ENHANCING COLLABORATION WITH BLOCKCHAIN-ENABLED DIGITAL TWINS: PERSPECTIVES FROM STAKEHOLDERS IN THE BUILT ENVIRONMENT

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ABSTRACT: *This study explores the potential of Blockchain (BC)-enabled Digital Twins (DT) using qualitative semi-structured interviews to investigate the perception of stakeholders in the Architectural, Engineering, Construction and Facility Management (AEC-FM) industry on the relevance of BC-enabled DTs in augmenting stakeholder collaboration. The findings revealed that most interviewees perceived the potential of a BC-enabled DT in fostering stakeholder collaboration, leading to enhanced project delivery. Some participants viewed affordability drivers, whilst some highlighted the desire to fulfil client demands as influencing drivers for BC-enabled DT implementation in the AEC-FM industry. The study's empirical findings align with evidence from other industrial sectors, proving that BC can ensure data integrity in a decentralised peer-to-peer framework, whilst DTs can leverage that data for effective and reliable decision-making. In the AEC-FM industry, these technologies are nascent; however, their potential integration could tackle critical issues regarding stakeholder collaboration and information fragmentation, leading to value generation in a decentralised and immutable manner. This study offers insights into implementation strategies for a BC-enabled DT collaborative environment and contributes to accelerating the industry's approach to digital transformation.*

KEYWORDS: *digital twins, blockchain, drivers, collaboration*

1. INTRODUCTION

In a project-dominant sector like the Architectural, Engineering, Construction and Facility Management (AEC-FM) industry, collaboration is seen as a critical catalyst in boosting efficiency, promoting information sharing, facilitating effective decision-making, and improving the quality of production processes and project-based performance (Koolwijk et al., 2018). Unfortunately, collaboration in the sector is beleaguered with mistrust, ineffective communication, adversarial relationships, and unnecessary disputes. This has resulted in the industry's fragmented nature and inconsistent activities by different participants, hindering progress towards project targets and creating a significant barrier to success (Li et al., 2021; Prebanić & Vukomanović, 2021).

Fragmentation of the AEC-FM industry is further compounded by the industry's complex activities due to the variety and volumes of entities involved (Chen et al., 2022), the duration of a project, the amounts of relevant data generated and dispersed stakeholders who work at the different phases of a built asset's lifecycle. Therefore, this creates breeding grounds for loss of crucial information, untracked implementation, and, most importantly, the failure to meet client requirements. Given the industry's complexities, it is essential to identify tools or solutions that can improve collaboration and contribute to process efficiency.

There has been an increasing trend in adopting digital technologies in various industries (Pour Rahimian et al., 2022), especially with the advent of Industry 4.0, to overcome industry complexities. However, the AEC-FM industry has slowly adopted, used, or applied emerging digital technologies (Newman et al., 2021). Studies show that applying digital technologies such as Building Information Modelling (BIM), Digital Twins (DT), Distributed Ledger Technologies (DLT) or Blockchain (BC), Internet of Things (IoT), and Augmented or Virtual Reality in the AEC-FM industry can increase productivity, collaboration, quality, and efficiency (Olanipekun & Sutrisna, 2021). Under the concept of Construction 4.0, the AEC-FM industry is making efforts to adopt such emerging technologies and utilise their advanced capabilities (Opoku et al., 2021).

BIM is now widely recognised as an effective way to facilitate collaboration, communication, and management. It is a common tool or process that provides a high level of information depth (Gan et al., 2019), containing all necessary details about objects and processes for the asset's entire lifecycle and the different stakeholders involved (Khajavi et al., 2019). Despite the well-known benefits of BIM in terms of collaboration, issues relating to collaboration persist (Oraee et al., 2021); these might stem from a lack of shared collaborative culture, limited understanding of emerging technologies among project teams, and a preference for traditional methods (Che Ibrahim et al., 2019; Ibrahim & Belayutham, 2019). Furthermore, the multi-level capabilities of BIM are limited to implementation without the inclusion of real-time information to achieve a close-to-"as-built" or "up-to-current"

Referee List (DOI: 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Nana Akua Adu-Amankwa, Farzad Rahimian, Nashwan Dawood, *Enhancing Collaboration with Blockchain-Enabled Digital Twins: Perspectives from Stakeholders in the Built Environment,* pp. 298-308, DOI 10.36253/979-12-215-0289-3.28

state of the built asset being actualised in physical form (Lu et al., 2021). Wang et al. (2020) suggest that the absence of real-time information exchange can lead to fragmented and discontinuous actions among participants. Therefore, a collaborative platform allowing real-time information sharing among all parties is necessary.

DT technology has immense potential to facilitate real-time communication and collaboration among project participants (Lee et al., 2021). DT surpasses BIM by providing more "up-to-current" modelling (Rao et al., 2022; Xie et al., 2020). Integrating IoT sensors and DTs can also transform BIM into a dynamic tool, automatically updating as-built BIM (Dudhee & Vukovic, 2021). Furthermore, DTs can simulate "what-if" scenarios with AI-based techniques to identify potential solutions to issues such as cost overruns and schedule delays, enabling stakeholders to make proactive decisions (Lee et al., 2021). In addition, DT technology offers a shared virtual environment where project participants can visualise the project, discuss options, and ultimately make well-informed decisions (Zhao et al., 2022). Several studies have emphasised that creating and managing DTs is a continuous process relevant throughout a built asset's lifecycle (Xie et al., 2023). However, these studies have also highlighted the importance of ensuring data security, reliability, and improved collaboration (Hellenborn et al., 2023).

BC technology is anticipated to fuel innovation in essential areas such as security, trust, and coordination with unified standards and protocols for information sharing. This decentralised, peer-to-peer framework is based on cryptographic mechanisms (Elghaish et al., 2022; Talla & McIlwaine, 2022) and could be an ideal solution to tackle the challenges of DT concerning security, reliability, and transparency (Kiu et al., 2022). BC enables a secure electronic ledger of digital information, utilising hash values to enhance security. BC uses consensus protocols through a decentralised network to ensure data reliability and encourages collaboration among project participants to record, verify, store, and extract construction project information and transactions without centralised data intermediaries (Kim et al., 2020).

When it comes to the digital transformation in the AEC-FM industry, the integration of BC and DT technology poses the potential to ensure data integrity, security, and trustworthiness, thereby enabling more effective collaboration among stakeholders (Adu-Amankwa et al., 2022); however, only limited studies on its potential integration can be found in AEC-FM literature. Additionally, its adoption and potential integration may be a complex phenomenon which could be influenced by factors considered from multiple perspectives. Hence, investigating and exploring stakeholders' perspectives on the potential of a BC-enabled DT collaborative approach can contribute to designing a framework and informing policymakers towards its successful adoption and implementation. To help contribute to the limited studies on BC-DT integration, this current study aims to explore and understand the perspectives of the industry's stakeholders on the potential applicability of BC-enabled DT collaborative approach using qualitative semi-structured interviews. In line with the aim, the study seeks answers to the following research questions:

- What do industry stakeholders perceive as the potential role(s) of BC-enabled DT collaborative approach?
- What factors would motivate industry stakeholders to pursue a BC-enabled DT approach to collaborative working?

The remainder of the article is structured as follows: Section 2 reviews relevant literature, while Section 3 explains the methodology used. Section 4 presents the results and discusses the perspectives of the study's participants. Finally, Section 5 summarises and concludes the study.

2. LITERATURE REVIEW

The impact of BC-enabled DT approach on collaboration is increasingly studied, particularly in the energy, health, manufacturing, and transportation sectors. For instance, studies by Huang et al. (2020) demonstrated the effectiveness of a data management platform for a turbine using a BC-based DT approach to help curb problems associated with data storage, data access, data sharing, data authenticity, and overwritten data. The results of their approach indicate the potential of BC-based DT to guarantee data storage, access to verified data, sharing efficiency via a peer-to-peer network, and data authenticity through traceability. In another study, EL Azzaoui et al. (2021) created a BC-based DT framework for a smart health city to ensure user identity is secure and data is anonymously available only to healthcare providers and professionals for real-time data analytics, research, and personalised treatment. The framework has the potential to enhance treatment accuracy, predict future diseases, and control them. The authors also suggest that in a COVID-19 scenario, this framework could be used as a collaborative approach to provide a secure, shared database where healthcare providers and professionals can access data anonymously and use that data to improve treatment and prevent future pandemics. In a recent study by Tao et al. (2022), a BC-based platform was proposed for better management of manufacturing services. The platform aims to improve trust among collaborators by ensuring accurate information sources and secure data. The authors explain that despite the challenges posed by the lack of interaction between physical and cyber spaces, the proposed platform offers a reliable solution for cyber-physical integration and addresses issues of distrust commonly associated with such service platforms.

In AEC-FM literature, Lee et al. (2021) developed and tested a BC-DT integrated framework to support accountable sharing of project-related information among stakeholders. According to the authors, integrating BC and DT can ensure authentic real-time construction-related data is traceable, immutable, and shared among project participants without an intermediary. Similarly, studies by Teisserenc and Sepasgozar (2022) posit that BC-enabled DT will allow real-time monitoring of assets whilst supporting data decentralisation and enhancing data traceability, security, and privacy. In another study, Jiang et al. (2022) suggested that a BC-enabled DT collaboration platform can establish a virtual space for real-time monitoring, decision-making, and communication among different parties in a project.

These studies demonstrate that integrating DT and BC can facilitate collaborative work practices by improving stakeholder communication, maintaining secure data integrity, and creating an authentic digital representation of the physical asset or process being twinned. In addition, these studies have management implications that can be useful for monitoring data in real time, exchanging data and information securely, and making trustworthy and transparent decisions. However, despite these studies, only a few have attempted to explore and understand its applicability in the context of the AEC-FM sector. Furthermore, there is a need to test these theoretical promises through empirical research, using both qualitative and quantitative methods to discover robust knowledge. This will help gain a more thorough understanding of their relevance within the AEC-FM industry and increase awareness about their potential benefits. Hence, seeking input from key stakeholders can offer valuable insights into the advantages of implementing a collaborative approach incorporating DT and BC technologies and the driving factors behind its adoption.

3. METHODOLOGY

A qualitative methodological approach focusing on conducting semi-structured interviews was mainly employed for this study. This approach was adopted due to its potential to gather comprehensive data and generate rich insights (Bryman, 2016). Hence, using this approach to explore and understand stakeholder perceptions about DT and BC technologies for the AEC-FM industry will enable participants to provide rich perspectives based on their knowledge and expertise. Through purposeful sampling, participants were sought through online networking websites (e.g., LinkedIn) and peer recommendations (Bryman, 2016). The main areas of interest were those participants with knowledge or experiences about DT, BC, or both in the AEC-FM industry. Nevertheless, flexibility was employed for some profiles which didn’t express explicit expertise in those fields but were keen to participate in the study because of their broader knowledge of digital transformation in the AEC-FM sector.

3.1 Data Collection – Semi-structured Interviews

After ethical approval was granted to engage participants for data collection, potential candidates were approached for their consent to participate in this study. According to Saunders et al. (2019), a range of 5-25 participants is adequate for qualitative interviews. Thus, this study included 19 AEC-FM industry professionals and scholars from Asia, Europe, North America, and Africa.

The researchers employed a semi-structured interview protocol to organise detailed and orderly interviews, including open-ended questions to collect meaningful comments from respondents (Yin & Campbell, 2018). The interviews were conducted via web meetings on MS Teams to accommodate a wider reach of participants and allow effective capturing of responses for transcription. Accordingly, before each interview session, participants were briefed on the study’s aims, any concerns were addressed, and their consent was formally sought to officially commence the interview process.

3.2 Data Analysis – Thematic Analysis

With the aid of NVivo, the transcribed responses from participants were progressed into the data processing and analysis, where available information within each response sheet was extracted into self-describing categories and held under thematic codes to identify the scope or variety of relevant constructs (Saldaña, 2021). Emerging themes highlighting the potential role of BC-enabled DT perceived by participants and the drivers or influential factors towards its adoption were identified. The emerging themes identified were guided by the study's focus, as suggested by Bryman (2016).

4. RESULTS AND DISCUSSION

4.1 Demography of Interviewees

A total of 19 participants hailing from Africa, Asia, Europe, and the Middle East were involved in this study. These participants were classified according to their field of expertise, which included Academics, Managers, Architects, Engineers, Programmers, and Surveyors.

4.2 Participants' Perspectives on the Role of Blockchain-enabled Digital Twins

During the interviews, individuals were asked to provide insights on a BC-enabled DT approach's role in collaborative working within the AEC-FM industry. Drawing from their extensive knowledge and understanding, they affirmed that a BC-enabled DT would be crucial for four main themed functions on effective collaboration, as it would provide a secure environment for accessing and sharing data, improve decision-making and promote trust and transparency (see Table 1).

Table 1: Summary of Themes about the Role of Blockchain-enabled Digital Twin from Participant

Theme	Descriptions	No of Participants
Enhanced Data Accessibility	This theme comprises views on the role of blockchain-enabled digital twin in easing stakeholder access to data	9
Data Security	This theme comprises views on the features of blockchain-enabled digital twin in assuring the security of data	3
Enhanced Decision-Making	This theme highlights views on the role of blockchain-enabled digital twins in assisting with decision-making	3
Trust and Transparency	This theme comprises views on the relevance of blockchain-enabled digital twins in ensuring trust and transparency	2

Regarding the popularity of themed responses, it is observed from Table 1 that most participants expressed sentiments about enhanced data accessibility, followed equally by data security, as well as enhanced decision-making, and finally, trust and transparency. Nevertheless, the number of participants is only an indication of interest as some participants may be represented across themes, so in this paper, the contents that comprise these themes are of interest. The subsequent subsections delve into the themes with supporting evidence quotes.

4.2.1 Enhanced Data Accessibility

Most of the interviewees revealed that opting for a BC-enabled DT solution will create a platform where data can be accessed easily by project participants and stakeholders. They expect that BC's added characteristic of a peer-to-peer decentralised network will empower each participant to easily access data without the need to depend on a central authority for data access. Some interviewees believed that accessing data is vital for collaboration as this would allow for timely retrieval of data or information since it is available to all parties. Extracted comments from a participant which align with the view of enhanced data accessibility include:

"I think the timely retrieval of information will be a major aspect that digital twin and blockchain technology eventually would be able to address."

"You need to focus on specific information that you want stored on the blockchain, but once you have stored the information, then it is available to all the parties involved. So, within the blockchain-enabled digital twin, you would have specific information that is useful for managing the overall lifecycle of the building and are

available to all parties."

The expectation of interviewees is corroborated by Sarfaraz et al. (2023), who revealed that BC poses a potential for ensuring the immutability, validity, and confidentiality of recorded data while enabling decentralised storage. Hence, BC's integration with DT can ensure access to information without a mediator, providing a decentralised solution to project participants. Additionally, the integration of BC and DT can enhance data visibility. Thus, all parties involved in a `built asset's lifecycle can access reliable data on a shared distributed ledger (Suhail et al., 2022).

4.2.2 Data Security

Data Security was also indicated as a key relevant attribute that a BC-enabled DT solution can enhance, resulting in improved collaboration. Most interviewees consider data security very relevant while managing a built asset's lifecycle. In their opinion, a BC-DT integration will ensure data security. Interviewees further indicated that data generated throughout a built asset's lifecycle needs to be protected due to the confidentiality of certain data types shared between project parties. In addition, interviewees highlighted that BC-enabled DT's incorporation into the management of a built asset lifecycle would prevent data from being tampered with due to BC's immutable nature. An extracted interviewee comment is presented below:

"*…but we want to protect this data, and not expose it to any cyber-attacks, or to expose it to people who do not have access to that kind of information. So blockchain data, in the end, will create big changes in how we manage assets, the way we manage the buildings by providing some good data, accurate data, real-time data about the buildings, and that is also secured."*

The views expressed on BC-enabled DT's capability in enhancing data security are corroborated by Shen et al. (2021), who confirmed via a secure data sharing framework that BC's distributed mechanism and cryptographic features can guarantee a higher level of security as compared with a traditional centralised solution. Sahal et al. (2021) revealed that the issue of security in collaborative working could be significantly enhanced by BC-enabled DT due to its potential to allow for secure real-time data exchange and analysis among multiple participants. Data breaches in real-life scenarios highlight the importance of ensuring data security and reliability, hence the need to integrate BC-enabled DT throughout a built asset's lifecycle.

4.2.3 Enhanced Decision-Making

The interviewed participants indicated that the unique characteristics of BC and DT will lead to enhanced decision-making. They highlighted that the feature of DT in providing real-time data on a built asset and BC's capability in ensuring secure, immutable data within a decentralised setting can contribute to timely and accurate decision-making. Additionally, participants revealed that using the real-time data available in BC-enabled DT platform can form a reliable base to improve performance and predict future occurrences. A comment extracted from an interviewee is as follows:

"The strengths of digital twin solutions, with real-time information on the built assets plus the decentralised and transparency strengths of the blockchain technology, I believe that will actually help you to manage facilities better and also, perhaps, generate more insights that can also help improve how facilities are being managed."

Studies by Suhail et al. (2022) have also indicated that integrating BC and DT can ensure that actionable insights are driven by trustworthy data. They further pointed out that BC-enabled DT approach can help stakeholders to acquire more thorough and accurate insights into asset performance based on generated reliable data. Sahal et al. (2021) highlight that BC-enabled DT collaboration can enhance decision-making in avoiding risks and proffer solutions to unexpected occurrences. These studies confirm the views shared by interviewees that incorporating BC-DT creates an enabling environment that can facilitate decision-making in the built environment based on reliable data.

4.2.4 Trust and Transparency

Enhancing trust and transparency between stakeholders involved in a project was also a key perspective shared by most interviewees. A participant believed that BC adds a layer of transparency when integrated into a DT depending on the defined protocols and its peer-to-peer network. Furthermore, participants were of the view that the layer of transparency can contribute to enhancing trust amongst stakeholders. One interviewee stated:

"… it would be that you can trust it because project parties would have the same records. Parties will not be

required to go through old extra records because every time data is updated, it is a universal update throughout the network."

Findings from the interviews are consistent with studies by Teisserenc and Sepasgozar (2021), who posit that incorporating a BC-enabled DT platform is crucial in establishing a reliable and secure data audit trail within decentralised ecosystems, from project initiation to completion. This shared data platform guarantees trust and transparency while ensuring data integrity throughout the project lifecycle. Suhail et al. (2022) suggest that by integrating BC and DTs, all parties involved in a product's lifecycle can effectively and efficiently manage data on a shared distributed ledger, thereby addressing data trust, integrity, and security concerns. In summary, a BC-enabled DT system will enhance stakeholder collaboration, improve transparency, and resolve trust-related concerns.

4.3 Drivers of Blockchain-enabled Digital Twins

Understanding the motivations behind the adoption of digital technologies is crucial, as these drivers can significantly impact behaviour and outcomes (Yang et al., 2021a). This study presents the driving factors, as perceived by key stakeholders, that will lead the AEC-FM industry towards undertaking and successfully executing BC-enabled DT approach. In this context, "drivers" refer to the motivating forces (Opoku et al., 2022) that will prompt stakeholders to execute BC-enabled DT projects effectively. After conducting a thematic analysis of interview data, five key themes emerged as the main influencing factors that would encourage stakeholders in the industry to adopt a BC-enabled DT collaborative approach (see Table 2).

Table 2: Summary of Themes about the Drivers of Blockchain-enabled Digital Twin from Participants

Theme	Descriptions	No of Participants
AFFORDABILITY AND COST-EFFECTIVENESS	This theme represents views relating to the cost involved in acquiring the approach and the potential value to be gained	8
STAKEHOLDER AWARENESS OF THE POTENTIAL BENEFITS	This theme comprises views relating to stakeholder understanding and perceptions of the benefits	11
STANDARDS, POLICIES AND REGULATIONS	The theme represents views shared on the need for rules, guidelines, and policy interventions.	6
REAL-LIFE IMPLEMENTATION	The theme revolves around views shared on the need to showcase practical approaches and demonstrate real-life examples	6
CLIENT'S DEMANDS AND INTERESTS	This theme encompasses perspectives shared on a client's role and interests	4

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4.3.1 Affordability and Cost-effectiveness

The participants revealed that stakeholders would be more likely to adopt a BC-enabled DT collaborative approach based on its affordability and cost-effectiveness. They mentioned that the affordability of the approach, especially for small-scale industry players, is considered the main driving force behind its development and implementation. In addition, some participants emphasised that a business's decision to invest in a new solution or innovation is primarily influenced by its cost-effectiveness, as businesses constantly strive to make returns on their investments. One interviewee's extracted comment is as follows:

"The main one is the cost to install a big platform. For a small-scale office, it is another cost. So, it only makes sense if the cost return works out. The equity returns on their investment in that platform should justify that investment and make sense if they scale up to larger scale projects for greater returns."

Considering the novelty of a BC-enabled DT approach, its initial cost and affordability are crucial to its potential adoption. Studies by Cheng and Chong (2022) revealed that perceptions about the costs of adopting and implementing emerging technologies can significantly influence stakeholders' adoption decisions. Suhail et al. (2022) pointed out that adopting emerging technologies can help reduce operational costs, reinforce productivity, and enhance operational efficiency. However, industry players still face high initial investments despite the potential benefits gained from their adoption (Toufaily et al., 2021), which could be an obstacle (Rind et al., 2017). Suhail et al. (2022) further suggest that adopting these emerging technologies would require a detailed cost-benefit analysis; otherwise, they may pose a significant challenge to an enterprise's resources.

4.3.2 Stakeholder Awareness of the Potential Benefits

In the AEC-FM industry, BC and DT are emerging technologies many stakeholders may not yet be familiar with. Hence, to promote their adoption, interviewees believe it is important to spread knowledge about their potential benefits. Some interviewees suggest that stakeholders need to be educated and convinced about the added value of these technologies before they can be implemented. The interviewees also underscored the need for continuous advocacy and education to shift the mindset of industry players, especially in an industry that is slow to adopt new technology and where stakeholders may resist new innovations. A typical view shared by interviewees is as follows:

"I believe people need to be convinced that this approach can save them money, make them more efficient, or maybe make them more competitive against their peers or give them some competitive advantage. So, they need to be convinced that investing in tools or new approaches like this will actually be worth it. In the long run, as a business, you don't want to invest your time and resources into something that would actually drain your limited resources. So, people need to be convinced and encouraged to adopt such technologies."

Perspectives shared by participants are supported by Orji et al. (2020), who indicate that having a comprehensive understanding of the advantages of new technological advancements can inspire stakeholders to invest in digital innovations. Therefore, it is recommended that stakeholders who are well-informed about these emerging technologies should emphasise and create awareness of their benefits, such as their ability to improve productivity based on an organisation's resources and traits.

4.3.3 Standards, Policies and Regulations

During the interviews, it was discovered that industry players are more likely to adopt new innovations if stakeholders or policymakers in the built environment develop and implement standards and procedures to guide the adoption and implementation of BC-enabled DT collaborative platforms. The interviewees also highlighted that implementing standards, policies, and regulations would create an environment that enables the proper implementation of new innovations and encourages their adoption. Additionally, some interviewees suggested that the government could spearhead the use of new innovations by establishing and implementing specific project requirements that make adoption necessary. One of the interviewees intimated that:

"So, if the stakeholders or the policymakers in the built environment can come up with standards and procedures, and also give policies and regulations which motivate or promote the adoption of this technology, then it is imminent that professionals in the built environment would definitely adopt it."

The impact of governmental policies, standards, and guidance on the perceived usefulness and complexity of new technologies cannot be underestimated (Cheng & Chong, 2022). Abideen et al. (2022) pointed out that governmental regulations and laws can influence innovation adoption and further cited the 2016 UK construction strategy as a notable instance of such regulations. Hence, regulatory bodies need to create policies and provide support to drive the adoption of BC-enabled DT platform.

4.3.4 Real-life Implementation

Participants suggested that in addition to communication and raising awareness about the benefits of BC-enabled DT platforms, it is important to demonstrate their real-world applications. Most interviewees agreed that developing case studies showcasing the tangible benefits of implementing such platforms would be an effective way to convince industry stakeholders of their value. Some interviewees also recommended creating prototypes to demonstrate the viability of collaborative working using these platforms. Implementing pilot projects was also suggested to illustrate the benefits and encourage adoption. Finally, interviewees emphasised that showing use cases would also educate people about the necessary resources and requirements for successful implementation, given that these technologies are still emerging. One of the interviewees stated that:

"The development of case studies that showed real application of this technology. So, we have to show how these technologies can be applied, and I think that this is the only way in which we can prove to industry and academia the values and the benefits that we can realise using the integration of BC and DT."

The views expressed by interviewees are further supported by Zhang et al. (2023), who suggest that pilot projects are a practical approach to tackling technical concerns that stakeholders may have and enhance their appreciation of the advantages of implementing emerging technologies. They further pointed out that many stakeholders hesitate to embrace new technologies because they lack real-world case studies to prove their effectiveness. Hence, the deployment of pilot projects cannot be discounted as a driving force during decision-making in adopting digital solutions.

4.3.5 Client's Demands and Interests

Interviewees emphasised the role of the clients or owners as driving forces in adopting innovation. They explained that clients have the potential to fuel innovation through their desire to explore novel approaches and optimise project execution methods. Additionally, interviewees confirmed that some clients often support new strategies that can motivate adoption. However, some interviewees caution that clients without knowledge of new technologies or a clear understanding of their needs may demand unrealistic solutions. An interviewee shared the view that;

"So basically, what I'm trying to say is that professionals and clients that would love to see new ways and better ways of doing things will easily find this approach very valuable to them."

Similar studies on the adoption of digital technologies corroborate the role of the client as an important driver. According to Yang et al. (2021b), increasing market demands for digitalised solutions in many industrial disciplines have driven firms to adopt digital technologies to meet client demands and requirements and maintain client relationships. Abideen et al. (2022) also pointed out that industry professionals are driven by clients' awareness of potential enhancements in the digital built environment, and this usually motivates industry players to achieve competence and excellence when adopting and implementing new solutions.

5. CONCLUSION

This paper explored the perspectives of industry and academic professionals about the potential roles that BC-enabled DT collaborative approach could play in the AEC-FM industry, as well as the influencing drivers that would motivate such stakeholders to pursue BC-enabled DT approach to collaborative working. Emerging themes from respondents revealed that participants perceived that BC-enabled DT could create an enabling environment for enhanced data accessibility, data security, enhanced decision-making, and promote trust and transparency, thus making it vital for collaborative work across the AEC-FM industry. Meanwhile, it was discovered that five main factors emerged from participants' responses as motivational drivers to pursue the path of BC-enabled DT; these are affordability and cost-effectiveness, stakeholder awareness of the potential benefits, standards, policies, and regulations, real-life implementation, and client's demands and interests.

Despite BC-enabled DT solutions being explored in other industries for collaborations, the lack of attention to its combined potential in the AEC-FM leads to the heart of this study's novelty, which lies in its focus on empirically identifying its anticipated roles and influential drivers. By conducting semi-structured interviews with industry and academic practitioners, the findings are expected to resonate with readers who seek to understand key considerations that come into play beyond the promised potential within literature.

A significant limitation of this study was the difficulty in finding participants with knowledge or experience in both BC and DT applications to respond to the study's questions.

Based on the findings of this study, it is recommended that further empirical investigation be conducted to gain a holistic understanding of the capabilities and implications of adopting a BC-enabled DT approach to address the collaboration challenges inherent in the AEC-FM industry as it gears up towards embracing digital transformations.

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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