Impact of Building Information Modelling in achieving Sustainable Efficiency

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Abstract

This review paper explores into the impact of Building Information Modelling (BIM) implementation on sustainable efficiency within construction projects. It systematically examines BIM's influence on sustainable project performance, its utilization in construction organizations, and the identification of barriers and enablers affecting the integration of sustainable practices through BIM, with recommendations to overcome these barriers. Methodologically, the review synthesizes extensive literature on BIM in construction field is conducted through systematic searches across databases like Scopus and Google Scholar from 2006 to 2024. The findings reveal BIM's transformative role in the construction industry's digital evolution, enhancing collaboration, design clash detection, cost estimation, and scheduling, with promising potential for environmentally conscious design through its integration with sustainable practices. Nonetheless, challenges such as high adoption costs, expertise limitations, and software compatibility hinder widespread BIM implementation, particularly in sustainability-focused projects. The study underscores the immense potential of BIM in supporting sustainability within construction, emphasizing the necessity for guidance, training, modified business models, and collaborative efforts to unlock its full potential. This review bridges the gap between BIM's potential and practical implementation, providing insights into leveraging BIM for sustainable construction practices, thereby promising a more environmentally conscious future for the construction industry.

Keywords: Sustainable efficiency, Building Information Modelling, Sustainable construction projects.

I. INTRODUCTION

The construction industry's environmental impact is substantial (Lima et al., 2021), with traditional methods contributing to significant carbon emissions from non-renewable sources (Uddin et al., 2021). Incorporating building energy modeling into digital design processes streamlines construction (Gao, Koch, & Wu, 2019). BIM simplifies sustainable design creation by providing necessary data for green building evaluations during the design stage (Uddin et al., 2021). Acting as both a technological tool and procedural framework, BIM enables stakeholders to visualize construction and fosters collaboration, improving project predictability (Azhar, Khalfan and Maqsood, 2012). BIM's adoption enhances project collaboration, profitability, cost management, time efficiency, and client relationships. However, it risks losing adversarial scrutiny, posing challenges for error identification (Azhar, 2011).

1.1. Problem statement and rationale

Over the past few years, the construction sector has witnessed substantial progress and innovation. Nevertheless, it frequently faces criticism due to its substantial energy

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consumption and the environmental pollution it generates. Shockingly, Buildings carry significant weight in climate action, accounting for approximately 37 percent of CO2 emissions related to energy and processes, as well as over 34 percent of energy consumption (UNEP,2024). Buildings in the United States utilize nearly 40% of the overall energy and contribute to approximately 30% of the country's greenhouse gas emissions (Azhar and Brown, 2009). The construction industry's significant environmental footprint, marked by resource depletion, energy consumption, and carbon emissions, has compelled a growing urgency to adopt sustainable practices. Within this context, BIM stands as a technology with the potential to revolutionize construction by enhancing sustainability. By optimizing resource management, reducing waste, and improving project efficiency, BIM holds the promise of driving sustainable efficiency in the construction sector. However, a comprehensive understanding of the specific contributions and potential challenges associated with BIM's role in achieving sustainable efficiency remains vague. While BIM has made considerable progress in visual representation and clash detection, its utilization beyond these functionalities remains inadequately explored in academic literature (Cao et al., 2015). Stakeholders are advised to consider the following recommendations for future research on BIM for sustainable practices in the construction sector: Subsequent research endeavours should prioritize the improvement and exploration of the interconnections between various aspects of BIM and sustainability to identify concrete evidence and progressively validate the proposed framework. Moreover, additional investigation is warranted to determine the effective implementation strategies for integrating BIM with green principles to foster the sustainable advancement of the Architecture, Engineering, and Construction (AEC) industry (Datta et al, 2023). This research examines BIM's role in sustainable construction. By evaluating its capacity to improve resource efficiency and meet stakeholder sustainability goals, it offers practical recommendations for construction professionals and policymakers, aiming for a greener, more efficient future.

This paper will explore the following research questions:

Main Research Question:

- How does the implementation of BIM impact the achievement of sustainable efficiency in construction projects?

Research Objectives:

- Examine the impact of BIM on the efficiency and sustainability performance of construction projects.
- Assess the extent to which construction organizations are currently using BIM in their projects.
- Identify the specific barriers and enablers in integrating sustainable practices into construction projects using BIM.

Research Questions:

- What is the impact of BIM on the efficiency and sustainability performance of construction projects?"
- To what extent are construction organizations currently utilizing BIM in their projects?
- What are the specific barriers and enablers that influence the integration of sustainable practices into construction projects using BIM?

The subsequent chapter investigates into a comprehensive review of the existing literature on BIM.

II. LITERATURE REVIEW

2.1. Review of BIM in construction industry

2.1.1. Digital transformation of a construction organization

In today's global economy, digital technologies are crucial for driving efficiency across sectors (Kudryavtseva, Nikishina, & Vasileva, 2020). The construction industry is undergoing a digital transformation, pushing companies to integrate digital tools into operations. To tackle challenges from this transformation, firms must adapt operational models and prioritize client collaboration (Koscheyev, Rapgof & Vinogradova, 2019). This revolution reduces costs, enhances efficiency, and lessens environmental impact while fostering economic growth (Kudryavtseva, Nikishina, & Vasileva, 2020). Using digital tools like segment analysis and BIM is crucial for reaping these benefits. Integrated management systems ensure stability and aid in adopting new technologies rapidly. Additionally, prioritizing digital education and cultural transformation unlocks human potential and meets client demands (Koscheyev, Rapgof & Vinogradova, 2019).

Chuck Eastman introduced BIM in 1974, highlighting computer-based building descriptions' potential in enhancing visualization and analysis in construction projects. "BIM" refers to both the building information model and building information modelling, used interchangeably in research and software development communities (Eastman, 1974). A building information model is a data-rich, object-oriented, intelligent, and parametric digital representation of a facility, while BIM involves generating and managing the digital representation of a facility's physical and functional characteristics throughout its life cycle (Fernandez, D., 2015). BIM concepts empower engineers to create digital models for owners to visualize buildings before construction, enhancing decision-making, collaboration, and innovation throughout the construction lifecycle (Jrade & Jalaei, 2013).

2.2. BIM at Different Construction Phase

While BIM technology has received positive attention in the construction sector, its adoption remains slow (Rogers et al., 2015). Moving to BIM presents challenges, requiring strong management involvement, convincing stakeholders of its benefits, and investing in education and new roles (Cao et al., 2015). Primary obstacles to BIM adoption include insufficiently trained personnel, inadequate guidance, and lack of governmental support (Rogers, Chong, & Preece, 2015). To mitigate risks and evaluate staff competencies while identifying BIM experts, establishing a specialized BIM team is advisable. Gradually transitioning from BIM level 0 to level 1, with a focus on the design phase initially, is recommended. Using a unified BIM software across all stakeholders ensures alignment with project objectives. Efficiently streamlining this process requires careful planning, management commitment, and a phased strategy towards comprehensive BIM integration (Zahrizan et al., 2013). The construction sector sees Building Information Modeling (BIM) as a platform for fostering collaborative practices within the industry. Consequently, clients increasingly mandate BIM usage in their projects, prompting many construction firms to invest in BIM technology to meet these requirements (Zahrizan et al., 2013). Maximizing benefits necessitates fully integrating BIM across various project stages (Cao et al., 2015). BIM has been employed to oversee various aspects of construction planning, including design, cost estimation, and project scheduling. Integrating Building Information Modeling (BIM) in construction planning enables early clash detection during the design phase, enhances project scheduling, cost management, and overall project quality. Additionally, it improves communication among stakeholders in the construction process (Mohd and Ahmad Latiffi, 2013). BIM implementation in projects aids in identifying and resolving structural design clashes during the pre-construction phase. Eliminating design clashes in advance prevents delays and reduces work redundancy, particularly in MEP ductwork design adjustments during the construction process (Mohd & Ahmad Latiffi, 2013).

2.3. BIM Adoption in different countries

People's proactive engagement plays a pivotal role in the adoption of new technologies in this domain. There is a growing interest in integrating BIM technology with sustainable construction practices. Prior research underscores the critical role of behavioral intention, highlighting its substantial influence on sustainable construction and the imperative to enhance users' intention behavior conversion for effective BIM technology application (Zhang, Chu, & Song, 2019). The Technology Acceptance Model (TAM) provides a framework for comprehending these dynamics. In Hong Kong, the Government's dedication to sustainability is evident in the incorporation of BIM throughout various stages of building development. The Hong Kong Housing Authority (HKHA) has been leading the way in adopting BIM. By 2011, approximately 11 projects were utilizing BIM, with the objective of implementing it across all projects by 2014. Significantly, an HA IT Manager emphasized BIM's substantial role in advancing sustainability within HKHA projects (Hong Kong Housing Authority, 2011). Conversely, in Egypt's construction sector, the focus on enhancing project quality propels the exploration of BIM adoption to mitigate risks and foster sustainability. Despite its potential, BIM adoption remains limited among stakeholders. Previous research indicates a significant correlation between BIM, particularly in the design phase, and the overall success and sustainability of construction projects (OSS). BIM implementation notably impacts OSS by approximately 30.2%, offering valuable insights for countries like Egypt, guiding efforts to enhance construction efficiency, reduce costs, and cultivate client trust (Abdel-Tawab, 2023). Earlier research examined the construction sector's role in the economies of the USA, China, and the UK, highlighting its unique volatility and influence on economic trends. It advocates for blending statistical methodologies and sustainability principles for enduring sustainability, addressing challenges such as escalating material costs, unemployment in the USA, digital integration issues in the UK, and environmental concerns in China. The study dispels misconceptions about the sector's reliance on other industries for materials and its excessive energy consumption, emphasizing its significant impact on employment and output, alongside potential long-term unsustainability due to heavy CO_2 usage (Alaloul et al., 2022).

2.4. BIM and Sustainable Efficiency

Improving construction practices to benefit the environment is at the core of sustainable development in the industry (Zhang, Chu and Song, 2019). The adoption of Building Information Modeling (BIM) is often associated with positive outcomes, particularly in task effectiveness, which is considered more significant than efficiency improvements (Cao et al., 2015). By integrating revisions during the design phase, project teams can effectively translate clients' environmentally conscious goals beyond regulatory compliance into tangible results aligned with technical and economic considerations. In this regard, BIM emerges as a valuable tool, providing essential information to calculate credit points, thereby aiding in setting targeted sustainability objectives within rating system frameworks (Maltese et al., 2017). Previous literature predominantly emphasizes environmental aspects in sustainable construction, such as sustainable resource use, eco-efficiency, and energy efficiency, while giving less attention to social sustainability. However, there is a notable gap in addressing social sustainability, urging project managers to deepen their understanding in this area. Regional differences are evident, with Europe prioritizing economic performance, while Asia and Africa emphasize political stability and project control. Bridging these gaps is crucial for a more holistic approach to construction sustainability (Stanitsas and Kirytopoulos, 2023). Previous studies indicate that achieving Sustainable Development Goals (SDGs) within the construction sectors of developing countries post-COVID-19 requires unified efforts, particularly under governmental leadership. Collaboration among key stakeholders remains essential for effectively implementing proposed strategies, guiding the construction industry towards sustainable development objectives (Ebekozien, Aigbavboa, and Aigbedion, 2023). The rapid evolution of Building Information Modeling (BIM) technology has transformed traditional practices in the Architecture, Engineering, and Construction (AEC) sector. BIM serves as a communication platform for integrated design, construction monitoring, and facility management. It is increasingly utilized to predict and monitor environmental impacts while supporting sustainable design. BIM streamlines decision-making processes and enhances efficiency, productivity, and cost-effectiveness in construction, making it well-suited for integrating sustainable practices in both new and existing structures (Hasanain and Nawari, 2022).

2.5. Exploring the relationship between BIM and sustainability.

There has been a growing interest within the construction industry to develop environmentally sustainable buildings that offer both high performance and cost savings (Jrade & Jalaei, 2013). BIM plays a crucial role in streamlining the intricate process of sustainable design and alleviating the tedious aspects of tasks such as material take-offs, cost estimation, and construction schedules. By consolidating information into a unified model, BIM proves to be a valuable tool for practitioners in the field. The primary adopters of BIM-based sustainability analyses are predominantly architects and contractors. Practitioners utilizing BIM for sustainability analyses report significant time and cost savings compared to traditional methods. This highlights the effectiveness of BIM in enhancing efficiency and reducing resource expenditure in the realm of sustainable design (Azhar, S. and Brown, J., 2009). The inclination to engage with BIM, the execution of actual behaviours related to BIM, and the attitude towards these behaviours all contribute positively to sustainable construction (Zhang, Chu and Song, 2019).

2.6. Impact of BIM on sustainable construction

In recent times, the construction industry has increasingly valued innovation and collaboration in project management and risk evaluation. BIM has gained prominence due to its sustainability, flexibility, productivity, cost efficiency, and comprehensive understanding of building complexities (Zhang et al., 2023). BIM enhances project efficiency in various aspects like time, cost, quality, output, and safety. Engineers need a deep understanding of a building's structure for accurate energy estimation. Energy performance audits offer benefits such as cost reduction, sustainability increase, emission reduction, and lifespan extension. Early-Stage Sustainable Structural Design Optimization (ESSDO), a BIM-based framework, integrates architecture and structural engineering for efficient design and analysis, streamlining coordination and automating the design process (Afzal et al., 2023). Sustainability involves environmental, economic, and social well-being. At the conceptual stage, integrating these aspects entails employing sustainable design practices and identifying appropriate materials and systems (Jrade & Jalaei, 2013).

2.7. Benefits associated with using BIM for sustainability.

The recognition of BIM's benefits, such as accelerating project timelines, drives its adoption in construction projects (Rogers, Chong, & Preece, 2015). BIM-based modelling helps optimize resource efficiency in green building projects, leading to heightened user satisfaction (Uddin et al., 2021). Other drivers include market demands, competitive advantage, and increasing BIM awareness (Rogers, Chong, & Preece, 2015). BIM integration allows for the evaluation of locally sourced construction materials' impact and enables tailored design choices (Uddin et al., 2021). BIM offers numerous benefits, including enhanced client satisfaction, improved teamwork, streamlined data sharing, better information control, environmental analysis capabilities, error reduction, safety enhancement, and scheduling accuracy (Ghaffarianhosein et al., 2017). Integrating BIM techniques in construction is pivotal for optimizing performance and reducing environmental impacts (Uddin et al., 2021).

2.8. Common barriers to BIM adoption in sustainability-focused projects:

Adopting BIM tools faces significant barriers, including high upfront costs for training and procurement, legal uncertainties, and interoperability challenges (Cao et al., 2015; Mohd & Ahmad Latiffi, 2013; Rogers, Chong, & Preece, 2015). These hurdles, coupled with the need for comprehensive training, disrupt workflow and productivity. Overcoming them requires careful financial planning, stakeholder engagement, and clear contractual frameworks (Mohd & Ahmad Latiffi, 2013). Software incompatibility and lack of expertise also hinder adoption, especially for smaller firms with limited involvement in BIM projects. Successful implementation demands substantial investments from AEC firms in software, hardware, and training (Ghaffarianhosein et al., 2017).

Table 1.
Barriers to adoption of BIM

Category	Barrier	Sources
Financial factors	• Initial investment	(Cao et al., 2015; Mohd & Ahmad Latiffi, 2013; Saka & Chan, 2021).
	• Cost of training	(Cao et al., 2015).
Legal factors	• Legal Uncertainties	(Cao et al., 2015).
	• Lack of support from government	(Rogers, Chong, & Preece, 2015)

Organisational factors	•	Resistance to Change	(Cao et al., 2015; Acheng et al., 2023).
	•	Inexperience of employee	(Mohd & Ahmad Latiffi, 2013).
Technical factor	•	Interoperability Challenges	(Cao et al., 2015; Acheng et al., 2023)
	•	Lack of standardisation	(Mohd & Ahmad Latiffi, 2013)

From the literature, eight barriers to adoption of BIM have been identified, categorized into financial, legal, organizational, and technical domains.

2.9. Strategies and solutions to overcome barriers to BIM adoption:

Strategies for BIM implementation address inadequate standards through robust guidance plans, emphasize training via courses and workshops, and attract experts while ensuring technical support. Managing costs involves dedicated budgets and modified business models. Additionally, integrating BIM into education, fostering collaborations, and offering scholarships aim to overcome barriers, facilitating seamless integration in construction and engineering (Manzoor et al, 2021).

2.10. Summary of literature review

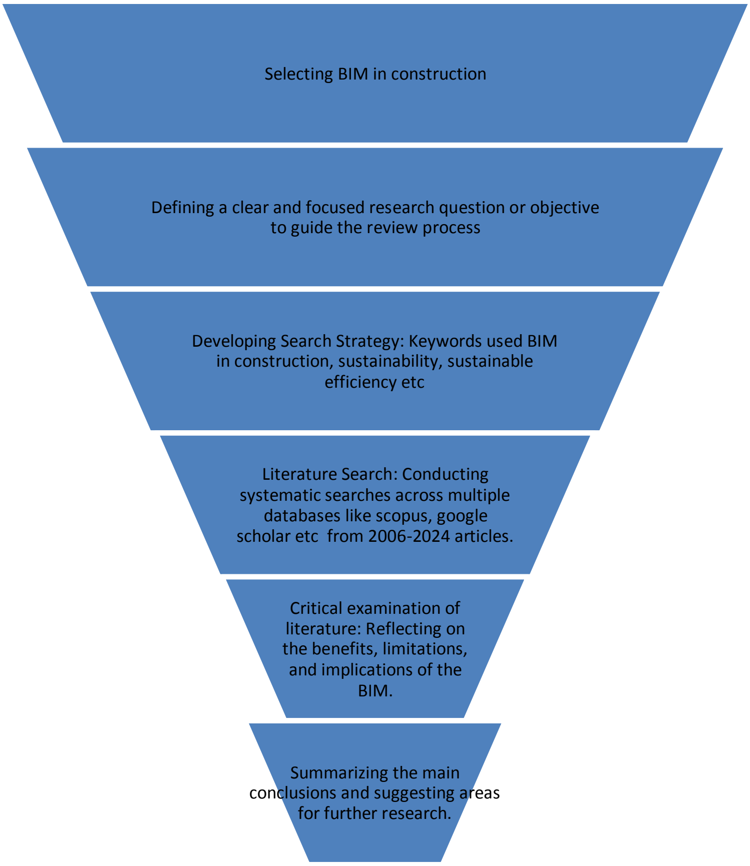
The literature underscores BIM's transformative impact on the construction sector, shaping digital representations throughout a building's lifecycle. It enhances design, cost estimation, scheduling, and quality, particularly in sustainable construction. Despite challenges like high costs and expertise gaps, strategies such as robust guidance, training, and collaboration foster its adoption. BIM offers benefits like improved communication, error reduction, and support for eco-friendly practices, making it pivotal for construction's digital evolution.

III. RESEARCH METHODOLOGY

The research method used in a systematic review involves a structured approach to identifying, evaluating, and synthesizing existing literature on impact of BIM in achieving Sustainable Efficiency. The literature search was conducted across multiple databases, including Scopus, Web of Science, and Google Scholar, to identify relevant studies published between 2006 and 2024. The search was conducted using keywords including Building Information Modelling, BIM adoption, sustainable construction, sustainable design, sustainable efficiency, and enablers and barriers to BIM adoption. The selection criteria were defined to include studies focusing on BIM's evolution, enablers and barriers to adoption.

Here are the key steps involved in conducting a systematic review:

Figure 1.
Systematic Review Method



1. Selecting BIM in construction
2. Defining a clear and focused research question or objective to guide the review process.
3. Developing Search Strategy: Keywords used BIM in construction, sustainability, sustainable efficiency etc.
4. Literature Search: Conducting systematic searches across multiple databases like scopus, google scholar etc from 2006-2023 articles.
5. Critical examination of literature: Reflecting on the benefits, limitations, and implications of the BIM.
6. Summarizing the main conclusions and suggesting areas for further research.

IV. RESULTS AND DISCUSSIONS

BIM plays a crucial role in the construction industry's digital transformation and sustainability integration. It offers benefits like clash detection, cost estimation, and quality enhancement (Cao et al., 2015; Mohd & Ahmad Latiffi, 2013; Saka & Chan, 2021). However, challenges such as high adoption costs and expertise limitations hinder its widespread use, especially in sustainability-focused projects. Strategies like guidance plans, training programs, and modified business models are proposed to address these barriers. Integrating BIM into smaller construction projects in Malaysia could serve as a model for other developing nations. Seamless interoperability among BIM solutions is crucial for supporting sustainable designs (Rogers, Chong, & Preece, 2015). Despite hurdles, BIM offers advantages like error minimization and eco-friendly building construction. Collective actions and training initiatives are needed to fully realize BIM's potential (Wong and Fan, 2013). Partnerships between multinational firms and local authorities are essential for boosting expertise and driving sustainable practices (Alaloul, 2022).

V. CONCLUSION

In conclusion, BIM holds immense promise for enhancing sustainability in construction. However, obstacles such as cost constraints and expertise limitations hinder its widespread adoption. Collaborative efforts and improved integration are crucial in overcoming these challenges. While BIM significantly enhances quality, cost estimation, and sustainability alignment, comprehending its varied impact across diverse projects is pivotal. Bridging these gaps is fundamental to unleash the complete potential of BIM, paving the way for a more sustainable future in the construction industry.

5.1. Findings and Future Research direction

BIM in construction signifies a collaborative shift towards enhancing awareness and competency. Challenges like inadequate experience and a shortage of skilled personnel hinder widespread involvement. Addressing concerns about costs, technology obsolescence, and ROI uncertainties is crucial for broader adoption. Future BIM research focuses on tailored generative design, Cloud-based integration, robotics, and big data analytics, promising substantial industry advancements (Ghaffarianhosein et al., 2017; Yin et al., 2019). Exploring BIM’s effectiveness in diverse project types and user perspectives, particularly regarding intangible returns, is essential for informed implementation strategies and maximizing ROI (Sompolgrunk, Banihashemi, and Mohandes, 2023). Closing these research gaps will enable more informed decision-making and tailored approaches in harnessing BIM’s transformative potential in construction

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