

# Cloud-Based Building Information Modelling (BIM): Transforming Architectural Design and Collaboration in the Digital Era

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**Abstract.** By combining Building Information Modelling (BIM) with cloud computing technologies, the architecture, engineering, and construction (AEC) industry is undergoing a paradigm shift. This paper will examine how design processes that were formerly disjointed and non-integrated are transitioning to a state where design activities are coordinated and seamless, utilising cloud-based BIM systems. This study helps to understand how cloud-enabled BIM platforms create Common Data Environments (CDEs) that can act as centralised stores of project information, considering a comprehensive technological framework, implementation approaches, and performance indicators. The proposed treatment involves a mixed-methods design, where case study analysis, performance benchmarking, and evaluation of stakeholder feedback are utilised across various types of projects. It shows substantial growth in the level of design coordination (up to a 50 % reduction in meeting times) and a reduction in errors (a 75% decrease in clash-related problems), as well as increased stakeholder satisfaction levels. Nonetheless, there are still problems in the spheres of data safety, managing organisational change, and dependency on technical infrastructure. This study found that Cloud-Based BIM is a fundamental shift necessary to support the competitiveness of the AEC industry moving forward, and new integrations of artificial intelligence, digital twins, and extended reality are areas of potential transformation. The paper contributes to the emerging research on digital construction technologies and provides best practices for industry practitioners transitioning to new technology.

**Keywords:** BIM; cloud computing; digital collaboration; construction technology; common data environment.

## INTRODUCTION

The architecture, engineering, and construction (AEC) sector has long been described as highly fragmented, with poor communication and significant cost overruns on projects [1]. The conventional project delivery processes built on independently operated information systems and sequential lines of communication have led to an industry with low productivity growth relative to other industries [2]. Building Information Modelling (BIM) emerged as a leading technology development. Still, its initial applications were hampered by silos that were desktop-bound and could not achieve a broader reach [1].

The combination of BIM and cloud computing technologies has brought about a paradigm shift in architecture, enabling real-time collaboration, central data management, and enhanced coordination capabilities [3]. The core issues of the industry are addressed through the use of Cloud-Based BIM platforms, which establish Common Data Environments (CDE) as single-source-of-truth elements for project stakeholders [4]. Such technological development aligns with the overall effort to enhance digital transformation in the construction industry, in line with the principles of Industry 4.0 and smart construction practices [5].

Recent research suggests that the adoption of Cloud-Based BIM systems has led to a marked increase in organisational performance, including style. At the same time, the errors involved in design decreased as the projects proceeded at an accelerated pace, accompanied by significantly improved customer satisfaction [6]. Nevertheless, the organisational change management issues regarding the adoption process are complex and involve data security and technical infrastructure prerequisites [7]. These dynamics are instrumental in helping industry players leverage the use of cloud technologies.

This study presents a critical examination of cloud-based BIM implementation, discussing its technological architecture, team workflow, performance, and future development direction. The proposed research involves well-known researchers in the field of digital building. It will contribute to increased knowledge in the field of digital construction technologies, alongside practical recommendations for industry stakeholders as they navigate this technological change.



Figure 1 – Cloud-Connected BIM Workstation

## Literature Review

*History of Digital Design Technology.* The shift from manual drafting to computer-aided design (CAD) and the subsequent shift to Building Information Modelling are apparent steps within a growing trend toward integrated and intelligent design [8]. The first CAD systems computerised the conventional drafting and maintained the basic style of describing three-dimensional buildings as discrete two-dimensional perspectives [9]. This process recreated coordination difficulties and information fragmentation, which were used to define pre-digital workflows.

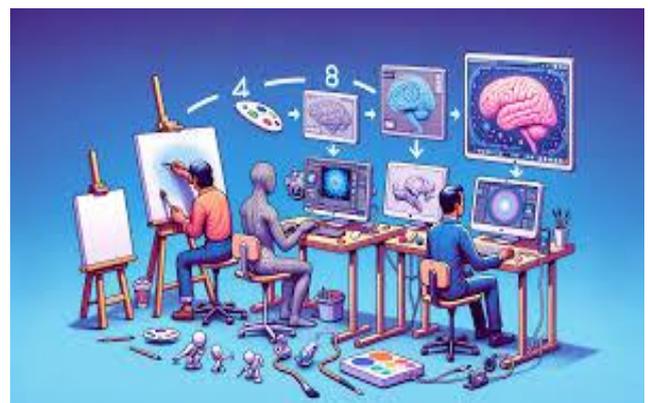


Figure 2 – Evolution of Digital Design Technologies

The BIM technology was used to introduce parametric modelling performance, which allowed for creating intelligent building objects with embedded properties of geometric, semantic, and behavioural nature [1]. Nevertheless, early BIM adoption was primarily desktop-driven, offering

complex yet isolated virtual environments that did not facilitate cross-industry collaboration [1]. The disadvantages of file collaboration, such as version control problems and data synchronisation problems, generated the demand for more interconnected methods in digital design.

*Construction & Cloud Computing.* The use of cloud computing in the construction sector has increased rapidly, driven by the need for greater mobility, scalability, and collaborative functionality [3]. According to the National Institute of Standards and Technology [10], cloud computing is a model that allows the availability of computing resources on demand (accessible anytime, anywhere, and conveniently) in a shared, common manner across networks. In the world of construction, cloud platforms offer data storage, computation, and workflow among staff members who break down organisational walls.

Authors [5] conducted research that identified three main cloud deployment models in construction: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). All of them have different benefits depending on the different organisational issues and technical requirements. The combination of BIM and the cloud infrastructure can be another logical step toward interconnectivity and teamwork in the design process [11].



Figure 3 – Cloud Computing in Construction

*Collaborative Design and Integrated Project Delivery.* The IPD project delivery methodologies focus on the inclusion of stakeholders at an early stage of the project, risk and reward distribution, and decision-making processes [12]. Sequential design stages and other forms of limited interdisciplinary coordination typify traditional project delivery methods, which have been named as

major sources of inefficiency within the industry [2]. Any IPD strategies involve technology that supports co-creative work in real-time and facilitates the open flow of information.

Cloud-based BIM platforms provide the technological foundation necessary for the effective implementation of IPD, as they facilitate seamless coordination of models, real-time communication, and joint access to created data among various project participants [7]. The study [13] demonstrates that projects utilising cloud-enabled collaborative platforms are associated with better results in terms of coordination and shorter timeframes required to address arising conflicts compared to their more traditional methods.

*Standards of the Common Data Environment.* Lately, the International Organisation for Standardisation (ISO) has defined the complete requirements for information management with a BIM perspective, and the ISO 19650 series has offered the structures to implement the Common Data Environment apparatus [4]. Such norms characterise the orderly methods of producing, reviewing, approving, and archiving information during the project lifecycles. This principle of the CDE concept is the core of transitioning from document-based to information-based approaches in project management.

The modern solution of CDE involves cloud-based infrastructure to deliver secure, convenient, scalable information management functions [14]. Cloud-based CDEs can be used to achieve advanced workflow governance processes, integrated version control, and access control systems, thereby supporting complex, multi-organisational projects [13].



Figure 4 – Common Data Environment Standards

## METHODOLOGY

The presented research employs both performance analysis (quantitative methodology) and a qualitative assessment of stakeholders to evaluate the results of implementing Cloud-Based BIM. The three main research components employed in the methodology are case study analysis of the company, performance benchmarking, and evaluation of stakeholder feedback.

*Selection of cases to study.* The three case studies were chosen as representatives of different types of projects and organisations: a large project at a high-traffic international airport terminal, a fast-track healthcare structure, and a multi-firm urban master planning project. Some of the selection criteria included the complexity of the projects, the heterogeneity of stakeholders, and the availability of comparative performance data from other projects using conventional delivery approaches.

*Metrics of Performance.* Quantitative performance measurement was centred on efficiency performance measures, such as the speed at which design iterations were carried out, documents were produced, and accuracy measures, including reduction in errors, rework costs, and the degree of collaboration, measured in terms of the frequency of meetings and the time it took to resolve issues. The items of data retrieval included the analysis of the project management system, studies of time-tracking, and a comparison of financial performance.

*Stakeholder Assessment.* Qualitative analysis was also conducted through structured interviews with various stakeholders involved in the projects, including architects, engineers, contractors, and clients. Interview procedures focused on the experience of using technologies, the efficiency of collaboration, and the perceived advantages and obstacles of working in the cloud. Thematic analysis was employed to identify patterns and draw conclusions across the stakeholder groups.

## RESULTS AND DISCUSSION

### Cloud-Based BIM Architecture and Platforms

*Technological Framework.* Modern Cloud-Based BIM systems have been designed to have numerous technology modules aimed at facilitating a fully integrated project collaboration process. The most fundamental architecture is based on scalable cloud, parametric data management sys-

tems, web-based visualisation interfaces, and application programming interfaces (APIs) to integrate systems with third parties [3]. This is enabled by the service-oriented architectures employed by these platforms, which allow for modular functionality and a tailored user experience.

Data synchronisation mechanisms are essential technical qualities that enable real-time collaboration and facilitate model integrity and version control [5]. Advanced platforms utilise delta synchronisation technologies, which can only transmit the modified aspect of data; once the bandwidth is reduced, distributed teams can respond more quickly. The approach enables both parallel modelling efforts and maintains full audit trails of design histories simultaneously.

*Chats and control package.* Cloud-based BIM platform data security frameworks must encompass the specifications of construction project information, including the protection of intellectual property, regulatory compliance, and multi-organisational access control [14]. Trusted platforms employ a multi-layered security tier, including encryption of information at rest and during transit, multi-factor authentication, and role-based access control.

Governance frameworks introduce policies and procedures to the creation, review, approval, and archival processes of information compliant with the ISO 19650 standards [4]. These frameworks establish responsibility matrices, information exchange needs and quality assurance, which would guarantee data integrity across project lifecycles.

*Interoperability and Integration.* Efficient use of Cloud-Based BIM implies close interaction with existing design, analysis, and plan management instruments [11]. The industry foundation classes (IFC) and the BIM collaboration format (BCF) are standards that enable a structured flow of information and issue management across any software platform. Modern cloud platforms are providing more and more native APIs/middleware which support custom integration scenarios.

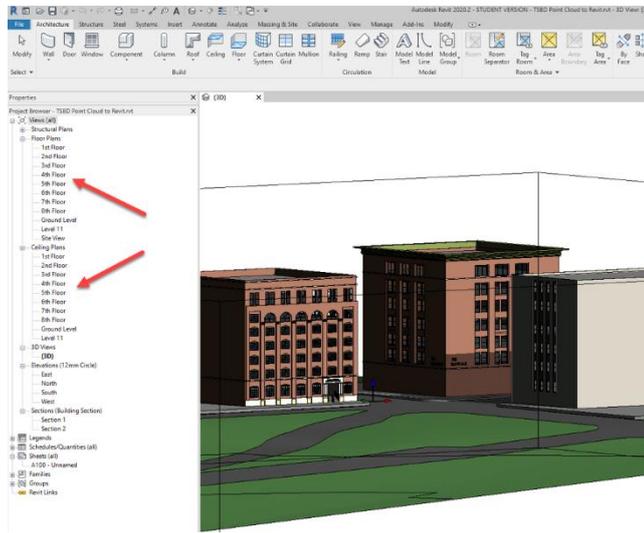


Figure 5 – 3D Building Information Model Hub

**Implementation Across Project Phases**

*Conceptual and Schematic Design.* Real-time co-modelling of collaborative conceptual design activities in Cloud-Based BIM platforms can occur with the integration of co-modelling and analysis capabilities [6]. The low-cost computing power of the cloud can be beneficial in the initial stages of design exploration, parametric design optimisation, environmental impact assessment, and feasibility studies. The capability of working directly with geographic information system (GIS) data and regulatory data in a cloud-based design environment strengthens site analysis and promotes the decision-making process.

Shared cloud workspaces enable collaborative massing and facilitate design evaluation during option selection in a distributed team, regardless of team member location [13]. The latter capability is especially useful in international projects, where, in some cases, face-to-face design workshops might not be feasible or expensive to organise.

*Developed design and documentation.* The second stage of architectural design development utilises cloud-based coordination features to manage multidisciplinary design efforts [7]. The approaches, as federated models, enable the simultaneous development of both architectural, structural, and mechanical systems, with the capability to conduct real-time clash detection and coordination reviews. With the automated generation of drawing production and specifications, the manual documentation incurred is mitigated, as consistency is provided between the information

on the model and the information on the drawing.

Material libraries and building component databases hosted in the cloud provide standard bank-specific construction products, which enhance specification precision and design uniformity [9]. Specification of items to manufacture information (databases) integration provides an opportunity to make a wise choice of materials and help to optimise performance on the environment.

*Building and Servicing.* The implementation of BIM, combined with cloud-based construction phase support, extends access to the model to field personnel using mobile devices and tablet applications [5]. Model visualisation at the site contributes to the knowledge required for complex assembly and reduces building mistakes due to the improved flow of information about the building's intent. Model-based context can be used to help efficiently transfer information from the field to the office, provided through mobile issue tracking and request for information (RFI) management systems.

The digital handover procedures utilise cloud-based information management to provide in-depth as-built documentation and operational data to the building owners [14]. This data serves as the basis for knowledge on facility management systems and any future renovations that may occur, providing an extension of the value of BIM even beyond initial construction processes.

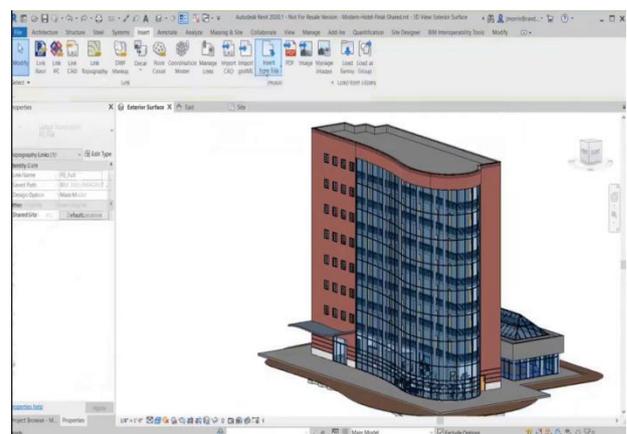


Figure 6 – 3D Building Information Model Hub

**Performance Analysis and Results**

*Efficiency Improvements.* An evaluation of the three case studies reveals a consistent trend in the improvements made across various aspects

of performance. An average of 45% reduced the typical cycles of design iteration compared to traditional workflows. Real-time collaboration in the cloud infrastructure facilitated an accelerated design iteration process and the inclusion of stakeholder feedback (see Table 1).

Table 1 – Performance Improvement Summary

Metric	Traditional Approach	Cloud-Based BIM	Improvement
Design Iteration Time	12 days	6.6 days	45% reduction
Documentation Production	25 hours	10 hours	60% reduction
Coordination Meetings	8 hours / week	4 hours / week	50% reduction
RFI Response Time	5 days	2 days	60% reduction

Automation drawing generation and model-driven specification systems reduced documentation production time by an average of 60%.

The frequency and time spent on coordination meetings also demonstrated considerable improvements, as the average frequency of meetings dropped to 4 hours per week, compared to 8 hours per week when studying the researched projects. This enhancement was made possible by the fact that continuous model-based coordination and capabilities for solving issues asynchronously have been made possible on cloud platforms.

*Quality and Accuracy Better Outcomes.* Error reduction analysis reveals a significant improvement in the accuracy of design coordination. The efficiency of clash detection and the consequent resolving process increased exponentially, with the airport terminal project resolving more than 10,000 potential conflicts identified at the design stage, compared to an estimated 2,000 conflicts that would have been observed using the traditional methodology. Such a proactive practice reduced the number of coordination problems during construction by 75%.

The average reduction in RFI volumes during construction was 40% across the three projects, and the average response time decreased from 5 days to 2 days with the model-based communication and capability to distribute the review functionality. This saved 65% of the construction rework expenditures attributed to misarranged

coordination, which is also present in identical projects with conventional delivery techniques.

*Stakeholder Satisfaction Assessment.* The analysis of stakeholder interviews reveals that collaborative processes based on the cloud are highly satisfying. Architects noted that it led to better design as a result of improved coordination abilities and real-time feedback being incorporated. Engineers appreciated lower interdisciplinary conflict and better cross-disciplinary communication. Contractors found that better constructability review processes and easy access to field information were valuable.

Particularly, the satisfaction scores of clients indicated a positive change in terms of the level of transparency within the project and the effectiveness of communication. The capability to participate in design reviews using web-based model visualisation and provide feedback through structured cloud-based operations augmented client involvement and minimised late design variations.

*The analysis of Return on investment.* The financial review of the case studies indicates that the Cloud-Based BIM implementation will yield a positive return on investment. The average cost of paying a subscription on the Platform, including training and implementation support, was approximately \$125,000 per project. The reduction in errors, shortened schedules, and increased efficiencies was documented as averaging about \$480,000 per project, representing an overall ROI of 284%.

There are long-term benefits beyond the initial project delivery, as the quality of as-built documentation improves and digital assets are created. The projected future operational savings amount to an annual savings of \$ 50,000, as the healthcare facility case study effectively manages the facility due to the comprehensive as-built BIM data.

### Problems and constraints

*Dependencies of Technical Infrastructure.* In the implementation of Cloud-Based BIM, it is crucial to maintain a stable internet connection and have sufficient bandwidth capabilities to support real-time activities, as well as access to large files for models [3]. Sites with poor connectivity infrastructure in construction sites may be less functional or require augmentation with additional communications. The issue of network reliability may pose challenges to project continuity, par-

ticularly for geographically dispersed teams that rely on cloud access.

Interoperability issues in the sharing of data solutions continue to overwhelm all the efforts to develop industry standards. Such interpolation of complex model data between the software platforms may lose information or corrupt its contents, necessitating validation and quality assurance processes [11]. There is a risk that it plugs into legacy systems, and to advanced analysis tools (it may need custom development or workarounds).

*Change Management in an Organisation.* The adoption of Cloud-Based BIM requires substantial organisational transformation, more than just technology implementation, to be successful [7]. The established pattern of professional needs and functions should adapt to accommodate the co-working processes and shared ownership of models. Even in the face of technological capabilities, an organisational culture resistant to change and other preferences may frustrate the adoption process.

Needs to train not just on software proficiency but also on the understanding of the collaborative processes and processes of information management. Organisations typically mention a 12–18-month implementation timescale to reach full penetration of the project teams, and continued support is needed for new team members and project types.

*Intellectual Property and Data Security.* There is indeed a reason to be concerned about personal project data saved to third-party cloud systems [14]. The Denial of data sovereignty could limit the use of the cloud platform for data with government or sensitive company purposes. Contractual terms must be established to address issues such as liability assignments, data breach response protocols, and long-term rights to access data.

The role of professional liability insurance in cloud-based collaboration has to be considered critically, especially when considering the designation of responsibility (who does what and when) and quality assurance steps during the process of shared modelling. The legal system by which multi-party BIM collaboration would operate remains in development, leaving risk-averse organisations in a state of uncertainty.

*Vendor Lock-in and Long-term Sustainability.* Locking into narrow cloud platforms can lead to

lock-in problems that may reduce flexibility in the future or potentially incur greater long-term system costs [5]. Support for export formats and data migration becomes a crucial factor in choosing a Platform. The fulfilment of open standards will have to be balanced with rich/proprietary solutions so that organisations can survive in the long term.

Archival and long-term access to data continue to pose significant challenges to projects with operational lifetimes that are longer. Access to historic project data may be affected by platform changes and version incompatibility, necessitating proactive archiving plans and the development of migration plans between formats.

### **Future Trends and Prospects**

*Integration of Artificial Intelligence.* The integration of artificial intelligence (AI) and machine learning technology with Cloud-Based BIM platforms is expected to be a game-changer in automated design optimisation and code compliance checking, as well as predictive analytics [6]. The generative design tools that rely on AI can be used to search through large spaces of design options, whose performance is evaluated based on specific performance criteria and constraints. Intuitive model query and communication of design intent may be possible using natural language processing capability.

Predictive maintenance enhances the performance of building systems by utilising BIM data and information from IoT sensors to predict maintenance needs [13]. Machine learning algorithms can identify trends in building performance data that can inform the optimisation of design in future projects.

*Long-range Realities Technologies.* Such cloud-hosted BIM models can be secured and integrated with Virtual Reality (VR) and Augmented Reality (AR) to offer immersive design review and construction guidance applications [11]. Streaming a cloud-based model to a VR headset does not impose processing constraints; the model enables shared virtual design meetings between geographically separated users. AR applications superimpose data on a digital model of the actual construction, which helps with precise installation and quality control activities.

The Mixed Reality (MR) technologies combine the physical and digital worlds to create new ways of collaborating on the design and diversify the construction workflow. The computational

resources required for extended reality interaction and real-time rendering of complex BIM models are made available through cloud computing infrastructure.

*Development of Digital Twin.* Cloud-based BIM, as it evolves into an all-encompassing Digital Twin platform, now promises to become a significant source of lifecycle value creation [14]. Digital Twins combine design-stage BIM models with the feeds of IoT sensors and building management systems to run in real-time. It allows predictive analytics, energy optimisation, and usage analysis of spaces, which continue to deliver BIM value over building lifecycles.

Digital Twin data monetisation and multi-party collaboration can be facilitated through secure, transparent, and automated contractual procedures that integrate blockchain technology [3]. Payment transactions, verification of performance, and mutually agreed-upon data sharing arrangements can be automated using smart contracts in complex settings involving multiple stakeholders.

*The Evolution of Industry-Specific Platforms.* Market-specific cloud platforms are becoming available to address the unique needs and regulations of various industries [5]. Design platforms offered by healthcare facilities work in tandem with medical equipment libraries, infection control policies and specialised regulatory compliance. The infrastructure platforms have the functions of modelling traffic, conducting environmental impact assessments, and communicating with the people.

Vertical integration in the design, construction, and operation phases through the development of platform ecosystems portends a promise of greater value creation and reduced technology fragmentation. Such ecosystems can include supply chain integration, prefabrication coordination and lifecycle cost optimisation functionalities.

The above research findings demonstrate that Cloud-Based BIM is not merely another technological advancement that introduces incremental changes to the ways of AEC industries, but rather signifies a paradigm shift in the AEC industries. The strategic value of cloud-supported collaboration systems can be validated by the recorded performance gains in terms of efficiency, quality, and stakeholder satisfaction. Nevertheless, its effective implementation necessitates a massive change across organisations, which extends be-

yond the integration of technologies to encompass practices, procedures, and changes in contracts.

The emergence of AI, extended reality, and Digital Twin technologies presents an idea that existing Cloud-Based BIM platforms are just the initial steps in a larger, ongoing pathway of digital transformation. Companies that develop cloud-based working capabilities today stand on a strong platform for integrating technology in the future and achieving industry growth, thereby increasing their participation in the ecosystem. In technologically driven innovation ecosystems, the network effects of collaboration platforms can build competitive benefits that compound over time as additional players integrate them into their own ecosystems.

Changes in the regulatory and legal frameworks often lag behind advancements in technology capabilities, creating hurdles that can stall adoption in risk-averse organisations. The industry associations, professional organisations, and regulatory authorities should also come together to create guidelines for cloud-based collaboration, data ownership, and the distribution of professional liability. Developing standardised contractual guidelines for multi-party BIM collaboration would reduce implementation-related obstacles and expedite operationalisation.

The scope of the research involves large-scale and rather complex projects, which may highlight the advantages of cloud collaboration to the greatest extent. Small- and medium-sized projects may involve various cost-to-benefit ratios and implementation difficulties. The case studies, moreover, are early adopters possessing better-than-average technical capabilities and resources in change management. Wider industry acceptance may face additional obstacles not included in this analysis.

## CONCLUSIONS

As this research indicates, Cloud-Based Building Information Modelling is a transformative technology that addresses the root issues of collaboration and coordination within the architecture, engineering, and construction industry. Combined with the use of cloud computing infrastructure, BIM enables real-time project evaluation, centralised data management, and increased coordination of project delivery, facilitating meas-

urable performance gains in terms of efficiency, quality, and stakeholder satisfaction.

The recorded outcomes of the three different case studies demonstrate uniform positive gains, including a 45% reduction in design cycle time, a 60% increase in documentation generation, and a 75% decrease in coordination problems during the construction phase. Based on the financial analysis, it is clear that the returns on investment are high, with an average of 284% calculated on the researched projects. Furthermore, long-term savings will be observed as a result of improved as-built documentation and digital assets.

Nevertheless, it is challenging to implement it successfully, as numerous issues are associated with the technical infrastructure, change management within the organisation, data security, and vendor selection. Organisations need to develop a comprehensive approach to transformation that involves both technological, process, and cultural change, and must be cautious of the risks associated with data security and vendor dependency.

Further modifications to industry practices are expected to be brought about by the future trends of the evolution of Cloud-Based BIM into

the next generation of AI-integrated platforms, the use of extended reality, and the emergence of Digital Twins. Companies that build cloud-based collaboration capabilities today are well-positioned to integrate technology and differentiate their competitive advantage in the future.

This study helps expand the existing knowledge base on digital construction technologies by providing empirical evidence of Cloud-Based BIM performance results and practical applications. The directions of research would include further studies of small and medium project applications, standardising performance measurement, and the long-term effects of adopting cloud-based collaboration in the industry as a whole.

Industry players should work together to eliminate potential roadblocks to adoption, such as developing terms and conditions, standardising contracting practices, and implementing extensive cybersecurity guidelines. The effective digitalisation of the AEC industry with the help of Cloud-Based BIM will not be possible without technological development. Still, it will require the development of an ecosystem, which could entail the confident introduction into different organisational conditions.

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