field data capture, centralized information storage, BIM-based traceability, automated reporting, and analytical dashboards. This requirement provides the functional basis for the proposed BIM-integrated Digital Inspection and Testing System.

Table 2: Review of the Current Construction Quality Inspection Approach

Aspect	**Current Approach**	**Critical Limitation**	**Consequence**	**Digital Requirement**
Inspection initiation	Contractor submits RFI after work completion	Predominantly sequential and reactive	Quality problems may only become visible after work has progressed	Real-time digital inspection workflow
Site inspection	Visual inspection using paper checklists	Dependent on inspector judgement and manual recording	Potential inconsistency and incomplete records	Standardised digital checklist and evidence capture
Quality-test records	Paper records, physical files or spreadsheets	Information distributed across different storage locations	Difficult retrieval and weak traceability	Centralised digital repository
Defect management	Defects recorded and corrective work undertaken after rejection	Primarily corrective rather than preventive	Rework, repeat inspection and possible delay	Real-time defect tracking and status monitoring

Documentation	Paper forms, Excel and manual reports	Duplication, version inconsistency and potential data loss	Reduced reliability of project information	Controlled digital records
Communication	Manual submission, email and informal communication	Information transfer is not instantaneous	Delayed response and corrective action	Integrated stakeholder communication
Approval	Sequential contractor–consultant–client review	Multiple hand-offs increase turnaround time	Delayed construction progression	Digital review and approval
Data integration	Systems operate independently	Data silos and limited interoperability	No unified view of quality performance	Integrated information environment
BIM linkage	Inspection information generally independent of BIM	Defects cannot readily be associated with specific model elements	Limited spatial and lifecycle traceability	BIM-linked inspection records
Performance monitoring	Static and manually prepared reports	Limited real-time visibility	Management decisions depend on delayed information	Interactive quality dashboard
Cost control	Quality and cost information managed separately	Financial impact of defects is difficult to trace systematically	Weak linkage between quality failure, rework and cost	Quality-cost analytics
Decision-making	Primarily based on inspection reports and professional judgement	Limited analytical support	Reactive rather than evidence-based management	Data-driven analytics and trend identification

Proposed System Development

To overcome the limitations of the current manual inspection process, this study proposes a BIM-integrated Digital Inspection and Testing System that combines Building Information Modelling (BIM), Novade, and business intelligence platforms (Microsoft Power BI and Google Data Studio) into a unified digital quality management framework.

The proposed system is developed based on the System Development Life Cycle (SDLC) methodology, which provides a structured approach for analysing existing processes, designing the digital workflow, integrating technological components, and evaluating the proposed solution. Unlike the conventional inspection system, which relies on fragmented documentation and sequential information exchange, the proposed framework establishes a centralized digital environment that supports real-time inspection, automated reporting, and data-driven decision-making.

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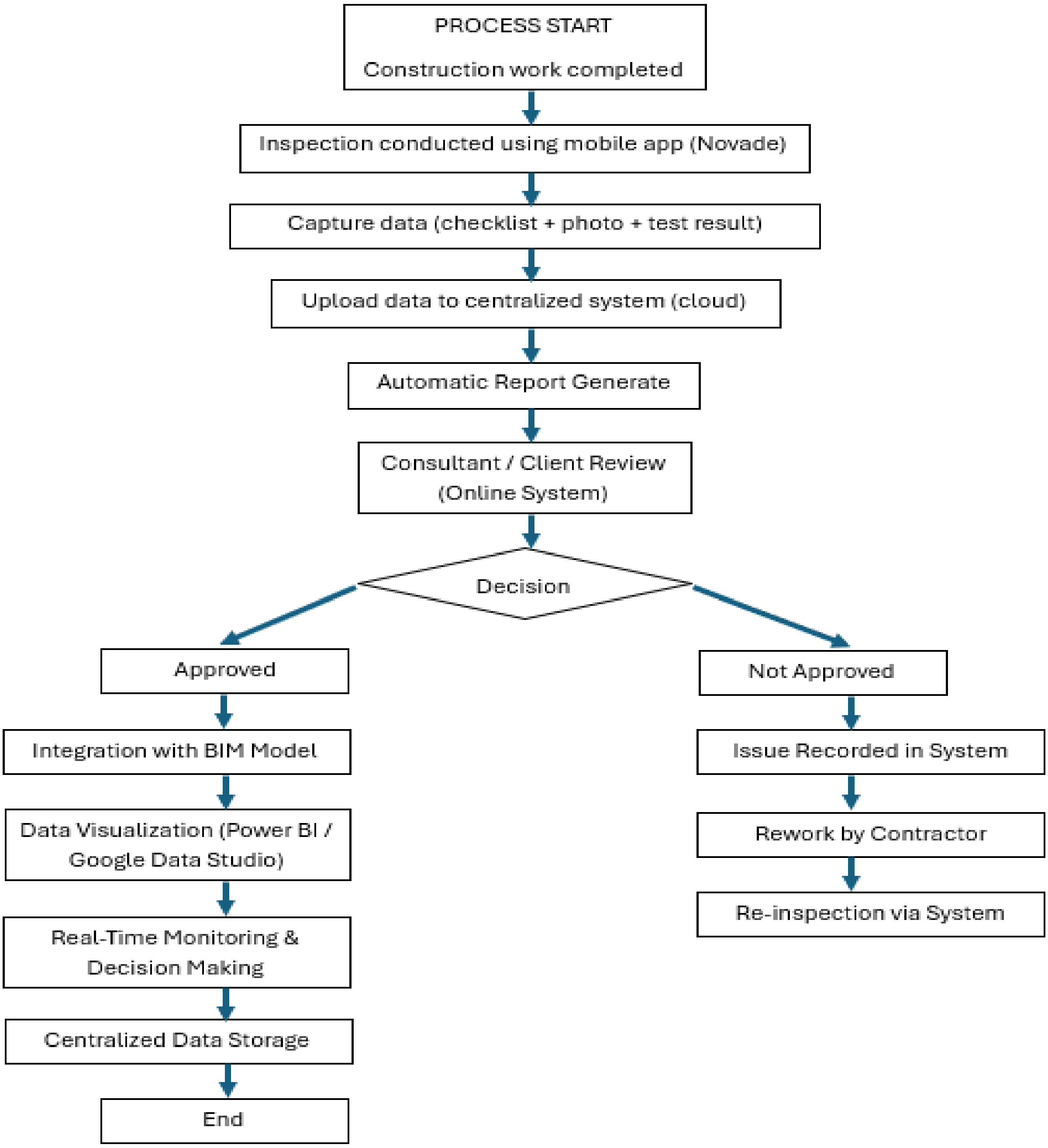

Figure 2 : Workflow diagram the proposed system

The proposed system begins when a construction activity is completed and becomes ready for quality inspection. Instead of submitting a paper-based Request for Inspection (RFI), the contractor initiates a digital inspection request through the Novade mobile application. Site engineers and quality inspectors complete standardized digital checklists, capture photographic evidence, record laboratory test results, and document observations directly on-site using mobile devices. Digital data entry minimizes transcription errors, eliminates duplicate documentation, and ensures that inspection information is immediately available within the centralized information system.

Following data acquisition, inspection records are automatically synchronised with a centralized cloud database. The centralized database serves as the project's single source of truth, consolidating inspection records, defect reports, approval status, photographs, and testing results from multiple project stakeholders. Unlike conventional document management, where quality records are distributed across paper files, spreadsheets, and email correspondence, centralized information management improves document consistency, traceability, and accessibility while significantly reducing administrative effort.

A distinguishing feature of the proposed framework is the integration of inspection information with the Building Information Model (BIM). Each inspection record is linked to its corresponding building component, enabling quality information to be visualized directly within the digital model. This integration enhances defect traceability by allowing project stakeholders to identify the precise location, status, and inspection history of individual construction elements. Consequently, BIM functions not only as a visualization tool but also as an integrated information management platform supporting quality assurance throughout the project lifecycle.

The proposed system further incorporates Microsoft Power BI and Google Data Studio to transform inspection records into interactive dashboards and management reports. Rather than relying on manually prepared spreadsheets, project managers can monitor inspection progress, defect trends, non-conformance status, approval turnaround time, and quality performance indicators through real-time visualization. These analytical capabilities enable proactive quality management by identifying recurring defects, evaluating contractor performance, and supporting timely corrective actions before quality issues develop into costly rework or project delays.

The digital workflow also improves stakeholder collaboration. Contractors, consultants, and clients access the same centralized project information through an integrated digital platform, thereby reducing communication delays and inconsistencies associated with manual document exchange. Digital approval workflows further accelerate the inspection process by allowing consultants and clients to review inspection submissions remotely, while automated notifications facilitate timely responses and corrective actions. This collaborative environment improves transparency, accountability, and coordination among project participants.

From a project management perspective, the proposed framework supports both construction quality improvement and cost control. Early identification of quality deficiencies reduces rework, minimizes material wastage, decreases repeated inspections, and shortens project delays. Furthermore, centralized quality information provides project managers with reliable evidence for monitoring project performance, allocating resources, and supporting managerial decision-making. The integration of inspection data, BIM, and analytical reporting therefore transforms quality management from a reactive process into a proactive, information-driven management system.

Table 3: SDLC-Based Development of the Proposed Digital Inspection and Testing System

SDLC Phase	Development Activities	Expected Output
Planning	Identify limitations of the current inspection and testing process; define system objectives and stakeholder requirements.	Project scope, objectives, and functional requirements.
Requirement Analysis	Analyse existing inspection workflow, documentation practices, approval procedures, and quality management requirements.	Functional and non-functional system requirements.
System Design	Design the integrated architecture linking Novade, BIM, centralized database, and Power BI/Google Data Studio.	System architecture, database structure, and digital workflow design.
System Development	Configure digital inspection forms, cloud database, BIM integration, and dashboard development.	Operational digital inspection and testing platform.
System Integration	Integrate inspection data with BIM models and analytical dashboards for centralized information management.	Unified BIM-enabled digital quality management system.

Testing and Validation	Verify system functionality, inspection workflow, data synchronization, and reporting accuracy.	Validated system performance and workflow reliability.
Deployment	Implement the proposed framework within construction quality management processes.	Fully operational digital inspection and testing system.

Overall, the proposed BIM-integrated Digital Inspection and Testing System establishes a comprehensive digital ecosystem that integrates mobile inspection, centralized information management, BIM, and business intelligence analytics into a single quality management framework. The system addresses the principal limitations identified in the current approach by improving information accuracy, enhancing traceability, strengthening stakeholder collaboration, supporting real-time monitoring, and facilitating data-driven decision-making. Consequently, the proposed framework provides a practical digital solution for improving construction quality management while simultaneously supporting more effective project cost control.

Table 4: Functional Components of the Proposed System

Component	**Technology**	**Primary Function**	**Contribution to Construction Quality Management**
Mobile Inspection	Novade	Digital inspection, defect recording, photographic documentation, digital checklist	Improves inspection efficiency and standardises field data collection
Information Repository	Cloud Database	Centralized storage of inspection records and quality documents	Enhances information accessibility, traceability, and consistency
Information Integration	Building Information Modelling (BIM)	Links inspection records with digital building components	Improves defect visualization, coordination, and lifecycle quality management
Business Intelligence	Microsoft Power BI	Interactive dashboards and quality performance analytics	Supports real-time monitoring and evidence-based decision-making
Reporting Platform	Google Data Studio	Automated reporting and visualization	Improves reporting efficiency and project transparency
Collaboration Platform	Integrated Digital Environment	Digital communication and approval workflow	Strengthens collaboration among contractors, consultants, and clients

The proposed system extends previous studies by integrating mobile inspection technology, BIM, centralized cloud-based information management, and business intelligence analytics into a single quality management ecosystem. While existing research has predominantly examined these technologies independently, this framework establishes an end-to-end digital workflow that connects field inspection, component-level BIM information, centralized quality documentation, and real-time analytical reporting. This integrated architecture enables more efficient inspection management, improves information traceability, facilitates proactive quality assurance, and supports better project cost control, thereby contributing to the digital transformation of construction quality management. The proposed framework will be validated in future work through expert review involving BIM specialists, QA/QC engineers, consultants, contractors, and project managers. The evaluation will assess system functionality, usability, information integration, quality management capability, and implementation feasibility using a five-point Likert scale. Feedback obtained from the experts will be used to refine the framework before prototype implementation and industry deployment.

CONCLUSION

This study proposed a BIM-integrated Digital Inspection and Testing System to address the limitations of conventional construction quality management, including fragmented documentation, manual inspection processes, and limited information integration. Developed using the System Development Life Cycle (SDLC) methodology, the proposed framework integrates Building Information Modelling (BIM), Novade, and business intelligence platforms to establish a centralized digital workflow for quality inspection, reporting, and performance monitoring. The proposed system has the potential to improve inspection efficiency, enhance information traceability, strengthen stakeholder collaboration, and support data-driven decision-making, thereby contributing to better construction quality and cost control. Unlike existing approaches that apply digital technologies independently, this framework integrates mobile inspection, BIM, and data analytics into a unified quality management ecosystem. As this study presents a conceptual framework, future research should focus on prototype development and empirical validation within real construction projects to evaluate its usability, effectiveness, and impact on project quality and performance. Overall, the proposed framework provides a practical foundation for advancing digital construction quality management and supports the ongoing digital transformation of the construction industry.

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