AMERICAN JOURNAL OF EDUCATION AND LEARNING
ISSN: 2996-5128 (online) | ResearchBib (IF) = 10.91 IMPACT FACTOR
Volume-3| Issue-7| 2025 Published: |30-07-2025|

DIGITAL TRANSFORMATION OF THE BUILDING LIFECYCLE

https://doi.org/10.5281/zenodo.16139207

Zafar Matniyazov
Tashkent University of Architecture and Civil Engineering

Abstract

This article examines contemporary approaches to the digitalization of all stages of the building life cycle, with a particular focus on Building Information Modeling (BIM), digital twins, and Common Data Environments (CDE). The construction industry has traditionally lagged behind in terms of digital maturity - according to McKinsey, it is among the least digitized sectors, surpassed only by agriculture [1]. However, the implementation of BIM and related technologies has significantly improved performance: reducing unplanned changes and rework, increasing cost estimation accuracy, and enhancing coordination and facility operations [2]. The study analyzes real-world case studies from Europe, the United States, and Asia, which demonstrate the benefits of digital approaches - from design to facility management. International standards such as ISO 19650 (successor to the British PAS 1192 series) and findings from academic sources, including the BIM Handbook and publications indexed in Scopus and Elsevier, are employed to support the conclusions. The results indicate that end-to-end digitalization of the life cycle - enabled through BIM models and digital twins integrated within a CDE - leads to time and cost savings, higher design quality, and more efficient building operation. The article also discusses key challenges such as data integration, standardization, and organizational barriers, and offers practical recommendations for successful technology adoption.

Keywords

Building Information Modeling (BIM), Digital Twin, Common Data Environment (CDE), Building Life Cycle, Information Modeling, Facility Management

Introduction

The construction industry is undergoing a rapid digital transformation that encompasses all phases of the building life cycle - from conception and design to construction, operation, and decommissioning. The imperative for change is driven by the need to improve efficiency: construction remains one of the least digitized sectors, associated with low productivity and high levels of waste [1]. Traditional processes rely heavily on fragmented paper-based drawings and documentation, resulting in significant information gaps between project stakeholders [3]. The digitalization of the life cycle represents a shift toward integrated data and model management across all stages, aiming to overcome these persistent inefficiencies.

Building Information Modeling (BIM) is at the core of this transformation. BIM refers to the process of creating and managing a digital representation of a building's physical and functional characteristics, serving as a single source of truth for all project participants [4]. Ideally, BIM encompasses the entire life span of a building, starting from the early conceptual design phase through to operation and even demolition [5]. According to the BIM Handbook, the information model acts as a comprehensive data repository that supports the building throughout its existence - from conception to facility management [5]. In practice, this means that once information is created, it can be reused and enriched at every stage, eliminating duplication and preserving institutional knowledge during the transition from construction to operation.

One of the key concepts within BIM is the Level of Development (LOD), which defines the degree of detail and reliability of model elements at various project stages. The American Institute of Architects (AIA) originally proposed a classification system ranging from LOD 100 to LOD 500, reflecting the model's evolution from conceptual design to as-built documentation [6]. Table 1 summarizes the main LOD levels and their corresponding characteristics. In the early pre-design phases, the model contains minimal detail (LOD 100), offering a symbolic representation of massing and basic geometry. As the project progresses, the level of detail increases: LOD 300 corresponds to a detailed design model with defined geometry, dimensions, and attributes; LOD 400 incorporates fabrication and construction details; and LOD 500 represents verified as-built conditions and is used during facility management [7]. In other words, the LOD increases progressively throughout the building's life cycle (see Figure 1), evolving from a general concept to a fully detailed construction model and, finally, to an accurate digital reflection of the built asset for operational use.

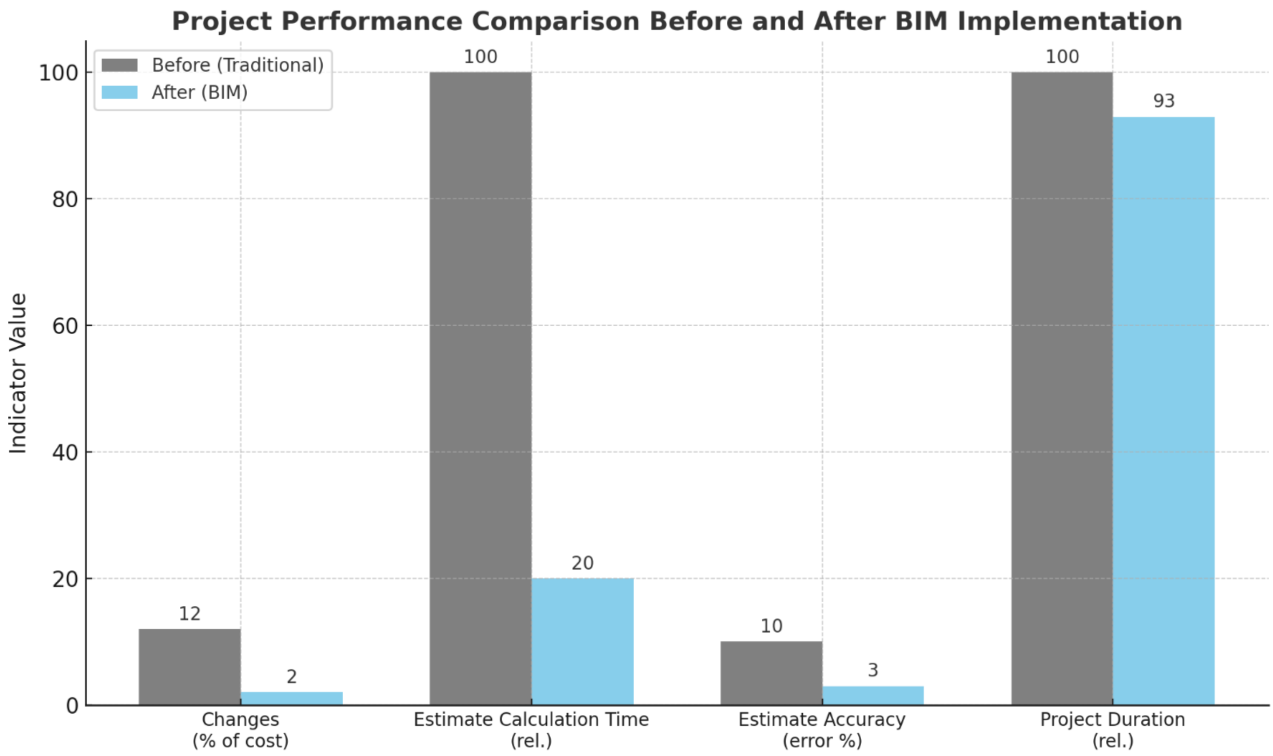

Figure 1. **Level of Development (LOD) of the information model at key project stages. At the conceptual stage, the model is developed to LOD 100 with minimal detail; during design and documentation phases, it progresses to LOD 200–300; by the beginning of construction, it reaches LOD 400 with fabrication-level detail; and upon completion, the model is finalized at LOD 500 with as-built information [6], [7].**

Alongside the advancement of BIM technologies, effective information management has become a critical success factor. To support this, the concept of the Common Data Environment (CDE) is introduced. According to the international standard ISO 19650, a CDE is defined as “an agreed source of information for any given project or asset, used to collect, manage and disseminate every information container through a managed process” [8]. In simpler terms, the CDE is a unified digital environment where all project-related data (models, drawings, documents, etc.) are stored and made accessible to stakeholders according to their roles and permissions. The use of a CDE ensures data consistency and currency, eliminates the problem of “multiple versions of the truth,” and establishes a foundation for multidisciplinary coordination [4], [8].

The concept of the CDE forms the backbone of the ISO 19650 standard series (2018), which is based on earlier British PAS 1192 specifications. ISO 19650 standardizes information management workflows across the entire asset life cycle—from design and construction (ISO 19650-2) to operation and maintenance

(ISO 19650-3) [9]. Transitioning from fragmented workflows to a unified information model supported by a CDE enables seamless data transfer between phases, including the handover of the as-built model for operation [9]. This significantly mitigates challenges associated with commissioning and long-term asset management [8].

The digitalization of the building life cycle extends beyond BIM models alone and encompasses a range of complementary technologies. In recent years, increasing attention has been devoted to the concept of the digital twin. A digital twin is a virtual representation of a physical asset that not only contains its information model but also receives real-time operational data from sensors, IoT devices, and other sources [10]. In this sense, BIM can be regarded as a static model, primarily used during the design and construction phases, whereas a digital twin is a dynamic digital counterpart that remains current and functional throughout the operational phase [10].

Digital twins enable continuous monitoring of an asset's condition, predictive analytics for maintenance planning, and resource optimization across the entire life cycle [10]. For example, in large-scale UK infrastructure projects such as Crossrail, elements of digital twins are employed to forecast delays and failures by analyzing real-time data and big data streams [10]. In building construction, digital twins are already being applied to high-profile assets; reports indicate their use in major facilities such as LAX Airport, The Shard skyscraper, and others—resulting in millions of dollars in operational savings and reduced downtime [10]. Thus, the integration of BIM with digital twin technology establishes a comprehensive digital infrastructure for asset management from inception to decommissioning.

The objective of this article is to investigate and systematize contemporary practices of life cycle digitalization in the construction sector, following the IMRAD structure (Introduction, Methods, Results, and Discussion). The Methods section outlines the research approach, which is based on the analysis of literature and case studies. The Results section presents specific examples of BIM, CDE, and digital twin implementations in various countries, highlighting measurable outcomes (including data tables and performance charts). The Discussion section summarizes the key advantages of digitalization while also addressing the challenges and limitations encountered during implementation.

The article draws upon international standards (e.g., ISO 19650), foundational texts (such as the BIM Handbook by Sacks et al., 2018), and recent peer-reviewed research from databases such as Elsevier and Scopus. All sources are cited in accordance with academic writing conventions and formatted using APA style.

Methods

This study employs a combination of two methodological approaches: (1) an analytical review of literature - including international standards, monographs, and peer-reviewed journal articles - on digitalization in construction and facility management; and (2) a qualitative analysis of case studies concerning the implementation of BIM and related technologies in various real-world projects across the globe.

The literature review was based on a curated selection of authoritative sources, including ISO and PAS standards (for understanding information management requirements), the BIM Handbook as a foundational reference, and scientific publications from high-impact journals such as Automation in Construction, Journal of Construction Engineering and Management, and Buildings (MDPI), indexed in Scopus and Web of Science. Special emphasis was placed on research published between 2018 and 2025 to reflect the latest developments, including the integration of BIM with digital twins and the adoption of Common Data Environments (CDE).

To identify relevant real-world case studies, the analysis incorporated industry reports and documented project outcomes. The selection criteria for the case studies included: (a) geographic diversity (Europe, North America, and Asia), (b) various asset types (residential and commercial buildings, infrastructure, and high-rise developments), and (c) availability of published results (both quantitative and qualitative). For Europe, the analysis included the UK's national BIM program and landmark projects such as Crossrail. For the United States, federal initiatives (e.g., the GSA's 3D/4D-BIM program) and private sector implementations (e.g., the digital twin used at LAX Airport) were examined. In Asia, the study considered large-scale projects like the Shanghai Tower in China and public sector strategies promoting mandatory BIM use in countries such as Singapore and Hong Kong.

The collected data were compared and structured according to the stages of the building life cycle. For each phase - planning, design, construction, and operation - key digital tools and the corresponding tasks they support were identified. Table 1 below presents a summary framework that maps the stages of the life cycle to the applicable digital technologies, including BIM models, data structures, and methods.

Table 1. *Stages of the building life cycle and corresponding digital technologies and methods.*

Life Cycle Stage	**Key Digital Technologies**
Concept and Planning	3D conceptual modeling (LOD 100) for early design assessment; spatial analysis using GIS; point cloud data from

	site surveys; CDE platforms for collecting initial project requirements.
Design (Conceptual and Detailed)	Building Information Modeling (BIM) with progressive refinement of LOD (up to 300 and beyond) [6]; interdisciplinary model coordination (e.g., Navisworks, Solibri); simulation modules for energy and structural analysis; collaborative work through Common Data Environments.
Construction	4D/5D BIM: integration of the model with schedule (4D) and cost estimation (5D) [11]; construction management via CDE (digital drawings, task delivery via tablets); laser scanning and drone monitoring; model-based change control systems.
Commissioning and Operation (FM)	Handover of an updated information model (LOD 500) to the facility management team [6]; integration of the BIM model with asset management systems (CMMS, CAFM), e.g., via COBie; digital twin for real-time monitoring of building systems; big data analytics for predictive maintenance using sensor data [4] [12]; use of the model for planning renovations and retrofits.
Renovation / Decommissioning	Updating the information model to reflect as-built modifications (creating an accurate digital twin); modeling of renovation or demolition scenarios; life cycle assessment (LCA) using digital data.

The methodological approach is based on the principles of systems analysis: by considering the building life cycle as an integrated value-creation chain, this study explores how digital technologies help bridge gaps between its individual phases. During the literature review, key performance indicators of successful implementation - such as cost savings, schedule reduction, and decreased frequency of clashes or errors - were recorded and analyzed. These findings are presented in the Results section (see Table 2 and Figure 2 for a summary of selected performance metrics). To ensure the reliability of the conclusions, all data and quantitative claims are supported by references to original sources.

Limitations of the method: this study is a qualitative review and does not include original experimental research or statistical analysis based on primary project datasets. Nevertheless, the breadth of sources and the consistency of observed trends provide a robust foundation for assessing the benefits and challenges of digitalization. Future research should include quantitative studies to empirically verify these effects across representative samples of construction projects.

Results

3.1. BIM Implementation Across All Project Stages

The analysis demonstrates that the use of BIM technologies delivers measurable benefits at every phase of the building life cycle. During the design stage, the use of a centralized 3D model improves decision-making quality and helps prevent design errors well before construction begins. Projects that adopted BIM-based coordination reported a significant reduction in clashes between disciplines (architecture, structure, and MEP) compared to traditional 2D design workflows [11].

For instance, a study conducted by Stanford University's Center for Integrated Facility Engineering (CIFE), covering 32 projects, revealed the following average benefits from BIM adoption: up to 40% reduction in unplanned changes (e.g., drawing errors, clashes) during construction; cost estimation accuracy improved to within 3% variance (compared to ~10% previously); and 80% reduction in time spent preparing cost estimates [2]. These metrics confirm that detailed planning within a digital model reduces uncertainty and improves the predictability of project cost and schedule.

At the construction stage, the primary benefit of BIM is the reduction of rework and the optimization of project schedules. In European infrastructure projects, notable improvements have been observed. For example, in Norway, the national road authority's adoption of BIM Level 2 requirements led to a reduction in the total cost of change orders during construction - from approximately 12% to just 2% of the project budget [13]. In other words, the volume of rework due to design errors became almost negligible, resulting in roughly 10% budget savings. Table 2 presents a comparison of key project performance indicators under the traditional approach versus a BIM-based approach. The same data are visualized in Figure 2.

Table 2. *Example comparison of key project performance indicators before and after BIM implementation (average or representative values based on empirical studies).*

Indicator	Before (Traditional Approach)	After (BIM Implementation)	Source
Percentage of changes (unplanned work) during	~12% of contract value	~2% of contract value	Norwegian infrastructure projects [13]

construction			
Time required for cost estimation preparation	100% (baseline)	~20% (80% reduction in time)	Stanford CIFE (32 projects) [2]
Cost estimation accuracy (average deviation)	±10%	±3%	Stanford CIFE (32 projects) [2]
Project duration (total execution time)	100% (baseline)	~93% (7% reduction in duration)	Stanford CIFE (32 projects) [2]

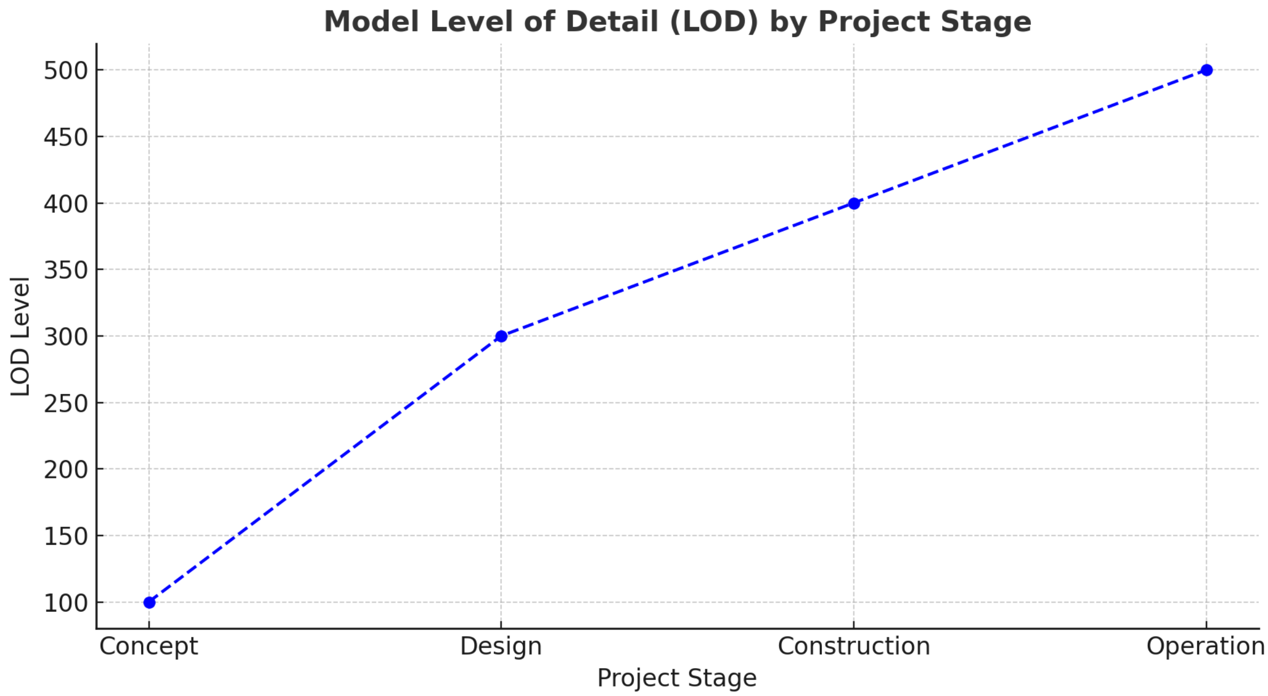

Figure 2. **Comparison of selected project performance metrics before and after BIM implementation. Grey bars represent the traditional approach; blue bars indicate the use of BIM. The adoption of BIM reduces the proportion of unplanned changes (rework) during construction, significantly accelerates cost estimation processes (due to automated quantity take-offs from the model), improves the accuracy of cost predictions, and moderately shortens project duration through enhanced coordination [2], [13].**

It is evident that during the construction phase, the primary gains from BIM adoption are related to the reduction of design errors and rework. The BIM model serves as a shared reference point for all contractors: clash detection within the virtual model allows engineering system conflicts to be identified and resolved "on paper," which can save up to 10% of the project's estimated cost by preventing costly modifications on-site [2]. Furthermore, 4D modeling - which links the model to the construction schedule - improves planning. For example, the major contractor Skanska reported that the use of 4D BIM in a metro tunnel project in Stockholm accelerated tunnel construction by 20% due to improved scheduling and logistics [10].

The operation phase (Facility Management)—until recently the least digitized part of the building life cycle - has enormous potential. Operating costs account for up to 80% of the total life cycle cost of a building [12], so even modest improvements in management efficiency yield substantial economic benefits. The use of BIM for FM involves having all information about equipment, finishes, maintenance logs, warranties, and other asset data consolidated into a single digital model of the building [4]. This addresses the common issue of fragmented data storage and the loss of documentation that often hinders facility managers [4]. For example, the model allows the user to quickly identify the type of filter installed in a ventilation unit and when it was last replaced - without digging through physical archives. Such a single source of truth facilitates planning for maintenance, procurement of spare parts, space management, and more. According to recent studies, implementing BIM during the operation phase supports proactive rather than reactive maintenance strategies [4].

When combined with BIM, digital twin technologies enable real-time monitoring of building performance metrics - such as energy consumption, temperature control, and equipment vibrations - and allow predictive maintenance based on data analytics [10]. For instance, in a high-tech hospital complex, the use of a digital twin enabled a shift toward predictive maintenance of HVAC systems, reducing unscheduled equipment downtime and energy costs by several dozen percent (based on pilot project data) [12], [14].

A real-world example of integrated digital facility operation is found in smart office buildings and data centers, where the BIM model is connected to the Building Management System (BMS). In such settings, an operator in the control center monitors a live 3D model overlaid with sensor data: if the temperature exceeds a threshold or a smoke detector fails, the issue is immediately visualized on the digital floor plan.

In Asia, Singapore was among the first countries to introduce the national strategy of Integrated Digital Delivery, which promotes the seamless use of BIM from building permit application through to facility operation. In China, the Shanghai Tower project (632 meters tall, 128 floors) was conceived from the outset with BIM as a coordination and future operations platform. As the project director noted, "Had we used the traditional method with fragmented drawings, it would have been nearly impossible to complete such a complex project" [15].

Beginning as early as 2008, the Shanghai Tower project implemented BIM across all disciplines: over 30 subcontractors and design firms collaborated within a single shared model using a central Common Data Environment (CDE). Autodesk Revit and Navisworks were used for design and coordination, and the finalized as-built model became the foundation for the skyscraper's Facility Management system [15]. This case became one of the first large-scale examples in Asia of establishing a new standard of information management in Chinese construction, clearly demonstrating that even the most complex engineering structure can be "built twice" - first virtually, then physically.

3.2. Regional Differences and Case Studies. The study revealed notable regional differences in the emphasis and implementation of digitalization, although all regions are moving in the same general direction. In Europe - particularly the United Kingdom and Scandinavian countries - the focus has been on standardization and the mandatory use of BIM in public procurement. Since 2016, the UK has required BIM Level 2 for all government-funded construction projects [16], which stimulated market adoption and produced measurable results: according to government data, the use of BIM by 2015 had helped save approximately 15–20% of construction budgets, amounting to nearly £900 million in taxpayer savings [17]. This success laid the foundation for the national strategy "Digital Built Britain", aimed at progressing toward BIM Level 3, which envisions a fully integrated information environment spanning the entire asset life cycle.

Europe is also home to several landmark projects with deep BIM integration. One such project is Crossrail in London - a new rail line that was developed from the outset with a focus on the Common Data Environment (CDE) and the creation of a "virtual railway" parallel to its physical counterpart [16]. During the operation phase, the Elizabeth Line (the current name of Crossrail) will utilize this digital twin for maintenance of tunnels, tracks, and systems. Another example involves infrastructure agencies in Northern Europe (e.g., Norway, Finland, the Netherlands), which have invested heavily in BIM standards for highways and bridges. Finland, for instance, has mandated the use of BIM for road design since 2007, and by 2020 had established the national InfraBIM standard.

In the United States, the digitalization landscape is more decentralized but still clearly advancing. As early as 2003, the General Services Administration (GSA) launched a 3D/4D-BIM program for federal buildings, requiring digital models for the design of courthouses, hospitals, and other facilities. Today, BIM is widely adopted by leading developers and general contractors. A prominent example is the renovation of Los Angeles International Airport (LAX), where a digital twin integrates terminal BIM models with sensors and control systems, helping to optimize construction schedules and save approximately $15 million, while also enhancing on-site safety (according to project management statements) [10].

In the field of high-rise construction, BIM has become the de facto standard in the U.S. Iconic skyscrapers such as One World Trade Center and Salesforce Tower were designed and built using BIM methodologies. For example, the firm Turner Construction reported that implementing BIM with real-time data integration on the Salesforce Tower project resulted in approximately $15 million in cost savings and helped achieve zero lost-time incidents [10].

Asia demonstrates the fastest rate of adoption of emerging technologies in the built environment. Singapore was among the first countries to mandate BIM model submission (e-submission) for regulatory review as early as 2015. Currently, Singapore is progressing further by developing a national digital twin of the city for planning and management purposes - an initiative known as the Virtual Singapore project.

China has incorporated BIM into several national standards and applies it extensively in mega-projects - from high-rise buildings (such as the aforementioned Shanghai Tower) to infrastructure, including the Hong Kong–Zhuhai–Macau Bridge, which was designed using BIM processes. South Korea and Japan are also actively exploring the potential of digital twins. For example, in Japan, companies are experimenting with integrating BIM models of buildings with real-time sensor data in alignment with the Society 5.0 framework, which envisions the convergence of the physical and digital worlds.

In the United Arab Emirates, the city of Dubai has announced the Paperless 2030 strategy, where BIM and digital platforms are set to play a central role in the construction of smart cities.

3.3. Consolidated Benefits of Digitalization

Synthesizing the findings from case studies and literature, several core areas of positive impact from life cycle digitalization can be identified:

- Reduction in costs and project duration. By minimizing design errors and rework, BIM enables cost savings of 5–15% of the total project budget [17]. The standardization of BIM workflows (e.g., following ISO 19650) reduces the time and expense associated with information retrieval and redundant work [8]. Construction duration is also reduced - on average by 7–10% - due to improved coordination and early clash resolution [2].

•Improved quality and predictability. Design decisions can be rigorously evaluated during the modeling phase using simulations, code compliance checks, and energy performance analyses. As a result, the final product (whether a building or infrastructure asset) more accurately reflects initial requirements and is less likely to require changes during construction. Project predictability improves, with reduced deviations in schedule and budget [2], as previously demonstrated.

•Enhanced interdisciplinary collaboration. BIM and CDE establish a common data structure for all stakeholders - architects, engineers, contractors, and facility managers. This promotes transparency and teamwork. ISO 19650 explicitly states the objective of creating a "universal language" for information management that is understood by all project participants [8]. The outcome is fewer misunderstandings, fewer disputes, and reduced contractual conflicts; reports indicate a decline in legal claims, as all correspondence and document versions are traceable within the CDE [8].

•Efficient operations and sustainability. The availability of an up-to-date digital model significantly facilitates asset management. According to recent studies, digital technologies in Facility Management can reduce operational costs by 10–20% through optimized maintenance, energy efficiency, and more rational space utilization [12]. A digital twin allows real-time monitoring of resource consumption and structural conditions, which is essential for sustainable development goals, such as reducing CO_2 emissions and extending the service life of buildings [12]. Moreover, centralized storage of maintenance data within the model contributes to knowledge retention during staff turnover, as the model serves as a long-term repository of operational history [4].

•Data-driven decision-making. In traditional construction, many decisions were based on intuition and past experience. Digitalization introduces data analytics into the industry: from big data generated by sensors to AI-driven assistants supporting designers. Based on the BIM model, it becomes possible to perform accurate quantity take-offs, generate multiple layout alternatives (generative design), and select optimal configurations based on specified criteria. During the operational phase, data analytics enables predictive maintenance (PredMaintenance) by identifying performance trends and anticipating system failures. This transition moves life cycle management toward a more evidence-based and scientific foundation.

Thus, the results indicate that a comprehensive approach to digitalization can lead to substantial improvements at every stage of the building life cycle. However, each benefit comes with its own implementation challenges, which will be discussed in the following section.

Discussion

4.1. Key Success Factors in Digitalization. The analyzed case studies demonstrate that merely purchasing software is insufficient - organizational changes and standardization are essential. In leading countries such as the United Kingdom, Singapore, and the Nordic states, the success of BIM initiatives has been closely tied to government support and the active involvement of major clients. The mandatory adoption of BIM in large-scale public projects served as an "entry point" for the broader industry, enabling the accumulation of successful case studies and the formation of a BIM services market.

Standards also play a crucial role. The British PAS 1192 series and the international ISO 19650 standard have provided a common methodological framework. The principles introduced by these standards - Employer's Information Requirements (EIR), BIM Execution Plans (BEP), and Common Data Environments (CDE) - establish a clear and structured approach to information management processes. As noted by Revizto (a provider of collaborative BIM solutions), the implementation of ISO 19650 brings multiple benefits, including reduced rework, improved coordination, and decreased risk and conflict [8].

Our review supports these findings: projects that strictly follow the protocols (including the use of BEPs, naming conventions, and standardized information exchange via CDEs) consistently demonstrate higher efficiency than those where BIM is used in an ad hoc or unstructured manner.

Another key factor is investment in personnel training and cultural transformation. Digitalization demands new competencies: the ability to work with models, interpret data, and collaborate within shared data environments. Both operational staff (e.g., modelers, field engineers using tablets) and project managers need to be trained to make informed decisions based on digital information.

Several case studies reported resistance to change among experienced personnel accustomed to traditional workflows. Addressing this challenge falls within the scope of effective management. Successful organizations foster a culture of openness to innovation, organize training programs, and facilitate knowledge exchange on internal platforms dedicated to BIM implementation. As one study put it, "digital transformation is 10% technology and 90% people," meaning the primary barrier is often human, not technical. Consequently, the presence of BIM managers and digital champions has become nearly indispensable in modern project teams.

4.2. Challenges and Limitations. Despite the clear benefits, the path toward digitalization is not without significant challenges, as identified in this study:

• High initial costs and economic justification. The implementation of BIM and CDE requires substantial investment in software, high-performance hardware, and workforce training. For small and medium-sized enterprises, the cost of licensing and the delayed return on investment (ROI) often become significant barriers. Senior management may be hesitant to allocate resources to initiatives that lack immediate financial payback. However, surveys indicate that 75% of companies report a positive ROI from BIM adoption [11], although the benefits tend to materialize only after the first one or two projects. It is essential to consider the long-term value creation, which may not be immediately evident at the project outset.

• Data compatibility and standardization issues. The diversity of software platforms used across disciplines leads to challenges in data exchange. While open standards such as IFC and COBie exist, achieving full interoperability among all stakeholders remains difficult. Frequently, architects work in one environment, contractors in another, and facility managers require data in yet a third. This necessitates the customization of data conversion workflows and the maintenance of a unified classification system. Standards such as ISO 12006 (for construction classifications) and national classification systems like OmniClass and Uniclass are not yet fully harmonized globally. The lack of standardization complicates sector-wide data integration and inhibits automation and consistency.

• Legal and contractual issues. The transition to collaborative BIM-based workflows introduces questions of liability and model ownership. Who "owns" the model? Who is responsible for errors introduced during the modeling process? Traditional contract forms such as FIDIC and others often lack provisions addressing digital deliverables, necessitating updates and the inclusion of BIM-specific protocols. Without a clearly defined legal framework, some stakeholders are reluctant to share full access to the model due to perceived risk exposure. The UK and the US have developed guidance documents (e.g., AIA E202, CIC BIM Protocol), but global legal practice is still evolving in this area.

• Lack of motivation during the operation phase. A critical observation is that although 80% of a building's life cycle cost is incurred during operation [12], this phase lags behind in BIM adoption. The main reason is the disconnect between construction and operations: by the time the building is commissioned, the project team has often changed, and the incoming facility management organization may lack the competence or willingness to use the BIM model. In some cases, operators may be unaware of the model's existence or distrust its accuracy. As a result, the valuable "as-built" model often goes unused. The solution lies in engaging FM teams early during the design stage, allowing them to define information requirements (e.g., specific attributes needed for asset management). ISO 19650-3 explicitly regulates information workflows during the operational phase, aiming to facilitate this integration.

• Cybersecurity and data integrity. The full migration of project data into digital environments introduces new risks: data loss due to system failures, and vulnerability to cyberattacks. The construction sector has already witnessed cases of malware attacks on CDE platforms, resulting in project delays or stoppages. Standards such as ISO 19650-5 (focused on information security) emphasize the importance of cybersecurity measures, including access control, data encryption, and backup protocols [9]. In practice, this requires the implementation of robust policies and tools, such as role-based access systems, offline backup copies of critical data, and cybersecurity training for project personnel.

4.3. Trends and Future Directions. Looking ahead, it is expected that the digitalization of the building life cycle will continue to deepen. Emerging concepts such as “BIM 2.0” are gaining traction - referring to the tighter integration of BIM with artificial intelligence (AI), augmented and virtual reality (AR/VR) technologies, and city-scale digital platforms. Initiatives are underway to develop smart city digital twins, which combine data from buildings, infrastructure, and transportation systems. These integrated models will enable comprehensive urban management - for example, simulating the impact of a new development on traffic patterns or energy distribution in a district, even before construction begins.

Another major trend is sustainability and decarbonization through digital technologies. BIM models are increasingly being used not just for construction coordination but also for calculating carbon footprints and optimizing energy performance. In many countries, regulations now require reporting of CO_2 emissions associated with construction materials during the design phase—typically as part of a Life Cycle Assessment (LCA). Digital models greatly streamline such evaluations. During the operation phase, monitoring systems connected to the digital twin can help regulate HVAC systems, lighting, and other energy-consuming processes to minimize resource use without compromising occupant comfort [12].

The widespread adoption of open data standards and APIs is also expected. Leading platforms such as Autodesk Forge and Bentley iTwin already enable developers to build custom applications on top of BIM data. This is paving the way for a robust ecosystem of specialized digital solutions - ranging from tools for biomechanical analysis of buildings under seismic loads to autonomous robots that navigate using digital building models.

Finally, one of the most promising future directions is the development of feedback loops from building operation back to design. Currently, data collected during the operational phase - such as equipment failure records or actual maintenance costs - rarely reaches the original design team. In the future, as large volumes of operational data are accumulated, architects and engineers will be able to derive insights about which design choices prove most reliable and cost-effective over time. Such a "quality loop" will help close the digital life cycle, continuously improving the design of next-generation projects.

Conclusion

As technology advances, the digitalization of the building life cycle is evolving from a forward-looking trend into a fundamental prerequisite for the successful delivery of construction projects. This study has confirmed that the integrated application of BIM, CDE, and related digital tools yields significant benefits at every stage - from enhanced design efficiency and reduced construction errors to improved building operations during the occupancy phase. Real-world case studies from various countries reveal consistent positive outcomes, including time and cost savings, higher quality and safety, optimized facility management, and improved transparency and predictability across the project lifecycle.

Naturally, the adoption of digital methods requires investment and the overcoming of institutional and technical barriers. However, the accumulated global experience - embodied in ISO/PAS standards and national-level initiatives - demonstrates how these barriers are gradually being addressed. The organization and standardization of information workflows has emerged as a top priority, as digital technologies cannot deliver their full potential without clear, coordinated processes.

A key conclusion of this research is that digitalization must be considered across the entire life cycle. Isolated use of BIM during either the design or construction phase fails to unlock its full value. Maximum impact is achieved when a continuous digital thread runs through all phases - from early concept design, where parameters are embedded into the model, through to operations, where the model is updated with as-built data. This end-to-end integration supports better decision-making, knowledge retention, and long-term value generation in the built environment.

For practitioners and stakeholders - developers, designers, contractors, and facility managers - this research emphasizes the importance of early planning for a digital strategy. It is recommended that BIM and data requirements (EIR) be defined at the project's outset, that responsibilities for information modeling be assigned, that a CDE platform be selected, and that data exchange processes be coordinated in advance. Investments in team training and the involvement of experienced BIM managers will pay off through reduced risk and smoother project execution. Facility management teams, in particular, should be actively engaged in the digital modeling process to ensure the delivery of a useful operational tool.

Looking ahead, the digitalization of the construction sector will continue to deepen. Emerging technologies - digital twins, artificial intelligence, and big data - will unlock new levels of optimization. Yet, the foundations for this digital future are already being laid through the widespread adoption of BIM and information management standards. The digital transformation of the building life cycle is not a one-off project but rather a continuous improvement process that requires sustained collaboration across all actors. Advancing along this path will enable the construction industry to reach a new level of productivity, innovation, and sustainability in response to the challenges of the 21st century.

REFERENCES:

16. **Institution of Civil Engineers. (n.d.).** *Construction industry is one of the least digitised compared to other major industry sectors.* ICE Training. Retrieved July 1, 2025, from icetraining.org.uk.

17. **Alleguard. (n.d.).** *BIM benefits: Efficiency and cost savings in construction.* Retrieved July 1, 2025, from alleguard.com

18. **McKinsey & Company. (2016, June).** *Imagining construction's digital future*. mckinsey.com

19. **Revizto (2025).** BIM for Facility Management: Definition, Benefits and How To Use It. *Revizto Blog*, June 12, 2025. revizto.com

20. **Revizto (2024).** BIM Level of Development (LOD): 100, 200, 300, 350, 400, 500 – Standards & Examples. *Revizto Blog*, Oct 16, 2024. revizto.com

21. **Autodesk. (n.d.).** *Levels of development in BIM: Enabling coordination and collaboration*. Retrieved July 2, 2025, from autodesk.com

22. **1-BIM. (n.d.).** *Уровни проработки LOD в BIM: от LOD 100 до LOD 500.* Retrieved July 2, 2025, from www.1-bim.ru

23. **Revizto. (n.d.).** *What Is ISO 19650 and Why Should US Firms Care About BIM Standards?* Retrieved July 3, 2025, from revizto.com

24. **El-Din, M. N., Pereira, P. F., Martins, J. P., & Ramos, N. M. M. (2022).** *Digital twins for construction assets using BIM standard specifications. Buildings, 12*(12), 2155. https://doi.org/10.3390/buildings12122155

25. **AlterSquare. (2025, June 10).** *Beyond BIM: How digital twins are revolutionizing construction project management.* altersquare.medium.com

26. **Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M., Bertram, N., & Brown, S. (2016, June).** *Imagining construction's digital future. McKinsey & Company.* mckinsey.com

27. **Gordo-Gregorio, P., Alavi, H., & Forcada, N. (2025).** *Decoding BIM challenges in facility management areas: A stakeholders' perspective. Buildings,* 15(5), 811. https://doi.org/10.3390/buildings15050811

28. **Federal Highway Administration. (2021).** *Global benchmarking of BIM in infrastructure delivery.* U.S. Department of Transportation. international.fhwa.dot.gov.

29. **Jaffar, N., Salim, N. A., & Adnan, H. (2022).** *Drivers, capabilities, and challenges for adopting digital twin in facility management.* Planning Malaysia, 20(3), 241–253. planningmalaysia.org

30. **Arch2o. (n.d.).** *Case study: BIM in Shanghai Tower*. Arch2o. Retrieved July 5, 2025, from arch2o.com

31. **Crossrail Ltd. (2018).** *Crossrail project: Application of BIM (Building Information Modelling) and lessons learned*. Crossrail Learning Legacy. learninglegacy.crossrail.co.uk

32. **Lynch, J. (2017, March 29)**. *BIM could save money in an infrastructure building surge. Engineering News-Record.* enr.com

33. **Buronov, N. S., Rakhmatillaeva, Z., Matniyazov, Z., Arabi, F., & Husainov, M. (2025).** *Advancing the understanding and application of building information modeling.* American Journal of Education and Learning, 3(3), 998–1006. https://doi.org/10.5281/zenodo.15083900

34. **Matniyazov, Z., Tulaganov, B., Adilov, Z., Khadjaev, R., & Elmurodov, S. (2025).** *Application of BIM technologies in building operating organizations.* American Journal of Education and Learning, 3(3), 957–964. https://doi.org/10.5281/zenodo.15081913

35. **Matniyazov, Z., Adilov, Z., Khotamov, A., Elmurodov, S., Rasul-Zade, L., & Abdikhalilov, F. (2025).** *Integration of BIM and GIS technologies in modern urban planning: Challenges and prospects.* American Journal of Education and Learning, 3(3), 972–976. https://doi.org/10.5281/zenodo.15083760

36. **Ikramov, Sh., Matniyazov, Z., Rasul-Zade, L., Safiev, T., & Avloqulova, X. (2025).** *Parametric modeling of multifunctional buildings in the BIM system.* American Journal of Education and Learning, 3(3), 978–984. https://doi.org/10.5281/zenodo.15083793

37. **Matniyazov, Z., Giyosov, I., Rakhmatillaeva, Z., Buronov, N., & Nigmadjanova, A. (2025).** *Requirements for the preparation of design documentation*

based on BIM technology. American Journal of Education and Learning, 3(3), 985–991. https://doi.org/10.5281/zenodo.15083815

38. **Abdujalilova, S., Matniyazov, Z., & Elmurodov, S. (2025).** *Реновация фасадов зданий социального назначения с применением BIM.* Международный научный журнал «Научный Фокус», (25) (100), часть 1*, 833–846.