DIGITAL TWIN AND BLOCKCHAIN APPLICATIONS FOR THE BUILT ENVIRONMENT: A SYSTEMATIC REVIEW

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ABSTRACT: *During a built asset's lifecycle, value-generating activities are performed by stakeholders at each phase according to defined requirements. Upon practical completion of construction, dedicated activities, including the transfer of critical information for efficiently operating and maintaining built assets, are performed during building handover. Building information modelling is essential for stakeholder collaboration when developing built assets. However, BIM is limited to providing up-to-date information. Thus, our proposal for digital-twin technologies allows real-time information integration to support building handover. Although enabling mechanisms exist for the handover of information to the facility management phase (e.g., COBie), these are challenged with inaccurate and fragmented information. Therefore, the paper proposes integrating blockchain technology to allow decentralised immutable data management to improve building handover and ensure stakeholders as-built requirements are fulfilled efficiently. A multi-strand literature review, focusing on our subject matter, is used in positioning our argument for the needed research on integrating digital-twin and blockchain to augment data management during building handover. Thus, improving our understanding of the potential role of these emerging technologies in digitally transforming building-handover activities for value retention during the built asset's post-construction phase. Our paper contributes to elucidating readers with the state-of-art from the literature on our study's focal area and suggests directions for future research.*

KEYWORDS: *DIGITAL TWIN, DISTRIBUTED LEDGER TECHNOLOGY, BUILDING HANDOVER, INFORMATION MANAGEMENT*

1. INTRODUCTION

The Architectural, Engineering, Construction, and Facility Management (AEC-FM) industry involves complex activities due to the variety and volumes of entities involved, the duration of a project and the amounts of relevant data generated. Therefore, this creates breeding grounds for lost information, untracked implementation, and most critically unfulfilled client requirements, especially during project handover. Koeleman et al. (2019) and Lee et al. (2021) highlight that these complexities result from the fragmented nature of the AEC-FM industry, with many geographically dispersed stakeholders and different layers of contractors and subcontractors involved in a construction project working together towards a common goal. Therefore, critical activities during built assets' lifecycle can often be skipped, rushed due to time constraints or even ignored completely despite the enormous criticality it plays for acceptance by the client and support for the smooth occupancy of the built asset (Baechler, 2011; Grondzik, 2009; Tan et al., 2018).

There's been an increasing trend in adopting digital technologies in industrial sectors, especially with the advent of industry 4.0, to overcome the complexities in these sectors. However, the AEC-FM industry has been slow in adopting, using, or applying emerging digital technologies in its activities. Current studies have shown that applying digital technologies in the AEC-FM sector brings benefits of increased productivity, improved collaboration, quality and efficiency, which contribute to project success (Gamage, 2021). Some emerging technologies include Building Information Modelling (BIM), Digital Twins (DT), Distributed Ledger Technologies (DLT) or Blockchain (BC), 3D printing, Internet of Things (Out), Artificial Intelligence (AI), Augmented or Virtual Reality (Olanipekun and Sutrisna, 2021). Within the AEC-FM industry, especially under the concepts of Construction 4.0, efforts are being made to adopt such emerging technologies and tap into their advanced capabilities throughout a built asset's lifecycle (Opoku et al., 2021).

A built asset's lifecycle can be divided into pre-construction, construction, and post-construction phases, where stakeholders perform value-generating activities at each phase according to defined requirements (Martínez-Rojas et al., 2016). Although management of each phase is generally done independently, a lot of data is shared across the different phases; participants in a project are confronted with these data throughout the built asset's development cycle to make decisions which contribute to the success or failure of a project (Russell et al., 2009). Therefore, effective data management is imperative for successful project management, especially due to each project's primary goal of completion on time, within budget limitations, and compliance with established quality requirements or other defined specifications(Aneesha and Haridharan, 2017). Accordingly, integrating data management is critical for organising and exploiting relevant information to support decision-making processes throughout the project lifecycle (Martínez-Rojas et al., 2016); especially during the transitional phase between construction and post-construction, usually referred to as handover.

Currently, BIM, a digital illustration of what will be constructed or manufactured (Lee et al., 2021), is the common tool or process in the AEC-FM sector used to ensure efficient collaboration and communication (Noruwa et al., 2020). However, despite the multi-level capabilities of BIM, it remains limited to implementation within the digital realm without in-feed of real-time information for a close to "as-built" or "up-to-current" state of the built asset being actualised in the physical state (Lu et al., 2021). Moreover, even with that challenge, complications from fragmentation with information sharing, communication inconsistencies and delays among participants result in accountability issues, especially concerning the handover process for supporting the operational performance of a building during its utilisation stages.

DT goes beyond BIM for more "up-to-current" modelling; however, IoT sensors coupled with DTs can make BIM a living instrument, automatically updating 'as-built' BIM (Douglas et al., 2021). In addition, DTs can be used to simulate "what-if" scenarios using AI-based techniques to find out potential solutions against arising issues such as cost overruns and schedule delays, which enables stakeholders to make decisions (Lee et al., 2021) proactively. Although several studies have highlighted that the creation and management of DTs is a journey relevant to the entire project lifecycle (Qi et al., 2018), most of these studies focus on potential use during the construction and post-construction phase of an asset's lifecycle. Thus, DT's role during the transition from construction to post-construction is still largely unexplored. Furthermore, DT studies have also highlighted the need for security, reliability and collaboration concerning the generated data (Teisserenc and Sepasgozar, 2021). Consequently, BC provides potentially unified standards and protocols for information sharing with a decentralised peer-to-peer framework and addresses information security and privacy based on the cryptographic mechanism (Elghaish et al., 2022). Hence, BC could be a suitable technology to overcome or address the challenges of DT regarding its security, reliability and enhancing trust and transparency throughout a built asset's lifecycle (Teisserenc and Sepasgozar, 2021).

The handover stage is a critical activity which is increasingly becoming a requirement for every building due to the recent incorporation of complex building systems (Sinclair, 2019). But often, the handover process is faced with the issues of manual data handling, which can lead to errors and data loss, fragmented and inaccurate information, and poor information fidelity. This results in critical issues or complications during post-construction activities, which costs time and money (Kumar and Teo, 2021; Tan et al., 2018; Zhu et al., 2021). To contribute to ensuring the success of the handover process, this study recommends the exploration of the applicability of the current construction 4.0 technologies, BC-based DT, to address handover data management issues. Consequently, effective 'real-time' monitoring and secured data management are needed to improve the management of the built asset during post-construction activities, which brings into perspective the potential capabilities of DT and BC.

Based on a systematic literature review on the state of the art of DT and BC studies in AEC-FM, this paper posits the possibility of a BC-based DT to enhance efficient data management during handover. Although the relevance of BC and DT encompasses all the phases of the lifecycle of a built asset, the study's focus is on the building handover due to the criticality of the transition between the construction and post-construction phase, as well as little focus of research on the role of these technologies during building handover. To help clarify the study's focus, this paper presents an abridged version of a more detailed systematic literature review to tackle the following:

1. Present literature findings on the state of the art of Digital Twin in the construction sector
2. Present literature findings on the state of the art of blockchain in the construction sector
3. Highlight gaps within both Digital Twin and Blockchain literature in the context of handover

The significance of this study lies in its contribution to the frontier of knowledge in the field of construction management. It supports nudging further research directions for actualising the desired state of digital construction, more specifically, incorporating digital technologies in handover data management activities. The remainder of the article is structured as follows: Section 2 outlines the systematic literature review process adopted for this study. Section 3 presents the results of the literature review. Section 4 discusses the findings from the literature and highlights the gaps. Section 5 finally summarises and concludes the study.

2. SYSTEMATIC LITERATURE REVIEW

A systematic literature review focusing on DT and BC technologies for the AEC-FM industry is the main methodological approach underpinning this study. The review was conducted in two strands, namely DT and BC.

Nevertheless, both strands shared the foundation techniques and principles of conducting a systematic literature review like replicability, transparency, summarisation and knowledge synthesis (Briner and Denyer, 2012). Furthermore, scholars like (Teisserenc and Sepasgozar, 2021) have employed a similar systematic literature review methodology which serves as a further justification for employing this technique.

2.1 Literature Search

A comprehensive search strategy was employed based on recommendations from the Peer Review of Electronic Search Strategies *(PRESS)* (McGowan et al., 2016). Two databases were searched for relevant literature: Scopus and Web of Science Core Collection. Both electronic literature databases were chosen because they are considered the top two of the world's largest databases for trustworthy and peer-reviewed research, which indexes most academic publications worldwide (J.Adwan and Al-Soufi, 2016). Furthermore, these databases were chosen following Gough et al.'s (2012) recommendation for utilising at least two literature sources for a comprehensive literature search since not all referencing papers may be cited by a single database.

Following the methodology defined by Tranfield et al. (2003), preliminary searching was conducted in both Scopus and Web of Science Core Collection to test the search terms' appropriateness and find relevant literature. Once confirmed, a proper comprehensive search was conducted in May 2022 using keywords and appropriate Boolean operators for each of their strands indicated below:

Digital Twin: *("digital twin*" OR "virtual counterpart*" OR "digital replica" OR "virtual twin*" OR "digital twin concept" OR "building twin*" OR "digital building twin")* AND *("construction" OR "construction industry" OR "built environment" OR "building industry")*

Blockchain: *("distributed ledger*" OR "block chain*" OR "blockchain*" OR "distributed ledger technology")* AND *("construction" OR "construction industry" OR "built environment" OR "building industry")*

Constraints applied to both searching processes included literature type (journal article, conference papers), language type (English), and publication date (2018 onwards). The results retrieved from each strand were checked for duplicates to eliminate them before advancing the results into the screening stage. As a result, **1,094** papers were retrieved for the DT stand and **1,453** for the BC strand, respectively. In addition, to duplicate elimination, some papers were excluded at the identification stage because it was identified that they were unrelated to the AEC-FM.

2.2 Screening of Relevant Papers

The identified papers progressed into the screening stage, where their titles and abstracts were read and assessed for relevance to the subject matter. The full texts were sought after from each strand at retrieval; however, not all were accessible. Each retrieved full-text paper progressed into the eligibility stage, where these full texts were read and assessed for content relevant to the subject matter. Upon completion of the screening stage, **51** papers were included for further analysis from the DT strand, while a total of **84** papers were included for further analysis from the BC strand. The process flow for each strand is captured with the PRISMA flow diagram in Fig. 1 (DT strand) and Fig. 2 (BC strand), respectively, according to a recommendation from Page et al. (2021).

2.3 Extracting Relevant Information from Papers

With the aid of NVivo, the previously mentioned papers that were identified were progressed into the data extraction process, where available information within each paper was extracted into self-describing categories and held under thematic codes to identify the scope or variety of relevant constructs within each strand (Saldaña, 2021). These classifications were then later quantified by counting discovered instances to establish the potential gravitations of themes and priority areas inferred from literature (Adu, 2019). After performing the content analysis, similar areas were merged, and their quantities reconciled to avoid errors in the quantification process. Additionally, defining features on the nature of included results were assessed based on the representative publication years and popular publication outlets potentially gravitating in attention. Finally, the findings were used to arrive at the state of the art and gaps in the literature by cross-comparison of DT and BC strands.

3. RESULTS

3.1 Descriptive Analysis: Digital Twin in Construction

The results of the DT strand of the systematic literature review process to answer this study's aim about the state of art and potential gaps are presented hereafter. Beginning with the search and identification process in Fig. 1, **51** papers were utilised within this section to derive the presented results.

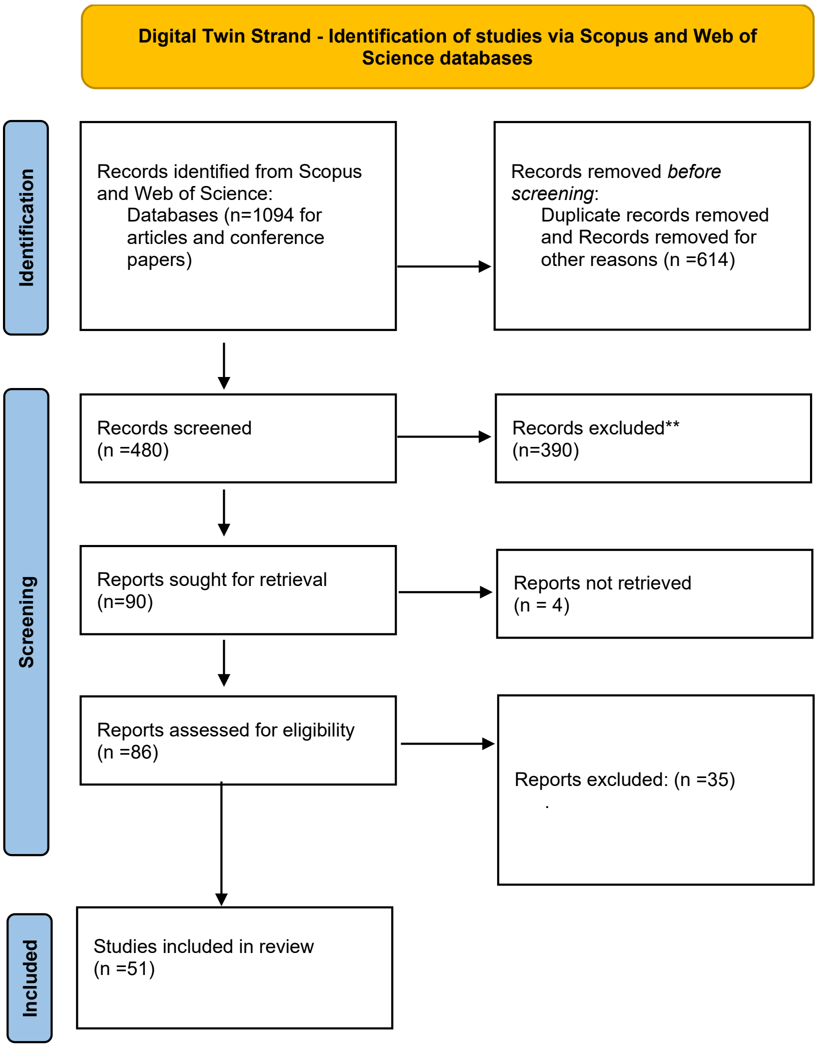

Fig. 1: PRISMA Flow Diagram for Digital Twin Strand

Publications included within the DT strand span over a timeline from **2019-2022** and are growing significantly, as revealed in their distribution: **2019** *(2 papers)*; **2020** *(10 papers)*; **2021** *(29 papers)*; and **2022** *(10 papers)*.

3.2 Content Analysis: Digital Twin in Construction

Studies on DT in AEC-FM literature are growing, making the concept of DT gain some awareness in the industry (Alizadehsalehi and Yitmen, 2021). DT studies retrieved explicitly excluded studies that were related to BIM. Studies of DT in the AEC-FM sector were clustered into themes based mainly on a built asset's lifecycle phases *(pre-construction, construction, and post-construction)*. Some of the studies where the focus was not on a single lifecycle phase were clustered based on the construction-related activity or the perspectives being studied. DT literature focused on its potential applicability to construction activities, post-construction activities, asset management, and enhancing collaboration. Other studies also focused on general implementation strategies, opportunities, challenges, etc. Due to the restrictions on the number of pages required for this paper, the focus will be limited to DT studies relating to the phases of a built asset's lifecycle.

In line with the decision to adopt a search criterion in strictly selecting only DT literature, no studies of DT application in the pre-construction phase were found at the time of the literature search. Therefore, it could be assumed that most of the literature at the pre-construction stage was mostly centred on the use of Building Information Modelling (BIM) for its activities. This finding is also corroborated by the work of Opoku et al. (2021). They indicated that most of the literature regarding DT applications at the pre-construction stage was mostly centred on BIM models.

In the construction phase of a building's life cycle, potential applications of DT have focused on construction progress monitoring (Alizadehsalehi and Yitmen, 2021; Jiang et al., 2022); construction safety (Chronopoulos et al., 2021; Harichandran et al., 2021; Hou et al., 2020); construction management (Rausch et al., 2021; Sacks et al., 2020; Wang and Wu, 2020) and site monitoring (Dietze et al., 2021). In the activity of progress monitoring, Alizadehsalehi and Yitmen (2021) presented a framework that integrates BIM, DT and extended reality technologies in developing an automated construction progress monitoring system. The studies highlighted that integrating DT with other technologies can support collaborative work in the creation, analysis, visualisation and management of construction progress data and reports (Alizadehsalehi and Yitmen, 2021). To enhance safety during construction, Chronopoulos et al. (2021) proposed a safety framework which involved the interaction with a DT platform to aid in the reduction of potential hazards on construction sites. As part of the framework, sensory information was continuously integrated in the DT in a construction environment for the identification of hazard areas, prediction of accidents and its impacts and notified the workers on these hazards. In the area of construction management, a DT-BIM was proposed to enhance the management of building construction. The proposed model has the potential of aiding in decision making, progress updates, dispatching resources and identifying the shortage of resources. To evaluate quality during construction, Tran et al. (2021) developed a framework based on a digital twin approach for automated quality assessment of building façades to support decision making. According to the study, the framework developed also provides insights into geometric quality, checking completeness and accuracy and help guide adjustments.

For post-construction activities, research on DT mainly focused on the use of DT for operation and maintenance activities, facility and asset management. In work undertaken by Y. Zhao et al. (2022), a framework involving combining a machine learning algorithm with a digital twin for building operation is proposed. The proposed digital twin model is to help realise data-driven intelligent forecasting via the integration and visual display of data of a building's operation and maintenance activities. Liu et al. (2021) also focused on developing a cost management system for a green building based on a DT. The cost management system proposed is intended to provide owners and property managers with real-time operational costs of the green building, providing a good basis for effective decision-making. As part of a wider research aim of improving Facility management, (Antonino et al., 2019) proposed a method to measure real-time occupancy data stored in the DT of a building using Image Recognition (ImR) sensors and computer vision to detect people's movements in a crowded environment. With regards to asset management, Heaton and Parlikad (2020) proposed a methodology that aids in creating DT with the support of an Asset Information model required for an efficient asset management system. The methodology was demonstrated using a creation of a campus DT. Further, according to Abdelmoti et al. (2021), DTs can help address the gap of fully linking accurate data/information management to managing an asset's lifecycle for proper decision-making.

Although studies have highlighted DT as a promising concept that can benefit different processes within the AEC-FM sector, it is still farfetched in the early stages of development and implementation in academia and industry (Shahzad et al., 2022). According to Boje et al. (2020), adopting DT would inherently deliver improved lifecycle costs, reduced carbon emissions, and resilient built assets in an ever-increasing environmental aware society. However, some of the roadblocks highlighted in the literature that threatens the implementation of DT in the built environment include lack of consensus on DT concepts in practice, difficulty in exhaustively evaluating DTs varied capabilities, and struggle experienced by practitioners in clearly understanding required changes in an organisation's processes to realise and sustain value generated from the DT (Agrawal et al., 2022). See Table 1 for the classification summary of the top three(3) literature in the DT strand according to constructed themes.

Table 1: Overview of Digital Twin Application Themes from Literature

Theme	**No of Studies**
DT FOR CONSTRUCTION	16
DT FOR POST-CONSTRUCTION	20
DT AS A COLLABORATIVE TOOL	4

It can be observed from Table 1 that the largest representative cluster of themes was related to **DT for Post-Construction** *(20 papers)*, which was followed by **DT for Construction** *(16 papers) and* **DT as a Collaborative Tool (4)**. Interestingly, there was no explicit identification of applications for building handover.

3.3 Descriptive Analysis: Blockchain in Construction

The results of the BC strand of the systematic literature review process to answer this study's aim about state of the art and potential gaps are presented hereafter. Beginning with the search and identification process in Fig. 2, **84** papers were utilised within this section to derive the presented results.

Publications included within the BC strand span over a timeline from **2018-2022** and are equally significantly growing as shown in their distribution: **2018** *(1 paper)*; **2019** *(11 papers)*; **2020** *(25 papers)*; **2021** *(32 papers)*; and **2022** *(15 papers)*.

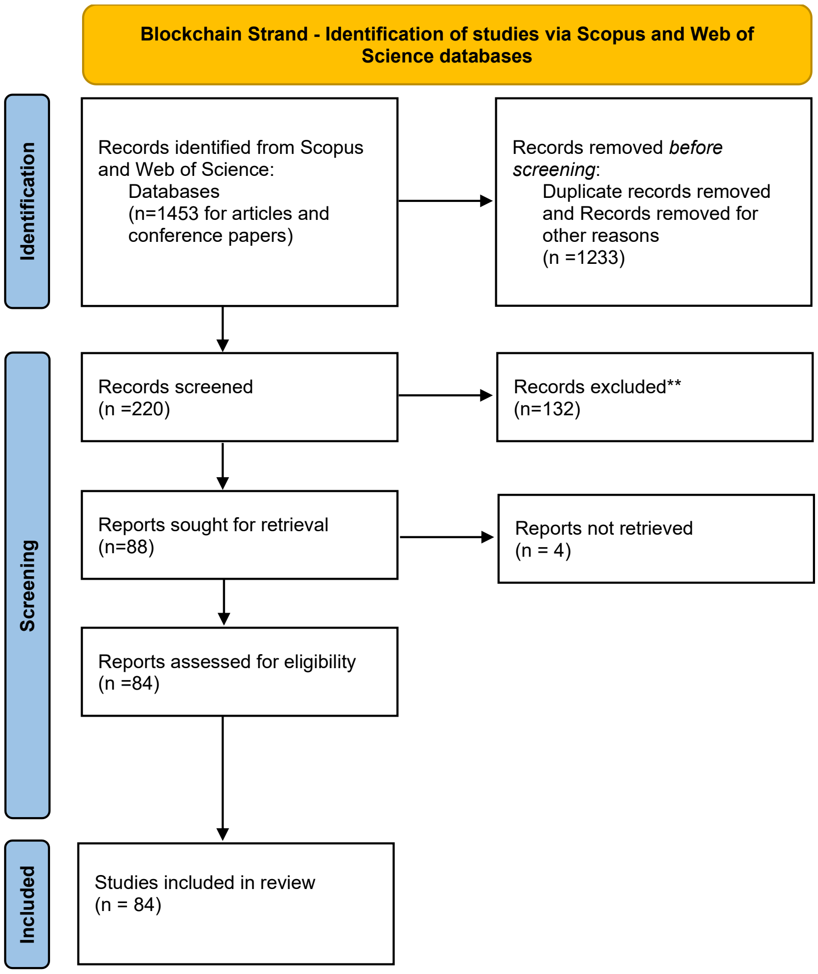

Fig. 2: PRISMA Flow Diagram for Blockchain Strand

3.4 Content Analysis: Blockchain in Construction

Studies on BC in the AEC-FM industry are growing, although still nascent in AEC-FM literature, due to the potential benefits to be gained from it. BC studies retrieved were clustered into themes based mainly on the study's focus or related construction activity under study. Research on potential BC applicability in the AEC-FM industry has focused on its potential integration with other technologies, its applicability to contract management and its impact on collaboration and information management. Other studies have also explored the applicability of BC to supply chain management, construction management, sustainability, circular economy, etc. However, as mentioned earlier, due to the restrictions on the number of pages required for this paper, the focus will be limited to the top three(3) focal areas on BC studies in the AEC-FM sector.

BC studies have explored its potential integration with BIM, DT, IoT, AI, Big Data, Deep Learning and Machine Learning. Work on BC integration with BIM was undertaken by Zheng et al. (2019), who proposed a novel blockchain-BIM (bcBIM) model as a solution to information security. According to Zheng et al. (2019), the bcBIM model can assure the integrity and provenance of data via the integration of blockchain to a BIM database; additionally, their study highlighted the potential of BC technology to enhance the quality and security of BIM data. Celik et al. (2021) also developed a decentralised BC-based BIM solution to help track and trace the various phases of a construction project's development cycle. According to Celik et al. (2021), integrating BC technology with BIM will ensure higher data traceability, enhance project transparency, and encourage greater participation amongst project participants. Singh (2020) also points out that integrating BC technologies with IoT can enable real-time applications in the construction industry; thus, it provides an overview of BC's potential with IoT to promote digital transformation within the construction industry to affect business development and productivity positively. In contributing to a performance-driven built environment, Hunhevicz et al. (2022) explored how integrating BC-based (smart) contracts, and DTs could enhance the execution of performance-based digital payments. The study further highlighted that BC-based smart contracts with DTs could support the digitisation of performance contracts in a trusted way which might encourage more stakeholders to explore a built environment as a service. Lee et al. (2021) also proposed a framework to enhance collaboration among project participants. The results from the proposed framework, which selectively stores and shares project-related information amongst project participants, indicate that real-time data could be traced and immutably shared amongst participants in a project.

In response to the need for enhanced information management in the sector, Wei and Cui (2020) proposed an information management model based on big data and BC for efficient management of construction safety information. The incorporation of BC into the model was to solve the issue with regards to the distortion, omission, inaccessible and low data utilisation of safety-related information of construction workers. Das et al. (2022) focused on BC-based management to enhance accessibility and share trusted and reliable information amongst participants in a network. The proposed framework leverages BC technology to enhance data integrity in document management during construction-related activities. In demonstrating BC's capability in enhancing information management, Cho et al. (2021) also proposed a BC network to distribute information reliably and transparently amongst participants in a network. The study presents a solution to monitor fine dust management at construction sites using BC technology to prevent data forgery and decentralise generated information.

Other studies have also focused on other AEC-FM-related activities. For example, Erri Pradeep et al. (2021) investigated the potential of BC to address design liability control issues and improve data security while exchanging information records. Furthermore, concerning enabling a circular economy in the built environment, Shojaei et al. (2021) explored the use of BC technology to create a system that can record, store, and distribute relevant information. Meanwhile, Gunasekara et al. (2022) developed a framework that offers a solution to the issues of data transparency and security of data to the management of the procurement process; their revealed that the data encryption mechanism and hashing mechanism of BC can be used to enhance the efficiency and security of the current procurement process.

Although BC technology is largely viewed as a potential solution to some problems experienced in the sector, it is still relatively new to industry players. Studies on BC in AEC-FM literature have so far indicated its potential to enhance construction efficiency, reduce issues with regards to fragmentation and communication and lessen paper-based operational activities (Kang et al., 2022). However, its development in the AEC-FM industry is still hampered by some challenges (Kang et al., 2022). According to Pattini et al. (2020), some of these challenges can be deduced from stakeholders' unwillingness to adopt and rely on new technology and the discomfort of sharing business information in a distributed environment. On the other hand, Sharma and Kumar (2020) suggest that the adoption of BC, like any new technology, may depend on stakeholders' willingness to take a risk and their preparedness to invest in this unproven concept even though it has great potential. See Table 2 for the classification summary of literature included in the BC strand according to constructed themes.

Table 2: Overview of Blockchain Application Themes from Literature

	No of Studies
COLLABORATION & INFORMATION MANAGEMENT	26
INTEGRATION WITH OTHER TECHNOLOGIES	19
CONTRACT MANAGEMENT	16

It can be observed from Table 2 that the largest representative cluster of themes was related to **Collaboration & Information Management** *(26 papers)*; which was followed by **Integration with Other Technologies** *(19)* and **Contract management** *(16 papers)*. Interestingly, two (2) instances were discovered that explicitly focused on DT and BC integration. Nevertheless, no explicit identification of applications within the handover.

4. DISCUSSION

Following the findings on DT and BC studies from the descriptive and content analysis within Section 3, an integrated discussion is provided concerning the outlined research objectives from Section 1, mainly about the discovered state of the art of DT and BC within the construction industry, to point out gaps from intersecting literature and their characteristics that make them viable for the building handover data management.

4.1 INSIGHTS ON DIGITAL TWIN AND BLOCKCHAIN IN CONSTRUCTION

The reviewed literature provided an indicative landscape overview of state of the art on DT and BC in the AEC-FM, mainly by revealing growing interest and efforts within these target fields. However, it was noted that while the trajectory of DT showed huge incremental gaps, that of BC suggested a reducing gap, which may suggest a potential relative saturation in BC-related literature compared to DT.

Regarding the contents within the included literature for this review, it revealed multiple perspectives about DT and BC applications, capabilities, and limitations. Most importantly, it reinforces the potential for DT and BC integration to support collaborative work practices by establishing enhanced communication among stakeholders, sustaining secure data integrity and an authentic environment within the digital space to represent the physical artefact or process that it aims to twin. Furthermore, our findings reveal that DT and BC promise real-time monitoring of project status and providing provenance of data throughout its lifecycle and can be used tactfully to predict future occurrences to realise data-driven intelligent forecasting practices. In line with that, DT and BC bring on board management implications that can be harnessed for real-time data monitoring, secure data and information exchange, trustworthy and transparent decision making, process automation to eliminate paper-based clutter and human errors, as well as mitigate poor data utilisation when faced with excessive sources of data.

The authors speculate that the discovered pattern relating to use of DT within both the construction and post-construction phases could be related to the need for an existing physical artefact to twin as a digital equivalent. This may clarify the absence of DT within the pre-construction phase, especially since BIM was excluded from our search strategy. One may perceive BIM statically tied to digital design development and no actual physical object on-site during pre-construction. Meanwhile, BC's integration was considered suitable for any phase dealing with data management, thus invariably making it suitable for managing each phase in a built asset's lifecycle. This may also clarify that BC, on its own, is limited in potential and is better suited when integrated with another technological adaptation. Therefore, BC-based DT applications make it a viable candidate for handover activities due to its ability to be harnessed as a secure collaboration tool, provide reliable data for quality assessment, and have direct applications to traceable progress monitoring and asset management within construction and post-construction phases within the AEC-FM industry.

4.2 GAPS WITHIN THE INTERSECTING LITERATURE OF DIGITAL TWIN AND BLOCKCHAIN IN CONSTRUCTION

Based on the above discussions and efforts identified in the literature, the following gaps were identified, especially relating to the perspectives of handover activities, to propose future research directions.

Despite the identified efforts by DT and BC studies across both construction and post-construction phases in a built asset's lifecycle, there is less attention paid to the transition between construction and post-construction concerning handover activities. In addition, no literature was identified explicitly studying handover concerning DT or BC. This leads to the recommendation that studies can be conducted about the potential applicability or role of DT and BC in handover activities to address this context gap.

Additionally, as rightfully identified by RIBA (2020), the building handover comprises activities where data is validated and signed off; hence data handed over must be up-to-date, available and accurate to enhance the efficient management of a built asset during its use. The authors propose a need to address the research deficiency within the handover stage by mobilising studies to focus on exploring, understanding, and harnessing the potential of DT and BC to address this knowledge gap in its performance within the handover context.

Furthermore, studies have revealed the potential role of DT and BC regarding collaboration in a decentralised and immutable manner, bringing into perspective their suitability within the AEC-FM industry due to the dispersed stakeholders involved. These stakeholders require credible large volumes of data or information to make informed decisions about the construction, utilisation, and maintenance. This reinforces the complementary nature of DT and BC, especially when dealing with critical verification of information and positioning the assets for usage or maintenance activities. Accordingly, there remains a void that tests these hypothetical promises and challenges using empirical research data from qualitative and quantitative methods to elucidate robust knowledge discoveries to deepen the understanding and create awareness about DT and BC for handover activities within the AEC-FM industry.

5. CONCLUSION

In summary, this paper's objectives were mainly to review the literature on DT and BC within AEC-FM to highlight the state of the art within literature and identify gaps in the context of handover within the intersection of DT and BC. These were addressed to reveal a complementary nature of DT and BC to tackle key issues regarding stakeholder collaboration and information fragmentation within the AEC-FM industry. Following the identified knowledge and context and gaps regarding the role of DT and BC during building handover, we argue a justification for further multidisciplinary research to contribute to the advancement of such emerging technologies within the AEC-FM industry. We, therefore, posit the potential for a BC-based DT to facilitate digital transformation within the AEC-FM sector by focusing on crucial value-adding activities (e.g. data management) at the handover stage. We, therefore, conclude this paper by raising the call for further research to address the subject matter with empirical evidence that supports a deeper understanding and adoption of these emerging technologies in the AEC-FM industry.

6. ACKNOWLEDGEMENT

This paper contains research which is part of the lead author's ongoing PhD research project, partially funded by Teesside University.

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