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INTEGRATING BUILDING INFORMATION MODELLING (BIM) INTO CONSTRUCTION: INNOVATIONS, CHALLENGES, AND GLOBAL PERSPECTIVES

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ABSTRACT

The contemporary construction industry is undergoing transformative changes driven by pervasive digitalisation, with building information modelling (BIM) emerging as a pivotal innovation. This paper explores the imperative of incorporating BIM into every new construction project, emphasising its potential to enhance collaboration, streamline processes, and foster innovation. Through a comprehensive analysis of BIM's application in Poland and globally, the review of current literature assesses various software tools and compares BIM methodologies with traditional construction practices. The paper also identifies opportunities and challenges associated with integrating emerging technologies in the construction sector. The findings emphasise the necessity of adopting BIM to improve efficiency, reduce waste, and enhance project outcomes. BIM technology has undeniably become an elementary component of the process of creating and managing information about a construction project throughout its life cycle, used in architecture, engineering, and construction management.

Keywords: building information modelling, facility management, augmented reality, clash detection, Revit, Archicad

INTRODUCTION

Due to its distinctive characteristics and the intricate processes involved, the construction industry offers a significant opportunity for innovation and the advancement of digitalisation capabilities in production. Building information modelling (BIM) is the most rapidly expanding application of computer-aided design and construction management (PwC Advisory, 2020b). The apparent necessity for advancement in this direction is driven by the requirement to coordinate the multidiscipline construction projects that are integral to computer integrated manufacturing (CIM).

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The primary drivers of growth in the construction industry are multi-faceted, but economic factors undoubtedly play a central role. This can be attributed to the substantial contribution of the architecture, engineering and construction (AEC) services sector to GDP, which has steadily increased over the years, and the rising value of construction investments annually. It is also worth noting that each investment project involves many participants, from architects and engineers to skilled tradespeople and labourers. The construction industry is a significant source of employment, with thousands of new workers joining the workforce annually, contributing to the economic vitality of communities nationwide (PwC Advisory, 2020a; Alirezaei, Taghaddos, Ghorab, Tak & Alirezaei, 2022).

The MacLeamy curve demonstrates the correlation between cost and time in construction projects, contrasting traditional design with modern design utilising BIM (Fig. 1). The curve illustrates project costs increasing in proportion to time, then increasing exponentially at a certain point. As a project progresses, the costs associated with revisions and changes begin to exert a dominant influence, although initially, these costs are primarily associated with planning, design, and construction. This principle underscores the significance of early involvement in meticulous planning and design to circumvent costly alterations later in the project. In the initial stages of a construction project, the decisions made can considerably affect the cost and efficiency of the project.

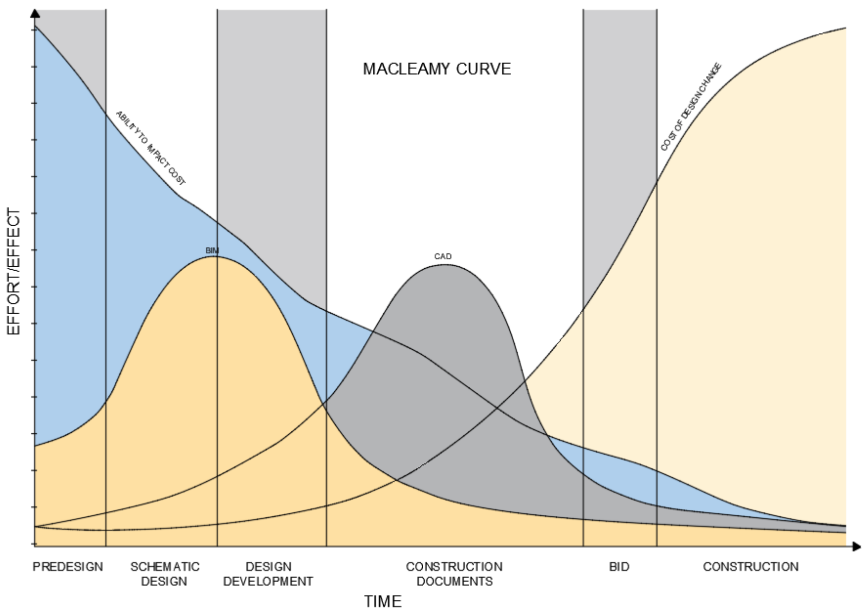

Fig. 1. MacLeamy curve

Source: Nguyen, Do, Le-Hoai, Nguyen and Pham (2022).

Another significant factor driving the expansion of this sector is the construction industry's relatively low productivity. This issue is closely linked to the reduced precision of manufacturing processes in comparison to other engineering sectors, a challenge rooted in the technical limitations of traditional on-site construction methods. These limitations stem from a lack of standardisation, limited repetition, and inefficiencies in design-build procedures. Shortcomings in process management, poor stakeholder coordination, and insufficient consideration of end-user requirements also further exacerbate these inefficiencies. The tightening of restrictive building regulations also poses a significant challenge. Moreover, the construction industry's inefficiency is amplified by the substantial waste generated during the construction and demolition of buildings, positioning it among the highest carbon footprint sectors. In response, researchers and entrepreneurs are actively seeking more effective strategies for reusing waste and mitigating its environmental impact (PwC Advisory, 2020b).

In response to the issues outlined above, an increasing number of solutions are emerging in the marketplace to facilitate the processes involved in the design of buildings, the management of documentation, and the enhancement of collaboration between stakeholders in the investment process. Furthermore, stakeholders' utilisation of computer-aided construction process software is also increasing. The market leaders in structural design using BIM elements are as follows: notable software programs in this field include Autodesk Revit (and its other programs, such as Autodesk Civil), Graphisoft Archicad, and Vectorworks. The European market leaders in construction document management platforms have been Dalux, PlanRadar, and Thinkproject over the past few years. These tools are continuously evolving, making BIM more accessible to engineers and architects, as well as to contractors and construction managers.

The paper presents a comparative analysis and assessment of the risks and difficulties associated with using BIM tools in the architecture and construction sector. It analyses contemporary scientific literature, identifying opportunities and risks associated with implementing computerised tools. This is followed by examining the validity of introducing BIM tools into any construction project. The paper concludes with an evaluation of the advantages and disadvantages of using BIM and the results of using BIM in different stages of a construction task.

Evolution of building information modelling software

BIM is currently the predominant methodology for creating and updating information about a building throughout its lifecycle. Although the concept of BIM has existed since the 1970s, it was not until the advent of advanced computer capabilities in the early 2000s that this methodology truly evolved. Today, we can observe its significant influence across various domains of architecture and engineering.

The origins of BIM can be traced back to the 1970s and 1980s, aligning with the development of early computer-aided design (CAD) systems. These pioneering advancements marked the initial attempts to integrate various building data into a unified digital representation (Borkowski, 2023). By the late 20th century, BIM was widely accepted, encapsulating a comprehensive array of information within a computer-aided design environment.

BIM is a multi-faceted concept, with various activities and organisations adopting their standards and implementations, shaped by their projects' specific natures and scopes. As we entered the 21st century, advancements in technology allowed the concept of BIM to take on a more defined structure and direction. During this period, the development of standards and communication protocols became more understandable, leading to BIM's acceptance as a fundamental approach in the construction industry. However, its implementation and effectiveness largely depend on national standards and the results achieved within those frameworks.

Historically, the United Kingdom is regarded as the country that first introduced the widespread use of the BIM environment. The UK developed the BS 1192 standard (British Standards Institution [BSI], 2007), which forms the basis of the current ISO 19650 standard (International Organization for Standardization [ISO], 2023). The UK government's robust commitment to introducing BIM in the UK building sector has made it a global leader. It is a model for other countries to develop their BIM implementation strategies. Despite the continued existence of varying levels of BIM implementations globally, there is a discernible shift towards BIM becoming the foundation for resource-efficient development in architecture and construction. The direction of this shift is being shaped by practitioners who are implementing BIM at the highest levels of maturity (Borkowski, 2023).

Software compatible with building information modelling

The most prevalent pieces of software for BIM design are Autodesk Revit, Archicad by Graphisoft, and Vectorworks (Waas & Enjellina, 2022). These programs facilitate the design of building structures with a high degree of precision, which mitigates numerous complications during the construction phase and throughout the operational lifespan of the building structure.

The impetus for developing three-dimensional modelling programs was the CAD programs utilised for an extended period in the architectural and engineering industries. The software in question is primarily designed for the creation of two-dimensional drawings. In contrast to Revit or Archicad, it cannot store detailed data on building elements. The comprehensive capabilities of BIM-supporting programmes facilitate the creation of detailed models encompassing all aspects of construction while enabling interprofessional coordination between architects, builders and plant designers. These programs are focused on three-dimensional modelling, which means that changes made in one place are automatically updated throughout the project. This has the effect of eliminating errors due to outdated information. The existing industry foundation class (IFC) file extension allows all involved to collaborate on their respective design areas, reducing the duration of the design process, minimising the risk of errors and reducing costs in the construction process (Alfalah, Al-Sakkaf, Elshaboury & Abdelkader, 2021). The study examines the efficacy of document and task management platforms at construction sites.

Many platforms are emerging to facilitate the essential technical documentation processes during the design and construction phases. An illustrative example of such a solution is the platform proposed by Dalux, which has recently witnessed a notable increase in its market share in Poland and on a global scale. Dalux represents a comprehensive solution comprising modules and products, including the BIM Viewer – a highly expedient, cost-free three-dimensional model viewer that supports files formats such as BIM, IFC, DWG and PDF. The modules encompass Dalux Box, Dalux Field and Dalux FM.

The Dalux BOX module facilitates collaborative document editing and review among teams. The module facilitates the tendering, acceptance and verification of projects and the identification of discrepancies between versions. Furthermore, it facilitates convenient access to files at any time on computers and mobile devices (Khemlani, 2022). Dalux Field, conversely, is beneficial for the administration of tasks in situ. The tool is convenient and facilitates collaboration with subcontractors, defect reporting and reducing inspection and quality check times. Another distinctive solution is SiteWalk, a reality-capture function that challenges the conventional approach to visual documentation of on-site progress. The model, created in a few minutes, makes it possible to identify potential hazards, which can then be eliminated to maintain the safety of the work (Pereira De Sa & Gonzalez Alfaro, 2021; Khemlani, 2022). Dalux is one company that also offers solutions for property managers. To this end, additional modules have been developed: (i) BIM and documentation: a comprehensive collection of building information and service history; and (ii) Operations and maintenance: a repository for repetitive work orders and maintenance.

Application of building information modelling in the context of augmented reality

In the present era, there is a growing prevalence of discourse surrounding the exponential advancement of virtual reality. These considerations are most often related to video games. Virtual reality (VR) and augmented reality (AR) are being employed to integrate the tangible world with the capacity to conceptualise design solutions and rectify errors in real time. Utilising these tools permits the virtual navigation of a three-dimensional model of a building prior to the commencement of construction. This is advantageous for investors, general contractors, and prospective occupants of new residential and commercial premises. The application of this technology is becoming increasingly prevalent in construction-related tasks. The preliminary development of this technology highlights the necessity of addressing the challenges that impede the comprehensive integration of these technologies in the context of modern construction sites.

The effective operation of VR and AR is contingent upon the availability of advanced equipment and high-speed, high-bandwidth networks, which is regarded as one of the principal challenges in this field. In the contemporary era, computer hardware is typically accessible; however, not all units possess the requisite computing power and, consequently, the accuracy to faithfully represent reality. To be fully convinced of the connection between the real and virtual worlds, sufficient accuracy needs to be achieved and ensure the image's smoothness. Further limitations relate to security and user privacy. As the technology develops, there are legitimate concerns about surveillance, espionage, privacy breaches, and data theft, particularly in the construction industry, where such sensitive data is desired by companies.

Notwithstanding the constraints outlined, virtual and augmented reality technologies demonstrate substantial potential for advancement within the construction industry. The principal limitation at this time is the cost of the equipment required to utilise VR and AR. Concurrently, concerning the developmental aspect, the objective should be to achieve greater accuracy and precision in the virtual world created with minimal hardware requirements. As this technology develops, it will also be necessary to establish appropriate regulations and standards regarding user protection issues.

Parametric design and fabrication in building information modelling

Software applications like Revit and Archicad offer distinct advantages over AutoCAD due to their incorporation of parametric tools like Dynamo and Grasshopper. These tools empower designers with the capability to create dynamic, data-driven models, providing efficient and systematic design processes. The incorporation further enhances the adaptability and versatility of these applications, making them indispensable for contemporary architectural and engineering practices.

The flexibility and adaptability of Dynamo and Grasshopper scripts make it easier to adjust designs in response to evolving project requirements and client feedback, promoting a more agile and responsive design process. This, in turn, leads to a more collaborative and iterative approach to design, which is particularly beneficial in complex, large-scale projects. Algorithms enhance processes in diverse technological fields, and their growing significance in defining architectural excellence is evident. Using computer-aided architectural modelling, including collaborative efforts such as BIM, has intensified the intrigue surrounding non-Euclidean geometric forms.

Moreover, BIM's importance in fabrication lies in its contribution to design flexibility, efficiency, and architectural precision. It empowers the creation of intricate, customised architectural forms while optimising material use and promoting sustainability. Integrating generative design and computational methods further enriches the design process by blending technical expertise with creative freedom (Stefańska & Dixit, 2020).

MATERIAL AND METHODS

This paper critically examines the risks and opportunities associated with utilising a BIM environment for interdisciplinary design and construction management during construction. These stages have been selected based on their potential for offering significant benefits and the availability of software on the market that is capable of supporting them. In light of the selected literature review findings, it was decided that investigating the necessity of utilising BIM for each construction project in the stages mentioned above would be beneficial. The potential applications of BIM at varying stages of its development were investigated. The selected literature comprises articles written between 2018 and 2023, thereby ensuring the inclusion of the latest capabilities and current technologies. The Scopus database was employed to identify articles that delineated contemporary issues about implementing BIM in construction practice. The terms 'building information modelling', 'facility management', and 'augmented reality' were used as search keywords in the Scopus database. A total of 319 articles meeting the specified criteria were identified by applying the above-mentioned boundaries. The subsequent analysis phase entailed selecting articles pertinent to utilising BIM in design and construction management.

As a consequence of this analysis, 20 articles were selected. Then, a compilation of different ways of using the BIM environment in the AEC industry was made, including a quantitative overview of the scientific articles (according to country of origin of the authors and publishers) on the BIM environment and the main thematic issues addressed in these articles. The results of the comparative analysis of the scientific literature are presented as a discussion of the advantages and disadvantages of using BIM in the construction sector and an exploration of potential future applications for this technology.

RESULTS AND FINDINGS

Incorporating BIM into the AEC industry has precipitated a profound transformation in how projects are designed, constructed, and managed. BIM is not merely a digital tool but a process that facilitates a collaborative environment where various stakeholders can contribute to a unified, comprehensive, and dynamic building or infrastructure project model. Such a model may encompass much information, including architectural details, structural elements, mechanical systems, and even construction schedules. The use of BIM facilitates improved coordination, reducing the probability of errors and conflicts occurring during the construction phase. A comprehensive, real-world view of the project by BIM facilitates improved decision-making, enhancing project outcomes and more efficient resource management throughout the facility lifecycle.

BIM is also being extended to facilities management (FM), where it is employed as a principal instrument for the upkeep and operation of buildings long after the construction phase has concluded. Implementing BIM provides facilities managers access to a comprehensive database that can be utilised for many purposes, including maintenance planning, space management, energy optimisation, and more. This integration of BIM with FM represents a shift towards more sustainable and efficient building management practices. Furthermore, combining BIM with new technologies such as the Internet of Things (IoT) and sensors enables real-time monitoring of building systems, thereby enhancing facilities' operational efficiency and sustainability. Consequently, the role of BIM in the AEC industry is expanding, from improving the accuracy and efficiency of design and construction to supporting the ongoing management and optimisation of built environments.

BIM facilitates interprofessional collaboration and enhances the efficiency and quality of technical design and construction process supervision. Table 1 delineates the principal research areas currently being investigated through the utilisation of BIM in the AEC sector.

The analysis focused on the application of the BIM environment in the AEC sector summarises studies that have employed BIM in the AEC industry (Table 1). It also provides a list of specific articles and keywords that are directly related to the topic under study. This enabled a more comprehensive understanding of the issue to be achieved, and demonstrates the evolution of the BIM concept.

Table 2 provides supplementary information to that presented in Table 1, including the names of the journals in which the articles on the topic were published, and the number of articles published in each journal, the years in which they were written, and the average number of citations per article.

In selecting the analysis papers, an attempt was made to obtain a comprehensive overview of the changes and perceptions of BIM technology between 2018 and 2023, considering the various aspects of its implementation. At the same time, the data was kept up to date by selecting articles no older than five years.

Table 1. Studies focused on the application of the building information modelling environment in the architecture, engineering and construction industry

Reference	BIM research subject
Antón, Medjdoub, Shrahily and Moyano (2018), Nguyen et al. (2022), Lucchi (2023)	architectural details
Li and Lu (2018), Huang, Ninić and Zhang (2021), Mei et al. (2021), Chi, Juan and Lu (2022), Son and Han (2022), Kang, Kang, and Kim (2023), Liu, Zhang and Osmani (2023), Pu et al. (2023)	structural elements
Hwang, Zhao, and Yang (2019), Wang and Meng (2021), Katiyar and Kumar (2022), Kang et al. (2023)	construction schedule
Hosseini, Roelvink, Papadonikolaki, Edwards and Pärn (2018), Li and Lu (2018), Moreno, Olbina and Issa (2019), Wang and Meng (2021), Nour El-Din, Pereira, Poças Martins & Ramos (2022), Kang et al. (2023), Lucchi (2023)	facilities management
Maskuriy, Selamat, Ali, Maresova & Krejcar (2019), Alizadehsalehi, Hadavi, and Huang (2020), Xia, Liu, Efremochkina and Lin (2022), Lucchi (2023)	Internet of Things

Source: own work.

Table 2. Selected articles for analysis

Journal	Number of papers	Year	Citation average
Automation in Construction	3	2018 2020 2023	4–6
International Journal of Architectural Heritage	1	2018	2–4
Buildings	3	2022 2023	3–5
International Journal of Building Pathology and Adaptation	1	2018	2–3
Tunnelling and Underground Space Technology	1	2021	5–7
Journal of Construction Engineering and Management	2	2019 2023	5–7
KSCE Journal of Civil Engineering	1	2023	4–6
International Journal on Recent and Innovation Trends in Computing and Communication	1	2022	2–3
Applied Sciences	1	2019	3–5
Journal of Management in Engineering	2	2022 2021	4–6
Advances in Civil Engineering	1	2019	3–5
International Journal of Construction Management	1	2023	3–4
Journal of Computing in Civil Engineering	1	2023	4–6
Sustainable Cities and Society	1	2022	5–7

Source: own work.

Advantages of building information modelling

BIM facilitates enhanced investment process management, encompassing the planning stage and extending to the facility's design, implementation, and completion. This is made possible through implementing the common data environment (CDE) platform and preparing the facility management (FM) platform, which is used to manage an existing facility (Baldwin, 2019). BIM furnishes users with the requisite tools to streamline the work of project participants. This approach to project management is conducive to the following aspects: site analysis, preliminary surveying, scheduling, energy analysis, sustainability assessment, three-dimensional coordination (e.g., clash detection and elimination), as-built documentation modelling, and FM platform planning. Furthermore, BIM facilitates improvements in contract management, task assignment and tracking, and project progress planning and reporting (Baldwin, 2019).

An investment process that is appropriately managed makes efficient use of all resources. BIM offers the potential to reduce the consumption of resources, including time, cost, and construction effort. Digital solutions that are both well-considered and effectively managed can facilitate the work of both client-side participants, and builders and designers (Wang et al., 2022). One potential application is the openBIM platform. This entails the establishment of an environment wherein each team member can operate at their optimal level, following their preferences and without the constraints imposed by other users. Implementing open standards and solutions enhances software interoperability and guarantees the precision of collaborative processes. Effective inter-industry coordination is a crucial aspect of BIM. This approach identifies potential conflicts before construction commences. Laser scanning techniques and 360-degree photography enable accurate building mapping, facilitating enhanced collaboration within the BIM environment, particularly in challenging, intricate, or linear objects (Stefańska, Markowski & Dixit, 2024) especially in the interdisciplinary Architecture, Engineering, and Construction sector (AEC). Such solutions permit expanding knowledge and facilitate the work of subcontractors, who frequently rely on two-dimensional documentation.

The utilisation of the CDE platform during the execution of a project facilitates the efficient management of subcontractors' work and the verification of tasks performed (PwC Advisory, 2020b). Fault forms, including photographic documentation and detailed descriptions, are assigned to the pertinent project participants responsible for a specific area. The information is catalogued appropriately, is readily understandable, and is accessible via a single phone or tablet application. The tools provided by the CDE platform serve to supplant the need for telephone or email communication and facilitate the reporting of work status tailored to the specific scope of work and project schedule. The platform facilitates various activities, including the management of tasks, health and safety inspections, and digital acceptance. Integrating a three-dimensional model, a comprehensive set of 360-degree photographs, and laser scanning technology enables a realistic representation of the site. It captures differences in documentation, thereby streamlining the creation of as-built documentation (Wang et al., 2022). The digital acceptance process allows for a more thorough inspection and quality control while reducing the time spent on excessive bureaucratic procedures.

Preparing an FM platform enhances facility management. It facilitates comprehension of and adherence to the client's requirements. The building transfer from one owner to another is contingent upon providing BIM and the capacity to utilise data accumulated from the project's inception. The FM platform facilitates data aggregation from manufacturers, subcontractors, and designers.

The three-dimensional model can also produce visual representations of the facility. By incorporating appropriate visual effects, the facility can be depicted at the proposed construction site as a standalone structure or in conjunction with surrounding buildings and landscaping. Such visualisations can be created to market the project effectively.

Incorporating contemporary technology into the construction industry represents a significant advancement in cost reduction and project acceleration. The overarching objective of BIM technology is to enhance the efficiency of routine operations, including the administration and documentation of projects, monitoring health and safety protocols, and facilitating inter-team communication. This aims to systematically organise information and analyse and learn lessons for future applications (Baldwin, 2019). The objective of BIM technology is to minimise and deconflict design flaws; that is, to reduce the incidence of human errors made during the preparation of design documentation and the implementation and management of the facility. Implementing more solutions and their regular use have increased employee and customer satisfaction.

BIM offers a multitude of benefits that can be leveraged to enhance various facets of construction projects. One of the principal advantages of BIM is its capacity to accurately represent intricate architectural elements, which is of particular significance in the context of historic building renovation projects (Antón et al., 2018). Furthermore, BIM facilitates the integration of disparate disciplines, thereby ensuring more consistent and precise project management (Nguyen et al., 2023). In the context of structural elements, BIM enables more effective visualisation, facilitating more informed design decisions and improving the final structures' quality (Chi et al., 2022). BIM also enables the management of construction schedules, reducing the number of revisions and accelerating projects through enhanced team coordination and resource optimisation (Hwang et al., 2019). In the context of facilities management, BIM facilitates the transfer of information from the construction phase to the operational phase, thereby enabling more effective monitoring of buildings and reducing maintenance costs (Hosseini et al., 2018). Furthermore, integrating BIM with IoT technology makes it possible to dynamically monitor construction processes and more efficiently manage resources (Alizadehsalehi et al., 2020).

Limitations and challenges during the introduction of BIM tools

Nevertheless, difficulties are frequently identified due to individuals' beliefs and apprehension about change. Standardisation and adherence to industry guidelines can prove challenging, and adapting the technology to existing processes can often encounter considerable internal resistance within many organisations. The effective management of data, the resolution of legal issues, and the reliance on particular service providers contribute further to the complexity and cost associated with implementing BIM.

The following aspects should be addressed in any form of digitisation:

- Lack of national and international standards. This is a significant challenge due to the lack of consistent guidelines across regions. This results in a dispersion of practices and data formats, complicating collaboration and hindering BIM implementation. There are, however, indications that progressive changes are being made to promote the development of BIM technology. Many countries, including China, the Czech Republic, and major technological giants like the UK and Germany, have started to create BIM standards, especially for infrastructure projects (Costin, Adibfar, Hu & Chen, 2018).
- Implementation of BIM is hindered by financial constraints, particularly the high initial investment required for software, hardware, and training. Furthermore, there are additional costs associated with ongoing software licensing, the necessity for robust hardware, staff training, integration with existing systems, data management and storage, difficulties in measuring return on investment (ROI), and additional costs related to risk management and legal and financial issues (Olawumi et al., 2018).
- Lack of qualified personnel. BIM is a nascent technology undergoing rapid development. Despite the numerous enhancements that have been made, it also presents new technological challenges for the construction industry. Technological advancement necessitates acquiring specialised skills, including software utilisation and data management proficiency. The process of sourcing and retaining experts can sometimes prove challenging, resulting in a discrepancy between the demand for and the availability of qualified personnel (Chan, Olawumi & Ho, 2019).
- Resistance to change. The apprehension surrounding the acquisition of novel technological skills impedes the rate of its integration. It can be challenging to persuade stakeholders of BIM's value, which can delay its broader implementation (Olawumi et al., 2018).
- The potential for privacy infringement, data security risks, and the possibility of technological obsolescence are significant concerns. Overcoming these challenges is essential to fully realising the potential of BIM in the construction industry.
- Software compatibility. In order for BIM to be effectively implemented, the various software applications must be compatible with one another. This can be a significant challenge, particularly in large-scale projects where multiple companies may utilise disparate BIM tools.

To address the challenge of the lack of consistent national and international standards for implementing BIM, it would be crucial to have a universal operational and technical framework that could be adapted across regions and for different projects. One potential solution is the development of a set of fundamental guidelines based on existing global standards, such as ISO 19650, which defines the principles of information management in BIM projects. Such a framework could be further enhanced by incorporating flexible components tailored to accommodate each country's distinctive legal, cultural, and technical requirements. A subsequent step would be to establish an international forum or working group comprising construction industry representatives from diverse geographical regions. The objective of this forum would be to monitor progress and develop standards by global trends in technology and construction practices. Furthermore, standardisation could encompass the harmonisation of data formats and software interoperability, which would considerably facilitate international collaboration and enable the full realisation of the potential of BIM in large-scale projects.

Numerous organisations have sought to leverage the experiences of other entities that have successfully deployed the technology to mitigate resistance to implementing BIM and to foster a culture of innovation. One illustrative example is the Crossrail project in the UK, which has become a model for BIM integration in infrastructure (Szarata, 2022). In addition to providing staff training, the project management team also established dedicated collaboration platforms to facilitate convenient access to project data for all stakeholders. The key to success was the gradual introduction of technology, which permitted teams to become accustomed to the new tools and processes. Similarly, in the Oslo Opera House project, the implementation of BIM was facilitated by educational initiatives and the involvement of technology leaders, which helped to overcome initial scepticism and resistance to change (Sauge, 2019). These examples illustrate that involving employees in the initial stages of technology implementation and providing the requisite tools and training to facilitate their adaptation to the novel working environment are pivotal to success.

RECOMMENDATIONS

To successfully implement BIM technology, it is essential to have clear, practical recommendations in place to overcome the challenges that have been identified. One potential solution is to establish and implement consistent national and international standards for BIM. Such a system would facilitate uniform cooperation between companies from disparate regions and facilitate data exchange. It is incumbent upon governments and industry organisations to provide active support for this process, including creating legislation promoting the use of BIM and allocating funding for training and technology investments. Providing tax incentives or subsidies for the early implementation of BIM could also provide further motivation for companies to overcome the financial barriers associated with the high initial costs involved.

One potential avenue for advancement is the implementation of comprehensive BIM training programs for both existing employees and students in construction and engineering. This would facilitate the widespread adoption of the technology by addressing the current skills gap. Concurrently, regarding software compatibility, the industry should develop open data formats (such as industry foundation classes), which would facilitate the integration of disparate BIM tools into complex projects. For instance, forming industry consortia to collaborate on developing interoperability standards between disparate software tools could potentially mitigate the challenges associated with software diversity.

To mitigate resistance to change, it is imperative to engage individuals at the outset of any BIM implementation and educate them on the advantages of the technology. Implementing change management strategies to overcome resistance to new developments and accelerate the adaptation process would be prudent. Moreover, in response to concerns about privacy and data security, it is imperative to implement robust data protection measures that align with the highest industry standards to enhance confidence in BIM technology.

It is worth considering cost-effective and strategic approaches to enable smaller firms to implement BIM incrementally and overcome financial barriers. One is a subscription model for BIM software, which reduces the one-off cost of purchasing a licence, allowing firms to spread the expense over time. Companies can also take advantage of free or cheaper versions of open-source software that offer basic BIM functionality, which can be a first step towards digitalisation. Another solution could be to gradually implement BIM technology in selected pilot projects, allowing firms to gain experience and assess the return on investment (ROI) before a full implementation. It is also worth considering working with third-party BIM service providers, allowing smaller firms to benefit from experts and technology without bearing the full cost of purchasing software and employing skilled staff.

DISCUSSION

The construction sector is experiencing sustained growth, which has resulted in an increased demand for integrating BIM into contemporary projects. BIM enables the simultaneous creation and management of virtual models. Such integration offers a multitude of advantages, including data aggregation, dissemination, and incorporation despite several constraints throughout the project life cycle.

A comprehensive analysis of the advantages and disadvantages of BIM was conducted through an extensive examination of 20 selected articles from the Scopus database, published between 2018 and 2023. The selected scientific articles were analysed according to the following topics: the subject areas under consideration are architectural details, structural elements, construction schedules, facilities management, and the Internet of Things.

The architectural details theme was the subject of analysis in three articles. The primary benefit of BIM, as posited by Antón et al. (2018), is the capacity to precisely model and document intricate architectural components, particularly in historical edifices. The creation of three-dimensional models semi-automatically is a possibility afforded by BIM, which significantly increases accuracy and reduces the risk of errors when reconstructing architectural details. Furthermore, the technology facilitates the integration of disparate engineering and architectural disciplines, thereby ensuring more consistent and precise management of restoration projects – a crucial aspect in preserving the authenticity of heritage buildings (Nguyen et al., 2022).

It should be noted, however, that BIM also has certain limitations. While the semi-automated modelling process increases precision, it is also time-consuming and requires advanced technical knowledge, which can be a barrier for some users (Antón et al., 2018). Moreover, implementing BIM in architectural detailing frequently entails considerable costs and the necessity for substantial financial and human resources, particularly in regions with limited access to technology (Nguyen et al., 2022). Moreover, the utilisation of digital twins in the automation of the building sector necessitates the continuous monitoring and management of buildings, which in turn requires the input of vast quantities of data and the deployment of sophisticated algorithms. This can prove challenging to implement in practice. Integrating these technologies with existing systems can be complex and costly (Lucchi, 2023).

The analysis was conducted on eight articles in the context of structural elements. Huang et al. (2021) emphasise the advantages of integrating BIM with machine learning and computer vision techniques in underground construction. This integration improves precision in planning and monitoring structural elements, which is crucial in environments where errors are likely to occur. In contrast, Pu et al. (2023) emphasise the importance of faster updating of BIM models in railway stations, which facilitates efficient management and maintenance of structural elements in dynamic environments while optimising interruptions. In their 2023 article, Son and Han present a method for automatically planning three-dimensional scans of prefabricated building components using BIM. This makes it possible to precisely adjust structural components on site, thereby reducing the risk of errors and improving assembly quality. Liu et al. (2023) posit that BIM is a crucial tool for sustainable cultural heritage management, as it facilitates precise documentation and analysis of the condition of historic structural elements, thereby supporting their maintenance and preservation over time. Chi et al. (2022) observed that BIM facilitates enhanced visualisation and comprehension of the structural characteristics of buildings, thereby fostering more judicious design choices and superior-quality final structures.

Conversely, as Li and Lu (2018) demonstrated, incorporating geometric models with site imagery and GIS-supported BIM facilitates the precise representation and analysis of structural elements on site, enhancing management and decision-making processes.

The authors identify several potential limitations of BIM technology that could restrict its efficacy despite its numerous advantages in structural management. Huang et al. (2021) observed that integrating data from disparate sources and the scalability of BIM models present significant challenges in underground construction. This can result in inaccuracies in the representation and monitoring of structural elements in challenging underground environments. Similarly, Pu et al. (2023) indicate that a dearth of data can result in incomplete or inconsistent information regarding structural elements. This renders updating BIM models time-consuming and inaccurate, resulting in delays in infrastructure management and maintenance. Son and Han (2023) suggest that creating optimal three-dimensional scanning plans for prefabricated building components can be challenging due to the diversity of technical parameters and the intricate nature of BIM models. Such issues can lead to inaccuracies in mapping structural components, which may result in reduced assembly quality. Liu et al. (2023) posit that implementing BIM in the context of sustainable heritage management may present certain challenges. This is due to the absence of established standards and difficulties in integrating historical data with contemporary BIM models. These challenges can result in inaccurate documentation and analysis of structural elements in historic buildings. As Chi et al. (2022) observe, the implementation of BIM can present certain challenges, particularly in the context of structural elements. Inappropriate utilisation of the technology has the potential to result in design errors or difficulties in interpreting models. In 2018, Li and Lu demonstrated that the accurate mapping and management of structural elements can be challenging due to limitations in input accuracy and compatibility issues between different systems. A long-term study by Kang et al. (2023) indicates that the advancement of BIM is constrained by resistance to change in established work practices within the construction industry. The absence of standardisation and the challenges associated with adapting the technology can give rise to complications in the management of construction elements, ultimately leading to a detrimental impact on the efficiency of construction processes. In turn, Mei et al. (2022) highlight the challenges associated with formwork planning using BIM, particularly in the context of the potential reuse of structural elements. The absence of accurate data or its inadequacy can result in inefficient planning and elevated material costs.

In examining the subject of the construction schedule, four articles were subjected to analysis. BIM has several advantages and disadvantages in construction schedule management that can impede its effectiveness. First and foremost, integrating BIM with IoT technology enables the automatic monitoring of the construction progress of precast concrete structures. This markedly accelerates the monitoring process and mitigates delays by furnishing precise data on the construction status. As Katiyar and Kumar (2022) have observed, this facilitates more effective construction schedule planning. However, they also note that integrating BIM with IoT requires advanced technical expertise, potentially leading to system implementation delays.

Furthermore, BIM significantly reduces the necessity for revisions (rework) in construction projects, thereby reducing the project's overall duration. Hwang et al. (2019) posit that enhanced team communication and coordination can positively impact construction scheduling. Nevertheless, preliminary delays may be attributed to constraints such as the need for staff training and resistance to the comprehensive implementation of BIM (Hwang et al. 2019). Furthermore, Wang and Meng (2021) indicated in their paper that BIM facilitates knowledge management in construction projects, thereby enhancing the ability to plan and respond to change.

It is, however, important to reiterate that a lack of staff comprehension and acceptance of BIM can impede the implementation of the technology and adversely affect schedules (Wang et al. 2022). In Korea, a construction engineering study by Kang et al. (2023) demonstrated that BIM enhances the efficiency of the construction schedule by mitigating the risk of errors and delays and by facilitating the more effective planning and optimisation of resources, thereby accelerating project delivery. Furthermore, they indicate that issues surrounding the integration of BIM can result in elevated costs and delays.

The subject of facilities management (FM) was examined through seven articles. Hosseini et al. (2018) emphasise that enhancing information management and optimising data transfer from the construction phase to the facility operation represents a significant advantage of BIM. This enables managers to monitor and maintain buildings in a more effective manner, which in turn results in reduced costs and improved efficiency. Moreno et al. (2019) observe that BIM facilitates enhanced coordination between project teams and facility managers, streamlining change management and ensuring access to accurate data throughout the building lifecycle. Another advantage of BIM is its capacity to integrate with digital twin technologies. This can assist facilities management in more precisely monitoring the condition of buildings and predicting maintenance requirements. Nour El-Din et al. (2022) demonstrate that such integration results in cost and resource savings. Wang and Meng (2021) highlight the potential of BIM to facilitate knowledge management, which is crucial for effective building maintenance and lifecycle management.

Nevertheless, certain issues in FM necessitate the implementation of BIM. Hosseini et al. (2018) highlight the challenges associated with standardising processes and information requirements, noting that facility managers often lack the requisite knowledge and skills, which impedes realising BIM's full potential. Moreno et al. (2019) indicate that traditional construction companies encounter challenges adapting to new technologies and absorbing the high upfront costs associated with implementing a BIM process. Moreover, they underscore the dearth of interoperability between FM tools and disparate BIM systems.

As Nour El-Din et al. (2022) observed, deploying digital twins necessitates a sophisticated IT infrastructure and specific expertise, which may prove challenging for numerous organisations. Wang and Meng (2021) posit that contemporary IT systems are necessary for the management of BIM data, which can present challenges, particularly in the context of older buildings. Lucchi (2023) notes that implementing BIM in the heritage industry can present unique challenges due to the distinctive characteristics of these buildings and the intricate nature of the conservation processes involved.

The subject of the Internet of Things was examined in four articles. Integrating BIM and the IoT provides the potential for enhanced monitoring and management of construction and operational processes within buildings. As Alizadehsalehi et al. (2020) observed, integrating real-time data gathered by IoT sensors into the BIM model facilitates more effective decision-making and enables dynamic model updates. Maskuriy et al. (2019) observed that the real-time monitoring capabilities afforded by integrating IoT and BIM facilitate the intelligent management of construction resources and enhanced operational efficiency. In the context of smart city design, Xia et al. (2022) posit that integrating BIM and IoT facilitates the dynamic monitoring and optimisation of urban operations by utilising real-time data fed into digital twins. In contrast, Lucchi (2002) asserts that integrating IoT and BIM in the context of building heritage facilitates precise monitoring of the condition of historic structures, thereby enabling the automation and safeguarding of these assets.

While there are numerous advantages to integrating BIM and the IoT, Alizadehsalehi et al. (2020) are aware that there are also some obstacles to be overcome. The process is complex and necessitates the presence of an advanced technological infrastructure and relevant expertise, which can impede the comprehensive integration of this technology within the construction industry. Moreover, as Maskuriy et al. (2019) discovered, the construction industry is not yet sufficiently prepared for the widespread implementation of these technologies. The potential issues of data security and the absence of established standards may impede the interoperability of BIM and IoT systems. Moreover, Xia et al. (2022) highlight the challenge of integrating disparate technologies, which necessitates a unified approach and a robust technological infrastructure. Furthermore, managing the vast quantities of data generated by the IoT may present challenges, potentially impeding its analysis and utilisation.

BIM plays a pivotal role in the optimisation of costs, as well as the generation of comprehensive cost estimates at various stages of a construction project. BIM facilitates the generation of precise cost predictions based on accurate data about materials, human resources, and work schedules. BIM facilitates the generation of cost estimates in real time, enabling dynamic budget monitoring and rapid response to project changes. BIM integrates various information sources, accurately tracking costs associated with each phase of a building's lifecycle, from design through construction to FM. It is also noteworthy that the technology permits the examination of disparate design alternatives in terms of their cost implications, thereby facilitating the decision-making process for investors and contractors. As Hosseini et al. (2018) observe, the automatic updating of BIM models ensures that changes to cost estimates are immediately visible, reducing the risk of budget overruns. The process of creating cost estimates using BIM does, however, require advanced technical skills and appropriate software, which can act as a barrier for smaller construction companies that do not have the necessary technological infrastructure. It is, therefore, essential to explore further how BIM can be used to improve costing processes and identify the technological challenges that must be overcome to implement this technology fully in construction cost management.

CONCLUSIONS

Notwithstanding the many impediments and constraints, BIM facilitates data aggregation, dissemination and integration throughout the project life cycle. The capacity of BIM processes to facilitate visualisation and interoperability is vital within the construction industry. The inherent uncertainty of construction projects and the difficulties associated with locating existing infrastructure are challenges that are not immediately apparent at the project's outset. Applying contemporary technology and utilising a BIM environment can effectively mitigate potential conflicts.

BIM is increasingly regarded as the future of construction, with the potential to deliver substantial benefits, including enhanced efficiency, superior project quality, and reduced operational costs. It is incumbent upon construction companies and contractors to carefully consider these limitations and adapt their approach to any BIM implementation in a manner that is sensitive to the specifics of the project in question and the available resources and technology.

BIM technology is most effective during the design stage. The maximum value of the work input, and therefore the cost, is reached at the documentation stage of a construction project, at which point, CAD programs are fully utilised. In contrast, at the construction stage, the value of the work input is diminished. Consequently, the total commitment required in the construction process with this tool is less than that required by traditional computer-based methods.

It should be noted that the interpretation of the results may be limited by using a single database, namely Scopus. Not all articles on BIM may be included. Furthermore, the restriction on the publication period of the articles analysed, which covers the years 2018–2023, represents an additional impediment to obtaining comprehensive results. It should be noted that the BIM topics extend beyond the present academic period and do not include papers currently prepared for publication. Moreover, the narrowing of the research scope using specific keywords, such as 'building information modelling', 'facility management' and 'augmented reality', limited the scope of articles to a mere 319 results, of which only 20 were selected for further analysis, reducing the fullness of the observations. These factors may restrict the scope of the conclusions that can be drawn and potentially impact the accuracy and generalisability of the results.

The study yielded several pivotal findings. These include a comprehensive grasp of the perils and complexities of deploying BIM in construction, encompassing its advantages and disadvantages. The study illuminates strategies for surmounting BIM's constraints and challenges to the construction sector. The analysis offered valuable insights for the construction industry, demonstrating how innovative programs can transform and optimise the construction process and assist in avoiding potential risks.

Authors' contributions

Conceptualisation: A.S. and M.Ku.; methodology: A.S. and M.Ku.; validation: M.Ko., M.N. and K.K.; formal analysis: M.Ko. and K.K.; investigation: M.Ku., M.N., Z.J., M.Ko., K.K., K.R., E.G., M.S. and E.F-P.; resources: M.Ku., M.Ko., M.N. and K.K.; data curation: M.Ku., M.N., M.Ko. and K.K.; writing – original draft preparation: M.N., Z.J., M.Ko., K.K., K.R., E.G., M.S. and E.F-P.; writing – review and editing: M.Ku., M.Ko., K.K. and A.S.; visualisation: M.Ku., M.Ko. and K.K.; supervision: M.Ku. and A.S.; project administration: M.Ku., M.Ko., K.K. and A.S.

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INTEGRACJA MODELOWANIA INFORMACJI O BUDYNKU (BIM) W BUDOWNICTWIE: INNOWACJE, WYZWANIA I GLOBALNE PERSPEKTYWY

STRESZCZENIE

Współczesny przemysł budowlany przechodzi transformacyjne zmiany napędzane powszechną cyfryzacją, stąd modelowanie informacji o budynku (BIM) staje się kluczową innowacją. W niniejszym artykule udowodniono konieczność włączenia BIM do każdego nowego projektu budowlanego, podkreślając jego potencjał w zakresie poprawy współpracy, usprawnienia procesów oraz wspierania innowacji. Poprzez kompleksową analizę piśmiennictwa w zakresie zastosowania BIM w Polsce i na świecie dokonano oceny różnorodnych narzędzi programistycznych i porównano metodyki BIM z tradycyjnymi praktykami budowlanymi. Dodatkowo w artykule zidentyfikowano możliwości i wyzwania związane z integracją nowych technologii w sektorze budowlanym. Konieczność wdrożenia BIM w celu zwiększenia efektywności, redukcji odpadów i poprawy wyników projektowych została potwierdzona empirycznie. Technologia BIM niezaprzeczalnie stała się elementarnym komponentem procesu tworzenia i zarządzania informacjami o obiekcie budowlanym w całym jego cyklu życia, wykorzystywanym w architekturze, inżynierii i zarządzaniu budownictwem.

Słowa kluczowe: modelowanie informacji o budynku, zarządzanie obiektem, rzeczywistość rozszerzona, wykrywanie kolizji, Revit, Archicad