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BIM AND BLOCKCHAIN INTEGRATED CONSTRUCTION MANAGEMENT: A REVIEW

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ABSTRACT

The Architectural, Engineering, Construction, and Operations (AECO) industry has implemented Building Information Modelling (BIM) for a significant time, and its applications are widely recognised. Nevertheless, numerous studies have emphasised that BIM in isolation is unable to tackle the difficulties encountered by construction stakeholders and needs integration with other technologies to augment its practicality. In the last few years, there has been an increasing curiosity and utilisation of Blockchain Technology (BCT) within the construction industry. Limited research has been conducted on the amalgamation of BIM and BCT across many domains of application. To undertake a thorough analysis of the integration between BIM and BCT, this study employed a Systematic Literature Review (SLR) methodology utilising the Scopus database. The research employed a combination of quantitative and qualitative content analysis techniques to examine the selected articles. The study has identified five distinct domains of integration between BIM and BCT. These domains encompass data management, contract management, facility/asset management, sustainability/waste management, and supply chain management. Furthermore, certain obstacles were identified that impact the incorporation of BIM-BCT in the industry. In general, this study can provide stakeholders with insights into the capabilities of BIM-BCT within the construction industry, enabling them to develop a strategic plan for improving the integration of these technologies.

Keywords: *Architectural, Engineering, Construction, and Operations (AECO); Blockchain Technology (BCT); Building Information Modelling (BIM); Systematic Literature Review (SLR).*

1. INTRODUCTION

The AECO industry is characterised by cost and time overruns resulting in low profit margins coupled with low stakeholder satisfaction (Selvanesan & Satanarachchi, 2023). In the intricate and dynamic operating environment of the construction sector, the utilisation of technology advancements is important to optimise its efficacy within the business. Among various innovations in the construction sector, BIM is one such technology that helps in developing n-dimensional models with multiple Levels of Development (LOD), further resulting in higher maturity levels (Sood & Laishram, 2022). Additionally, BIM was majorly employed for the designing and construction

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applications (Becerik-Gerber & Kensek, 2010), however, in the last few years, the applications of BIM can be seen during post-construction phases (such as the O&M phase, and demolition phase) as well (Motawa & Almarshad, 2013; Yung & Wang, 2014; Edirisinghe et al., 2017; Gerrish et al., 2017; Tsay et al., 2022), resulting in effective management of entire project lifecycle (Eastman et al., 2011). BIM enhances project delivery efficiency, fosters stakeholder engagement, minimises design errors and modifications, clash detections, facilitates sustainable material selection at the planning stage, and several other benefits (Azhar, 2011; Farghaly et al., 2019; Deng et al., 2019; Deng et al., 2020). However, various issues exist during the isolated use of BIM technology, resulting in lower operational value to stakeholders (Nawari & Ravindran, 2019b; Espinoza-Zambrano et al., 2023). A few of these issues include transparency and reliability of information that is exchanged between multiple parties resulting in contractual claims and disputes (Eadie et al., 2015; Zhong et al., 2020), and lack of security of the BIM model resulting in information leak, loss, or corruption/piracy (Nawari & Ravindran, 2019a; Das et al., 2021). The potential solution to these issues can be achieved by combining BIM and Blockchain (Chung et al., 2022) and the present study is focused on comprehending the applications and consequences of this integration. The operational weaknesses of BIM could be compensated by the unique properties of BCT, including very high safety, benefits for data sharing and reliability, and the capacity to design smart contracts that encourage conformity (Selvanesan & Satanarachchi, 2023). Nevertheless, despite the prevailing popularity of BCT in several sectors, its use within the construction industry remains rather limited (Kiu et al., 2024).

1.1 BLOCKCHAIN TECHNOLOGY (BCT)

BCT also known as Distributed Ledger Technology (DLT), is a decentralised and transparent system that aims to enable secure transactions in a thrustless way using a distributed directory (Wood, 2014). The preliminary review of BCT indicates that it possesses various suitable attributes and benefits, including enhanced transparency and security, the facilitation of trust, and reduced instances of non-compliance with contractual obligations (Zheng et al., 2018; Clohessy et al., 2020). To ensure transparency of activity, security enhancement, synchronisation, and recording of data in distributed environments, many technologies are employed, including encrypted data structures, peer-to-peer networking and consensus algorithms (Nawari & Ravindran, 2019a; Das et al., 2021). In the BCT network, transactions are recorded in blocks that are interconnected in a chain-like manner and arranged in a logical order (Huang et al., 2022), hence, avoiding a single-point failure without requiring any trusted third party.

The BCT had significant growth in recent years, evolved from the initial decentralised cryptocurrency Bitcoin (Nakamoto, 2008), known as BCT 1.0, to Ethereum, which incorporates smart contracts, referred to as BCT 2.0 (Buterin, 2014) and its subsequent development involves the emergence of permission-editable blockchains, such as Hyperledger Fabric, which operates on the 'Proof of Stake' (PoS) mechanism known as BCT 3.0 (Cachin, 2016; Nawari & Ravindran, 2019b). BCT 2.0 generates digital records that possess the property of being unalterable and can be transferred to another user by a trusted third party, such as a financial institution (Geipel, 2017). Whereas BCT 3.0 seeks to enhance the functionalities of BCT 2.0 by focusing on transaction speed, expansion, and deployment simplicity through the utilisation of decentralised tools (Raval, 2016).

Given its decentralised nature, BCT has successfully infiltrated various domains that are intricately interconnected with our everyday existence. These domains encompass cryptocurrencies, commercial applications, smart cities, Internet of Things (IoT) applications, government services, and almost every existing industry (Huang et al., 2022). Furthermore, there are few studies about the utilisation, impact, and possibilities of BCT in the construction sector (Penzes, 2018; Nawari & Ravindran, 2019b; Dakhli et al., 2019; Li et al., 2019; Perera et al., 2020; Prakash & Ambekar, 2021; H. Liu, 2023; Z. Liu et al., 2023; Kiu et al., 2024). The application areas in these studies include data traceability (Turk & Klinc, 2017; Amaludin et al., 2018), measuring construction productivity (Heiskanen, 2017), contract management (Wang et al., 2017), automated project bank accounts and other regulations and compliances (Li et al., 2019). Despite the numerous applications and benefits of BCT in the construction industry, its adoption remains significantly limited (Selvanesan & Satanarachchi, 2023) as compared to other manufacturing, finance, or service sectors (Nawari & Ravindran, 2019b).

1.2 RESEARCH PROBLEM

The utilisation of BCT in the context of Industry 4.0 has been the subject of extensive theoretical investigation, although there is a scarcity of practical applications that effectively demonstrate its capabilities (Dounas et al., 2021), whereas if we look at its integration with BIM, the studies are even less. The studies related to BIM-BCT have picked up pace in the last two or three years, with still ongoing research as well as few implementation gaps. Even though the value of combining BCT and BIM has long been acknowledged, there is a dearth of scholarly work demonstrating this integration's viability. Few studies have been conducted to explore diverse applications of this integration, which will be elaborated upon in the subsequent sections of this paper. Additionally, a few literature-based studies have tried to investigate the integration of BIM and BCT for different construction operations. However, such studies shed light on the individual applications of this integration and were limited to data management (Nawari & Ravindran, 2019b; Das et al., 2021), contract management (Chung et al., 2022), and supply chain management (Selvanesan & Satanarachchi, 2023). Hence, through a Systematic Literature Review (SLR) approach, the current study looks from the perspective of all the other application areas (such as sustainability, waste management, digital twin, facility management, etc.) that are possible with BIM-BCT integration but have not been included in other similar studies.

2. RESEARCH METHODOLOGY

To conduct a thorough and in-depth examination of the incorporation of BIM and BCT technologies in the construction industry, a SLR was carried out (refer to Figure 1). This review followed a three-stage strategy as suggested by Tranfield et al. (2003).

The first stage involves the selection of databases and the identification of the keywords based on our research problem. The study selected the Scopus database as it is widely recognised as a reputable database engine for academic data (Khan et al., 2021). Additionally, Scopus has indexed a greater number of journals compared to other databases such as PubMed, WOS, and Google Scholar (Chadegani et al., 2013; Fetters et al., 2013). Similarly, the keywords and their synonyms that were selected based on the building blocks include: “BIM” and “BCT” and were connected using Boolean operators “AND” and “OR” as shown in the syntax below:

[Title-Abs-Key ("BIM" OR "Building Information Model*") AND ("Blockchain" OR "Blockchain Technology" OR "BCT")]

This initial research resulted in 245 articles. The subsequent step involves screening and filtering of articles based on various options available in the Scopus database. Hence, the 245 articles were screened based on language and type of articles. The articles written in the English language and formed part of journal publications were only considered. It was found that two articles were in the non-English language whereas 165 articles were part of either conferences or book chapters due to their typically less rigorous peer-review process and less detailed content compared to journal articles, hence, not considered in a further step. This resulted in a list of 80 articles which were then further filtered based on their relevance to BIM and BCT integration by analysing their titles, abstracts, and conclusions. It was found that 22 articles were either from non-construction areas or were not relevant to our research, leaving us with a set of 58 articles.

The last stage involves analysis and reporting the review findings. The analysis of shortlisted articles was conducted in two forms i.e. (i) quantitative, and (ii) qualitative analysis. The quantitative analysis involves understanding the trend of publication of articles and for that, a data extraction form in MS Excel was developed. The information in the form included the title, author, year of publication, journal, and country. Additionally, the shortlisted articles were further analysed based on research type and application areas. Similarly, the qualitative analysis of these articles involves the description of the various BIM-BCT integrated applications in construction management and the barriers that are hindering BIM and BCT integration. The results of quantitative and qualitative analysis will be shown utilising various visualisation tools such as charts, graphs, and tables along with descriptive statistics.

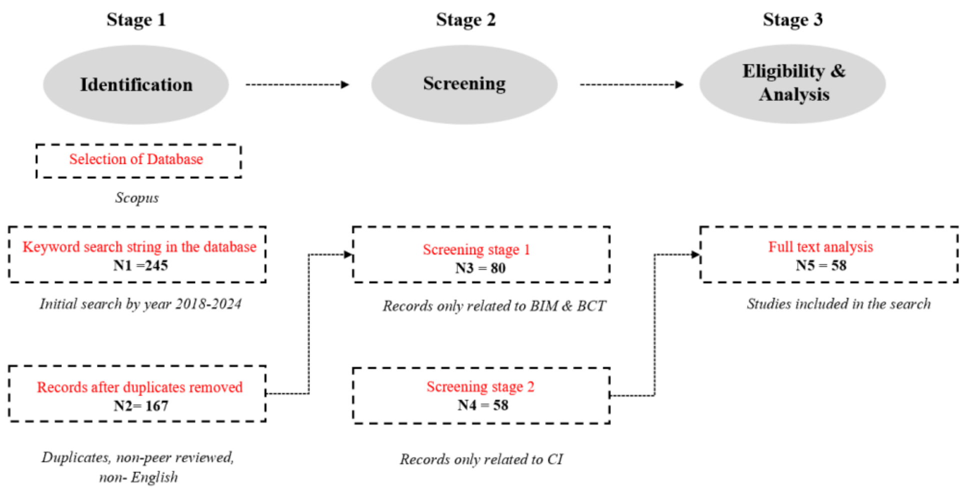
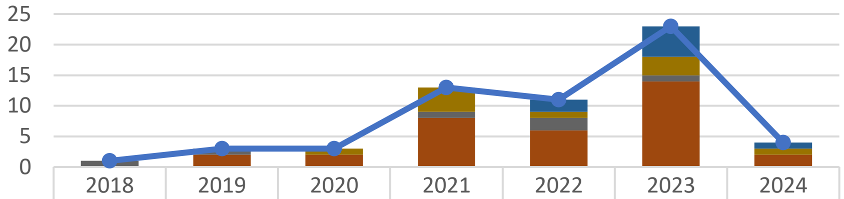


Figure 1: Research methodology

3. ANALYSIS

3.1 QUANTITATIVE ANALYSIS

It involves a chronological understanding of publications to identify the temporal distribution of articles. This aids in comprehending the progression of research interest in a specific field throughout time. Figure 2 shows the distribution of papers from the year 2018 to 2024 with publications increasing from 1 to 23 in the years 2018 and 2023 respectively.



	2018	2019	2020	2021	2022	2023	2024
Survey	0	0	0	0	2	5	1
Case Study	0	0	1	4	1	3	1
Literature Review	1	1	0	1	2	1	0
Conceptual	0	2	2	8	6	14	2
Total	1	3	3	13	11	23	4

Figure 2: Yearly publications

The initial year of 2018 shows that the research in this domain is very new and is still in the initial phase of implementation in the construction industry. Furthermore, the articles were categorised according to the study methodology employed by the authors of the shortlisted articles. It was found that 34 papers (59%) were conceptual, six papers (10%) were based on literature review, ten papers (17%) adopted a case study approach whereas the remaining eight papers (14%) involved survey-based methodology.

Similarly, the articles were also distributed based on their geographical location of studies. The 58 shortlisted articles belonged to 20 different countries. Among these, the top five countries with the highest number of publications include China (eleven papers), Hong Kong (eight papers), Australia (six papers), UK (ix papers), USA (four papers), Indonesia (four papers) and Spain (three papers). Additionally, the articles were also classified into five different application areas of BIM-BCT integration. These include data management (21 papers), contract management (ten papers), sustainability/waste management (twelve papers), supply chain management (eight papers), and facility/asset management (seven papers). Moreover, the shortlisted articles were also published in ten top-tier peer-reviewed construction journals, among which the top three include Automation in Construction (eleven papers), Buildings (eight papers), Journal of Information Technology in Construction and Computers in Industry (four papers each).

3.2 QUALITATIVE ANALYSIS

3.2.1 BIM-Blockchain Integration

Based on the analysis of shortlisted papers, it was found that the integration of BIM and BCT had been utilised in various applications of construction management. These are categorised into five areas i.e. (i) Data Management (DM), (ii) contract management, (iii) sustainability/waste management, (iv) facility/asset management, and (v) Supply Chain Management (SCM) which are briefly described below:

Data Management (DM)

The construction sector deals with a substantial volume of data that requires management, security, and exchange among multiple stakeholders. Therefore, construction firms must possess the ability to effectively manage and safeguard their data. Various research has explored the integration of BIM and BCT to effectively manage, exchange, and enhance the security of shared data. In terms of managing data, (Kiu et al., 2024) highlighted the role of BCT-based Electronic Data Management (EDM) in BIM models for BIM projects. Similarly, various other studies have developed BIM-BCT integrated frameworks for reducing data redundancy (Xue & Lu, 2020) and effective design data management (Tao et al., 2023b) in mega complex infrastructure projects (Sarkar & Dhaneshwar, 2023), offsite manufacturing (Brand & Abrishami, 2021), and even for Martian buildings (Javaherikhah et al., 2023a, 2023b). Similarly, BIM data exchange through BCT technology has been noted in various studies. The studies involve a BIM-BCT integrated platform for the automatic sharing of information in emergency construction projects (Tao et al., 2023a), among the group of related participants and stakeholders (Suliyanti & Sari, 2021, 2023), heritage structures (Kao et al., 2023) further resulting in reduces costs, and improves risk contingencies in construction projects (Celik et al., 2023). Furthermore, the aspect of data security, particularly in terms of data management and data exchange, is of utmost importance. Therefore, some studies have combined BIM and BCT to ensure the security of the data that is being stored or shared (Das et al., 2021). These include developing a double-fingerprint identity for the Industry Foundation Classes (IFC) (Darabseh & Martins, 2023), BCT-Based Parametric Model Library (BBPML) to protect from data tampering and copyright disputes (Hsu et al., 2023), protect the copyright interests of designers (Wang et al., 2022), protect sensitive data and enhance design collaboration (Tao et al., 2022), preventing data corruption and enhancing data privacy, data integrity and data longevity (Sai et al., 2021), eliminating BIM related digital safety vulnerabilities associated with misuse and blocking of permission to design data (Tao et al., 2021) and tackle information security in mobile cloud architectures (Zheng et al., 2019).

Contract Management (CM)

The construction projects involve a contractual agreement between multiple parties, which includes various clauses and conditions about milestones, automated payments, and deliverables, among others. Several researchers have attempted to employ BCT and combine it with BIM to enhance the administration of contracts more efficiently and intelligently. The studies involve the development of BIM-BCT integrated framework for administrating dispute resolution process (Faraji et al., 2024), performance-based smart contract (Hunhevicz et al., 2022), automated, transparent, and traceable payment in construction projects , metaverse/virtual construction applications and smart contracts (Huang et al., 2022), effective governance, trust and incentivisation for architectural design (Amaludin et al., 2018; Dounas et al., 2021), and improving the efficiency and quality of project management (Li et al., 2021).

Sustainability/Waste Management (WM)

The construction sector is commonly linked to unsustainable practices with a tendency to prioritize short-term and large amounts of resource use that possess high embodied and operational energy, hence rendering it a prominent contributor to carbon emissions. In addition, it encounters numerous other sustainability obstacles, including the generation of construction waste, the emission of construction noise, the presence of motor traffic near building sites, the release of dust and other air and water pollutants, and the assurance of safety and well-being for construction workers (Wong & Loo, 2022). Therefore, numerous researchers have attempted to combine BIM with BCT to improve sustainability and minimise waste by implementing the principles of the circular economy (CE). There have been studies based on BIM-BCT integration-based frameworks for implementing CE principles (Elghaish et al., 2023; Teisserenc & Sepasgozar, 2021a; Teisserenc & Sepasgozar, 2021b) in both organisational and inter-organisational contexts (Zandee, 2024), designing and cost improvement through sustainable/green buildings (Husin et al., 2023; Husin & Priyawan, 2023; Liu et al., 2019), reducing carbon emissions and enhance safety, the well-being of construction workers as well as future occupants (Loo & Wong, 2023), assist in making design choices and advancing health, while achieving the goal of creating a health metaverse within the framework of sustainable development (Liu et al., 2022b), for resource reduction and sustainability enhancement in Prefabricated housing construction (PHC) (Zhengdao et al., 2021), construction waste information management (Liu et al., 2022a) and WM strategies by adopting environmentally sustainable practices (Pellegrini et al., 2020).

Facility Management (FM)/Asset Management (AM)

FM is an essential component of construction management. It entails the coordination of several operations to guarantee a secure and operational facility that fulfils the requirements of its users (Demirdöğen et al., 2023). Similarly, AM evaluates the remaining useful life and performance capability of assets. This assessment provides crucial information for decision-making regarding asset maintenance, renewal, or replacement (Dejaco et al., 2017). The traditional FM is transitioning into asset life cycle management, since an effective O&M relies on the efficient management of the asset in all relevant strategic and operational elements throughout its life cycle (Wijekoon et al., 2020). For this purpose, DT is one of the most effective ways it offers asset managers the ability to access up-to-date, reliable, and unalterable documents on any asset or infrastructure (Macchi et al., 2018). Hence, various studies have developed an integrated BIM/DT-BCT framework (Gotz et al., 2020; Teisserenc & Sepasgozar, 2022) for effective designing, scheduling and procurement, construction and whole life cycle management (Ni et al., 2021), effective operations, maintenance, and renovations (Espinoza-Zambrano et al., 2023), improving the management of buildings and urban assets (Lawal & Nawari, 2023), and improving the asset monitoring and diagnostics in terms of financial, physical, functional and sustainability aspects (Ye et al., 2023).

Supply Chain Management (SCM)

SCM encompasses the oversight of establishments involved in the acquisition of raw materials, their conversion into intermediate commodities and final products, and the subsequent delivery of these products to customers via the channels of distribution (Lee & Billington, 1995). However, SCM in the construction industry is frequently characterised by its intricate nature and differs from the manufacturing industry in a significant way (Vrijhoef & Koskela, 2000). Hence, to optimise the efficiency and transparency of SCM operations in the construction industry few studies have tried to integrate BIM and BCT. These include improvement in SCM for offsite construction projects (Brandín & Abrishami, 2024), and exploration of potential benefits that can address significant inherent challenges which include hesitancy to share knowledge and trust, worries regarding sustainability, and safety (Selvanesan & Satanarachchi, 2023). A prototype was constructed in a study to assess the technological feasibility of combining BCT and BIM using a single source of truth (BIMSSoT) data model (Hijazi et al., 2023a, 2023b). This integration aims to facilitate the transfer of supply chain data for handover purposes. Similarly, an IoT-BIM platform that utilises BCT technology (BIBP) to enhance SCM and off-site production management in the context of modular construction has also been proposed (Li et al., 2022; Wu & Lu, 2022).

Even though the study identified five different application areas of BIM-BCT integration, however, the adoption of such integration remains significantly limited in the construction sector due to various hurdles. Hence, a few studies have also tried to find out different the critical barriers as well as provide strategies that affect this integration (Ebekozien et al., 2023; Selvanesan & Satanarachchi, 2023; Ye et al., 2023). As per Kiu *et al.* (2024), before utilising BIM-BCT-based data management the stakeholders need to focus on and overcome various challenges related to BCT scalability, industry knowledge, and culture. Similarly, high costs (Kiu et al., 2024; Wu & Lu, 2022), information redundancies (Wu & Lu, 2022; Xue & Lu, 2020), lack of pilot case studies (X. Li et al., 2022; Wu & Lu, 2022; Xue & Lu, 2020) low server capacities (Zhengdao et al., 2021), lack of stakeholder proficiency in using novel technologies (Zhengdao et al., 2021), lack of smart contracts (Li et al., 2022; Xue & Lu, 2020) and limited available technical infrastructure for all conditions (Li et al., 2022; Xue & Lu, 2020; Zhengdao et al., 2021) were highlighted as the most critical barriers. In another study, Singh and Kumar (2023) revealed challenges related to adopting BIM-BCT for the FM sector of the Indian construction industry. The most critical barriers include limited cooperation and interaction among stakeholders, regulatory limitations and challenges in establishing trust and governance models.

4. PRACTICAL IMPLICATIONS

The integration of BIM has significant practical implications for the construction industry, enhancing efficiency and transparency across various domains. Within data management, BCT enhances data integrity and security, reducing tampering risks, and optimising data handling processes. This leads to better coordination and reduced redundancies in large projects. BCT also benefits contract management through smart contracts, automating payments, streamlining dispute resolutions, fostering trust, and reducing delays. Moreover, sustainability practices are bolstered by BIM-BCT frameworks that facilitate the implementation of circular economy principles, leading to efficient resource management, reduced construction waste, and lower carbon emissions. In a similar vein, facility and asset management are improved by integrated lifecycle management, enhancing operational efficiency and extending asset longevity. In SCM, BIM-BCT integration ensures transparency and efficiency, addressing knowledge-sharing challenges and fostering collaboration. However, to fully realise these benefits, the industry must overcome barriers such as scalability, cost, technical infrastructure, stakeholder proficiency, and regulatory frameworks.

5. CONCLUSIONS

The paper has provided a comprehensive analysis of the integration of BIM and BCT, employing a systematic literature review methodology using the Scopus database. The study identified 58 articles suitable for conducting quantitative and qualitative content analysis. The quantitative analysis involved classifying articles based on year of publication, research methodology employed by authors, geographical location, journals, and application areas. However, in qualitative analysis, a comprehensive investigation was carried out to examine BIM and BCT integration. The study revealed the potential synergistic effects of these two technologies in improving the efficiency, transparency, and security of construction projects. Our investigation has shed light on the numerous benefits that are possible through BIM-BCT integration. These include streamlined data management, contract management, facility/asset management, sustainability/waste management, and supply chain management. Furthermore, we have highlighted the role of integrated applications in mitigating common challenges encountered in the construction industry, such as data inconsistency, lack of trust, and contractual disputes.

However, despite the promising opportunities presented by the integration of BIM and BCT, our analysis has also identified several barriers that hinder widespread adoption. These barriers include technological complexity, lack of knowledge among stakeholders, high cost of resources, regulatory concerns, and the need for industry-wide standardisation. Addressing these challenges will require collaborative efforts from stakeholders across the construction ecosystem, including policymakers, industry practitioners, technology developers, and researchers. Moving forward, future research endeavours should focus on developing practical solutions to tackle these hurdles and help in the seamless integration of BIM and BCT in construction projects. Moreover, continued exploration of emerging technologies and innovative applications will be essential in unlocking the full potential of this integration, ultimately driving greater efficiency, accountability, and circular economy within the construction industry.

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