Decentralised Automated BIM Collaboration: A Blockchain and WBS integrated platform

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Abstract

Purpose – In the current era of technological advancement, the architectural, engineering, and construction (AEC) industry is undergoing a radical transformation, prompting researchers to explore new breakthroughs that can revolutionise the construction process. This paper delves into the use of cutting-edge technologies such as Building Information Management (BIM), Blockchain, and the Internet of Things (IoT), along with advanced management techniques such as work breakdown structure (WBS) and Agile thinking, to enhance the industry's efficiency, productivity, quality, and cost-effectiveness. Moreover, the pressing need for a sustainable, secure, and transparent sector amplifies the significance of the proposed research.

Design/methodology/approach – This study's research approach comprises an intensive literature review to construct a conceptual framework, followed by an exploratory questionnaire to validate the framework.

Findings – This paper demonstrates how Blockchain combined with a work breakdown structure and a BIM platform may boost collaboration to experience efficient and trusted workflow scenarios that can overcome many of the challenges given by traditional building techniques. The research findings emphasise the benefits of the proposed new mentality approach, which incorporates all the previously described tools and techniques into the business.

Practical implications – This paper highlights the advantages of leveraging a combination of Blockchain, WBS, and BIM platforms to boost collaboration and enable efficient and trustworthy workflow scenarios that can surmount the difficulties inherent in traditional AEC industry collaboration methods.

Originality/value – This study provides original insights into the challenges and opportunities of using blockchain for AEC collaboration by exploring the potential of decentralised blockchain networks to improve the security, efficiency, and transparency of collaborative data sharing and management.

Keywords decentralised networks, blockchain, AEC collaboration, WBS, IoT, Agile thinking.
1. Introduction

According to the National Audit Office's 2001 report, Modernising Construction: Report by the Comptroller and Auditor General, 70% of government construction projects were completed late (NAO, 2001). There are plenty of factors affecting the project timeline, one of these issues is lack of organisation and coordination between the project parties (poor communication, lack of information, and inefficient planning and operation) (Vidhyasri & Sivagamasundari, 2017). Moreover, the building sector is vital to the economy's running and has ecologically detrimental ramifications (Pheng & Hou, 2019). Therefore, the improvement of construction is crucial (Blanco, Mullin, Pandya, & Sridhar, 2017) since it affects not only the users of the facilities but also the economic aspects. However, data indicate that the construction business lags far behind other industries; weak performance remains due to a lack of innovation and inadequate adaptation to rapidly developing technology, negatively impacting the industry's efficiency and productivity (Mansour, Aminudin, & Mansour, 2023). Industry and the government will fully commit to developing innovative construction and digital design as part of the Digital Built Britain agenda to build the UK's competitive advantage (HM Government, 2013). In terms of the 2025 vision goals, Blockchain technology has a great potential in making the sector more efficient, transparent, and collaborative through better planning, reduced costs, more efficient operations, and more sustainable solutions (HM, 2013). The research aims to bring new collaboration methods in the BIM-based construction industry by integrating novel techniques within the AEC industry, i.e. Blockchain and WBS.

The collaboration by utilising Blockchain means immutably preserving digital data without changing to share it throughout the network and users safely. It removes a significant quantity of records, which may become problematic when several parties engage in the transaction to determine when the terms and conditions have been met (Mahmudnia, Arashpour, & Yang, 2022). The peer-to-peer database initially collects all terms and conditions agreed upon by the parties. It then uses data gleaned across distributed nodes or servers to unify data and documentation so that all parties can form business choices on a standard set of reliable data in real-time (Tao et al., 2022). It is intended to instil confidence and transparency into the project by providing a unified picture of the data in which no party may make changes without the agreement of the other participants through cloud-based high-quality communication. On the contrary, the traditional method of exchanging project data is riddled with inefficiencies because each organisation retains its own data and must connect with the other for updates and keep track (Mahmudnia, Arashpour, & Yang, 2022). Moreover, it is ideal for supplying everyone with the same outline from the outset and keeping everyone aligned throughout completion by providing everyone with a straightforward task list and making it clear how those tasks contribute to the overall picture, as well as what other people are doing to contribute to the general concept as clear roles and responsibilities, which will ensure the secure feeling by doing their tasks and enabling others to do theirs avoiding putting their own responsibilities and objectives ahead of others, by building a trusted Inclusive strategy to foster affection for and dependence on other departments, contractors, and stakeholders rather than antagonism (Shumank, Gajendran, & Jefferies, 2020).
2. Literature Review

In recent years, there has been an increasing emphasis on the necessity for the construction industry to adopt more automated and digital methodologies, particularly in the UK. The pace of technological advancements has been remarkable, with innovations such as artificial intelligence, robotics, cloud computing, and the Internet of Things reshaping both everyday life and professional practices. The Institution of Civil Engineers (ICE) highlighted this imperative with a recent publication on the potential applications of Blockchain technology in construction. This report stressed the importance of agile adaptation to swift innovation and the incorporation of modern construction techniques. Technologies like Blockchain stand to have a profound impact on the built environment in multiple ways – from revolutionising financial systems and asset management to introducing and optimising smart contracts. As a result, there's been a notable uptick in research initiatives aimed at harnessing these technological breakthroughs to address the prevailing challenges in the construction sector, indicating a move towards a more digitised and innovative approach.

2.1. Blockchain in Construction

The Blockchain will have an enormous influence on the built environment by a plethora of benefits. It will revolutionise project management. The businesses complexity in the AEC industry urges us to investigate and use this potential by identifying blockchain use cases first. Look for situations where cross-company resource mobilisation is required, where identities, agreements, and payments must be safeguarded, and where asset origin and ownership must be monitored. Some ideas: Smart contracts that describe obligations and generate milestone-based amounts might automate agreements, while blockchain-enabled tools that aggregate information to a centralised project management portal could assist manage workflow. A distributed ledger may store all building inputs and liabilities, such as insurance and maintenance inspections. Or App that track materials, testing, and findings versus rules and standards might speed up inspections (Mahmudnia, Arashpour, & Yang, 2022). Several case studies from different institutions demonstrate how to potentially utilise blockchain technology to increase efficiency and unfragmented the construction industry.

Together with BIM (building information modelling), a decentralised, tamper-proof digital ledger of transactions can create a single source of truth to all aspects of a construction project (Elghaish, Pour Rahimian, Brooks, Dawood, & Abrishami, 2023) Where digital information is to be distributed but not copied, this will create a transparent, collaborative system where all stakeholders in the construction project value chain used as the standard to increase focus on optimum efficiency and sustainability (Brandín & Abrishami, 2021). Blockchain can alter the way construction projects are managed, and our optimistic inclinations may get enthusiastic about the efficiency prospects. However, the obstacle to accepting Blockchain will be our present inter-organisational barricades, the significance of which we tend to underestimate; without this trust amongst stakeholders, the efficacy is almost wholly diluted (Brandín & Abrishami, 2024).

2.1.1. Blockchain For Collaboration

The construction process is disintegrated, and coordination between the various project recipients is recurrently misguided, leading to low efficiency, re-verifying the project aspects magnifying the tasks, and escalating costs (Loosemore, 2014). However, the many previous years of attempts to innovate in the
building business have resulted in only minor productivity increases. While the amount of collected information has expanded exceptionally throughout the project life cycle, the AEC sector barely keeps up with the boom (Brandin & Abrishami, 2024).

Effective construction management must monitor every phase of the project, from managing data circulating to guaranteeing site safety compliance and quality (Arup, 2019) and compliance with the regulation. Despite the dangers, the sector must explore adopting blockchain technology. It makes analogies to the internet's adoption and the benefits it offers, such as enhanced communications. It contends that blockchain technology would provide a trustworthy platform to improve productivity and eliminate misconduct and conflicts. Additionally, the conclusion discusses how improved contract managing, more significant supply chain integrity, and functionality across the Circular Economy, BIM, IoT, and intelligent sensors enable output gains (Tao et al., 2022) BIM and Blockchain create a trusted single source of information concerning project aspects and can employ criteria for the addition of data, which will reduce the time that is typically wasted in reviewing and confirming the required information repeatedly. BIM and Blockchain create a digital asset with the transparency of information as a single source of truth, which at the same time is secure and cannot be copied (Elghaish, Pour Rahimian, Brooks, Dawood, & Abrishami, 2023). Blockchain enables project shareholders to integrate quickly, reducing technological obstacles and speeding up crucial information transmission. In addition, transparency and security characteristics can significantly influence the confidence relationship between project stakeholders, making it a dependable match for the BIM environment (Tao et al., 2022)

As a result of Digital Built Britain's facilitation of cooperation in the construction of assets and infrastructure, new possibilities for modern innovation and new methods of utilising data to enhance access to the construction industry will be made available. As a result, digital transformation will develop over time, altering the construction industry's structure, necessitating new skills, and significantly lowering prices. In BIM Level 3, all disciplines working in one model could present a problematic issue regarding individual parties' copyrights and intellectual property. However, with a trusted and automated single source, this can ensure the copyrights, providing a permissionless and censorship-resistant approach by reducing the construction progress monitoring stage. This will give the project flexibility, efficiencies, sustainability in energy and effort, and well-designed construction sequencing (HM Government, 2015).

The notion of Open BIM is introduced in BIM Level 3. BIM Level 3 is focused on asset management over its whole existence. Open BIM is the process of collaborating fully with all partners throughout all stages of a project, from inception through deconstruction. The objective is to have a single BIM model available to everyone throughout the lifespan. The goal is to avoid abortive work due to data inaccuracy or duplication of effort. At this level, it is critical to consider all stages, such as construction, operation, maintenance, and destruction (Esser, Vilgertshofer, & Borrmann, 2021). Developing a new set of worldwide 'Open Data' norms would clear the door for seamless data exchange throughout the whole industry. Creating a new contractual structure for projects bought using BIM to maintain uniformity, eliminate ambiguity, and promote transparent collaboration. The establishment of a shared cultural environment in order to learn and exchange Coaching the public sector client in the use of BIM methodologies such as information needed, operational procedures and contractual processes Technology and construction are fuelling national and worldwide growth and employment creation (Alshorafa & Ergen, 2021).

2020 was a challenging year all around the world. COVID-19 has jolted all industries and ushered in a fundamental change in global corporate work practices. This shift, which includes a large-scale transition from office-based to remote work, has increased the interest in technology and solutions to facilitate this new way of work with much flexibility and accessibility. This highlights the importance of implementing
BIM L3 in the AEC industry to enable users to collaborate more effectively regardless of geographic location, secure information with no risk of data being unintentionally exposed or lost, indisputable proof of changes and track modification throughout the project life cycle and beyond, and more sustainable resource solutions (Wang et al., 2021).

2.2. Work breakdown structure (WBS)

It is a detailed segmentation of the project team's complete statement of work at each step of the project's life cycle in order to achieve the project's planned outputs and goals (Al-Kasasbeh, Abudayyeh, & Liu, 2021). The WBS is a ranked fragmentation of the work that the project team will complete to meet the stated goals and produce the required outcomes. The WBS is used to regulate and hierarchise the work of the entire project. Consequently, having a work breakdown structure is crucial for efficient project planning, execution, administration, monitoring, and reporting. As a logical consequence, all work in the WBS must be recognised, estimated, scheduled, and financed before commencing. The WBS is technique business owners and project managers use to simplify complex tasks. The WBS is intended to assist in the breakdown of a project into manageable portions that can be estimated and managed successfully (Siami-Irdemoosa, Dindarloo, & Sharifzadeh, 2015). This section will provide some instances of work breakdown structures and outline how WBS can aid in project planning.

To achieve collaborative planning, we must first have a thorough understanding of all project stages and each department's responsibilities, which will aid in securing necessary resources and examining all potential hazards. First, WBS illustrates the project deliverables and work required, letting the team be directed through what must be done. Second, the WBS is straightforward and concise, emphasising the project's scope and deliverables. Third, it prevents modifications by showing the project's breakdown and underlining its scope. The graphic helps team members and stakeholders understand the project scope and deliverables. Fourth, simplified resource and timeframe prediction: WBS is the basis for your project budget and timeline. Assigning resources and creating timetables will be more accessible with all the linkages between deliverables. Finally, in a WBS, all items are mutually exclusive. This exclusivity makes responsibility. A work package's team is fully responsible for its completion and success. This avoids responsibility duplication (Al-Kasasbeh, Abudayyeh, & Liu, 2021).

Therefore, the work breakdown structure can be used as a core tool to produce and organise a BIM-based 3D model in a way that organisations can efficiently use to complete a project throughout multiple stages (Gijezen, Hartmann, Veenvliet, Hendriks, & Buursema, 2010). The work breakdown structure (WBS) helps integrate asset management’s life cycle phases. The detailed WBS structure consists of eight layers: asset management system, building category, major component, system, subsystem, floor, space function, and assets. It classifies and organises building assets in one system. The BIM model connects with a WBS framework to handle BIM and asset management classification variations. The study creates a structured asset inventory hierarchy based on Work Breakdown Structure (WBS) and links BIM data to it to improve asset management through BIM-asset management interoperability (Al-Kasasbeh, Abudayyeh, & Liu, 2021).

2.2.1. Breakdown Structure Types:

It can differentiate three types relating to approaching the projects and identifying the starting point of the work breakdown structure elements (Al-Kasasbeh, Abudayyeh, & Liu, 2021).
• **Phase based:** initial level will be typical project stages. The following phase will frequently have unique deliverables in each of the highlighted steps. The bottom level of both phase-based and deliverable-based WBS are deliverables. Using a phase-based work breakdown structure, work-related with distinct elements is separated into work specific to each component in the first level.

• **Responsibility based:** The organisational units that will work on the project specify the project's aspects. Responsibility-based work breakdown structures have the same level structure as the other two work breakdown structures, with the organisation units as the first level.

• **Deliverable based:** it reveals links between deliverables and scope.

### 2.3. Agile Mindset

Agile project management is an iterative technique that allows teams to offer value to their clients more effectively, efficiently and with reduced difficulties than traditional methods. In contrast to a classic team that relies on a "big bang" launch, an agile team produces work in small yet digestible chunks. In addition, because requirements, plans, and outcomes are assessed continually, teams are equipped with a built-in flexible mechanism for adaptive fast to variation (Malakar, 2021). Because the correct perspective may make a significant difference in how efficiently a team implements the practice, this mindset helps members exchange knowledge to make crucial project choices collaboratively, rather than having a boss who makes all those decisions exclusively. An Agile mentality entails including the entire team in planning, design, and process improvement. An agile team practises in such a manner that everyone in the team has access to the same information and has a say in how the tactics are used (Stellman & Greene, 2014).

The reality of agile for many teams who have not had as much accomplishment is quite distinct from its promise, and the key to that gap is frequently the mentality that each player offers to each project. The majority of firms who have tried with agile have seen some improvement in how they conduct their projects, making the effort to embrace agile worthwhile. Still, they haven't experienced the significant improvements that they believe agile guarantees. This is what the mentality shift is all about, adopting an agile mindset entail assisting the team in developing a practical attitude (Malakar, 2021). Agile allows teams to adjust fast to market developments or consumer input without compromising a year's worth of planning. With "just enough" preparation infrequent delivery, the team can quickly obtain feedback and incorporate it into future plans. Authentic human connections trump strict protocols, according to the Agile Manifesto. Collaboration with consumers and teams trumps predetermined goals. The customer's problem is more essential than hyper-detailed documentation. An agile team gathers around a shared vision and executes it as they see fit. Team criteria for integrity, efficiency and achievement vary from team to team. Their "definition of completion" determines their output speed. Putting faith in an agile team might be intimidating at first, but the team feels more accountable and strives to meet (or surpass) management's objectives (Stellman & Greene, 2014).

### 2.4. Agile Work Breakdown Structure (AWBS)

The WBS views the project as a succession of perfectly detailed technical tasks. On the other hand, Agile views the project as a succession of deliverables increments (Stellman & Greene, 2014). The PMBOK® Guide (2021), work breakdown structure building, and scope verification repeatedly occur in agile. A project's WBS is usually divided into phases: design, coding, testing, and expansion. Each stage is then
divided into a work package comprising related tasks. Typical project planning starts at the top and uses critical path analysis to drive the project timeline. It goes into great detail on WBS scope decomposition and warns that excessive decomposition can lead to inefficient management, resource use, and labour productivity (PMBOK® Guide, 2021). In Agile, features are defined high in the product backlog and then broken down into iterations during release preparation. Consider iteration, or even feature, as the agile work package’s equivalent. The product backlog estimates qualities at a high level; no tasks or resources are defined. The current iteration’s feature becomes a job for a future development strategy. Consider it just-in-time elaboration, eliminating unnecessary demand inventory building (PMBOK® Guide, 2021).

The tasks in the backlog in the Agile approach can be planned by using the WBS technique to split them down before shifting them to the next sprint (Dash, 2020). Furthermore, employ a WBS not just at the start of a project but also at the beginning of each sprint within the project. However, a task is a task regardless of whether it is completed in conventional or Agile projects (Sliger & Broderick, 2008). As a result, the simpler and more specific a task, the easier it is to predict the time required to accomplish it and delegate minor tasks to the appropriate resource. This mixed project approach provides the benefits of Agile project management, such as rapid delivery, with the precise planning and clarity on goals provided by WBS (Malakar, 2021).

2.5. Common Data Environment (CDE)

A CDE is a cloud-based platform that stores and makes data on construction projects available to project stakeholders. This availability is contingent upon the needs or permission level of users and their legal duties, this creates enticing new opportunities for BIM to centralise the management of projects and assets (Bucher & Hall, 2020). True CDE is founded on two core elements:

**Neutrality:** all project data is stored on a sole platform, but the participants only have access to the information they are permitted to see. Through safe, isolated workplaces, each company maintains control over their data and what to share. It facilitates the development of trust across project stakeholders. This results in increased engagement, which generates additional information and analytics. Additionally, it establishes an immutable electronic record, assisting in preventing conflicts and expediting their settlement when they do occur (Bucher & Hall, 2020).

**Security:** to guarantee that all stakeholders have confidence in their data security, it must be hosted in a guarded CDE. Furthermore, users should have protected access to the project using two-step verification and interaction with SSO providers via security assertion mark-up language (SAML). Finally, building project information is archived and made accessible to project participants based on their requirements and degree of authorisation (Bucher & Hall, 2020).

2.6. Integrated Project Delivery (IPD)

It is a collaborative alliance contract of stakeholder. The risk and reward are shared, and collective insurance responsibility for the project’s successful delivery to each party of the project (AIA, 2007).

The IPD approach has the advantage of removing obstacles to cooperation and creativity by combining rewards for the entire project team rather than making each participant pursue its own benefits from the project (Elghaish, Abrishami, & Hosseini, 2020). The collective performance is determined by the aggregate outcome rather than individual achievements or failures. By freely sharing project objectives,
challenges, and benefits, the main parties will provide a more reliable exchange of information, resulting in experience and technology sharing (Elghaish, Abrishami, & Hosseini, 2020).

3. Research Methodology

This study aims to lay a theoretical groundwork for an Automated BIM collaboration system, integrating blockchain technology with a work breakdown structure to address identified research problems and objectives. This methodology section not only outlines our approach to collecting and analysing data but also emphasizes the importance of ensuring the validity of our conclusions, as highlighted by Edmonds & Kennedy (2016). We employed a mixed-method strategy, gathering both primary and secondary data, and leveraging qualitative and quantitative insights to overcome the limitations inherent in each type. Qualitative analysis offers in-depth understanding but can be biased, whereas quantitative methods, although broader, might lack depth. The fusion of these approaches allows for a comprehensive validation of findings, with the qualitative insights being corroborated by quantitative data (Edmonds & Kennedy, 2016). Furthermore, our research methodology incorporates both positivist and post-positivist techniques to construct the framework, ensuring its robustness. This dual approach not only aids in confirming our interpretations through quantitative evidence but also in identifying and rectifying any potential oversights or misinterpretations in the framework's development, thereby enhancing its legitimacy and applicability.

3.1. Research Strategy

According to Naoum (2019), a research strategy is a tool for analysing and challenging the study objectives. As a result, a research plan for this study was devised to guarantee that the data collection and analysis procedures were adequate for attaining each of the study objectives. The best-suited approach for this inquiry is judged to be exploratory hybrid quantitative/qualitative research. This research approach has been demonstrated to be the most effective for developing innovative thoughts and analysing existing theories to identify broad patterns and forecasts for additional investigation.

Additionally, this technique takes a combined methods approach, collecting data from both primary and secondary sources. Firstly, secondary data was gathered to find and blast cutting-edge innovations in the architectural and engineering sectors, where the literature review collected this secondary data. Following that, a basic conceptual framework was constructed using the compiled data. Finally, an exploratory questionnaire was constructed to define and validate the framework. The key data gathered through the questionnaire were used to assess the framework's performance and identify its strengths and weaknesses. The decision to use a questionnaire to assess the conceptual framework was based on the belief that this method is a validated methodology that enables practical data collection by delving deeply into the various hypotheses in a real-life experience. This study's research strategy is depicted in the figure 1. Analysing each objective helps decide the best way to gather and analyse data. In addition, the expected outcome and intent of each aim are described.
3.2. Research methods

This study’s methodology is utilising a sequential mixed method approach that includes extensive literature review (ELR) and survey by questionnaire. ELR is a type of research that employs qualitative analysis to acquire insight into a subject by establishing what is previously known about it. Substantiate the notion that prior research can shed light on the linkages between various investigations and indicate forthcoming challenges that may be useful for the present inquiry. A preliminary conceptual framework was developed concurrently with the literature review. Following that, once the data had been re-evaluated and merged, a comprehensive framework was nearing validation.

Using their own primary data, the researcher can conduct a pragmatic analysis of the assumptions and assertions of knowledge claims identified in the study (Edmonds & Kennedy, 2016). To obtain valid and relevant questionnaire responses, preferably to target members of a specific demographic. (Edmonds & Kennedy, 2016) specifies four essential requirements for influential sampling: the development of a reason for the sample, the selection of a sample big enough to be statistically significant, the selection of a representative sample, and the recognition of the sample’s flaws. A questionnaire was distributed to construction industry experts who are knowledgeable about BIM and Blockchain. Participants were selected and suggested based on their knowledge of the study’s subject matter (Daniel, 2011). Snowball sampling, which is the procedure can be utilised to make statistical inferences about a specific topic by exploiting the relationships present in the finite population, is a systematic approach that will result in the efficient gathering of data to raise response rates, and they will be requested to share it with their network of other professionals to assist boost response rates (Noy, 2008).
According to the literature review, professionals are now less likely to use BIM due to its complexity and a lack of technology investment and other resources. As a result, a questionnaire distributed to a group of construction researchers, focusing on those with Blockchain and BIM skills or comprehension. As a result, educational and research institutions are critical to the advancement of BIM, particularly in the context of Blockchain within our industry, where most notions are still regarded as theories and research at the time of their foundation. As a result, with practitioners more aware of the practical challenges associated with BIM adoption and researchers more aware of the theoretical and technological components, this mixed sample should provide a solid overall understanding of the concerns and potential solutions associated with BIM development.

The snowball sampling technique was chosen as the optimum way to target the experienced population due to the rarity of the study subject. The questionnaire was distributed to a small group of Blockchain and BIM experts who were members of social groups interested in blockchain technology through online platforms such as LinkedIn using specific hashtags such as BIM, Blockchain, innovation, and technology, which aid in reaching out to blockchain experts within the AEC industry. Due it is more challenging to obtain factually correct samples from the online environment than from the physical one-on-one world, the researcher is aware that the answers they receive may not represent the entire community (Noy, 2008). However, given the limited number of experts available to the researcher and the uncertainty
surrounding the desire of participants to engage, the goal of 30 replies appears to be significantly achievable.

4. Findings and analysis of results

Over a span of one-year, secondary qualitative data was gathered from ELR, forming the bedrock for the initial conceptual framework's development. This secondary data underwent rigorous analysis using the NVivo document management software. The software not only facilitated a precise examination but also streamlined the process of identifying relationships and delving deep into the distinctive attributes of each research domain. A segment of the emerging framework was then validated through responses from questionnaires, furnishing the research with vital primary data. The subsequent section will delve into the details of the initial conceptual framework and the associated case study.

4.1. Conceptual BWBs Framework

The primary conceptual framework incorporates characteristics of the several methodologies tested in this research, including Agila thinking, WBS, Blockchain, and BIM as the targeted platform. The framework is presented in a diagram (See Figure 3). The assumptions made by the researcher are documented and organised in this section. To ensure that they are used effectively and in the most beneficial way possible, some features of these techniques are being incorporated at various framework phases. As illustrated in figure 3, there are two separate pillars that make up the initial conceptual framework, highlighting how important it is to begin planning early and to use procedures that distinguish the novel type of collaboration as early as possible and continue until the asset management phase. In addition, it illustrated the importance of a round cycle of revisions and shared information. Every step of each level of the framework will be presented in detail, emphasising the most critical features of each stage. Even though every job and activity involve some degree of interdependence with the others, each step ensures that the purpose of the previous step is met.
To illustrate, consider the activities of the project which have been meticulously detailed, as showcased in Figure 4. Imagine a scenario in which the Architect decides to alter the location of the building entrance (denoted as activity tag A.3). This alteration would instantly prompt notifications for relevant stakeholders – including the structural, MEP, landscape, ID teams, and the contractor. At this juncture, two potential pathways emerge:

Consensus-Based Modification: Initially, for the change to be documented and archived on the blockchain, all stakeholders must concur. An enabled distributed ledger involving all relevant members will then authenticate these new details, and as it’s already recorded on the blockchain, a new, immutable block (activity tag A.3’) will be created. Subsequent related activities will be automatically updated, taking on new tags like A.5’ and A.X’.

Disputed Changes: Conversely, should any members object to these modifications without providing authorisation, the changes would be declined. This would signal the responsible party to conceive a more agreeable solution, potentially proposing an alternative activity tagged as A.3”.

This modus operandi aligns with the Agile methodology. Here, activities undergo iterative adjustments, updates, verifications, and authorisations in a responsive manner. It’s incremental in nature, with the activity evolving gradually in stages to accommodate changes and unexpected outcomes.
4.2. **Framework Validation**

The questionnaire was designed to take no more than 10-15 minutes to complete. It was divided into four sections with twenty multiple-choice questions and three qualitative questions. The questionnaire was created in two parts. First, a questionnaire pilot was produced and distributed to people knowledgeable about the subject. Following the feedback, the final questionnaire was developed and structured into sections. To confirm that the questionnaire responses were trustworthy and consistent, an internal consistency reliability test was performed utilising two of the questions in a slightly modified format, using the Internal Consistency Reliability technique (Noy, 2008). One question questioned if they were familiar with the targeted phrases (BIM, WBS, and Blockchain). While 90% of respondents said they were familiar with BIM, only 39% said they were familiar with Blockchain. The other question asked respondents to rate their level of expertise and usage of the targeted terms (BIM, WBS, and Blockchain), and 55% scored a level of experience of 60% or higher with BIM, 5% were experts with Blockchain, and 52% had no experience with blockchain technology and how we can integrate it into the AEC industry. With the reasoning being that those who had been involved in BIM projects would be at the top and those with no experience would be at the bottom, and because Blockchain is still a new concept to our industry, it was
expected that expert participants in the subject would be minimal, with a minor of an average level of understanding.

![Participant Role in the AEC industry](image)

**Figure 5 Participant Role Chart**

Source: made by authors

Within the AEC industry, the participants' response rates varied. The design team had the highest response at 58%, followed by the management team at 13%. Other participants, including developers, clients, engineers, contractors, and specialist consultants, had response rates ranging between 10% and 3%. (Refer to Figure 5).

![Analysing the intersection of roles with Blockchain expert](image)

**Figure 6 Analysing the intersection of roles with Blockchain expert**

Source: made by authors
As depicted in Figure 6, the majority of participants lack blockchain experience, with only 29% possessing knowledge in this domain. This expertise is unevenly distributed among industry roles. The Construction team boasts the highest familiarity, which then progressively diminishes across the Design team, Management, Engineers, and Specialist consultants. Notably, only 16% of respondents demonstrated expertise in both blockchain and BIM, lending credibility to the framework. Given this narrow expertise base, the researcher can reasonably infer that the responses to subsequent questions were genuine and consistent. The findings from the questionnaire are detailed in the subsequent sections.

### 4.2.1. Explore the state of the collaboration techniques in the AEC industry.

From Figure 7, we can establish that majority agreed that the significant barrier to getting a collaborative project ecosystem is the lack of shared information simultaneously when it is beneficial and vital to the project workflow. Next, the lack of one source of information and an Isolated working mindset as individuals are also significant impediments. Moreover, as a whole practice, the AEC industry is still rigid and far behind in keeping up with rising technology. Furthermore, the main barriers are lack of time, meaningful communication, and Technological difficulties by around 50% of respondents. Secondly, lack of guidelines and standards received the most votes as a minor barrier. Finally, lack of trust in data security oscillates between minor obstacles; therefore, we are ready to share with transparency and secure data as professional individuals. Consequently, the critical challenge to address is shared information in dynamic communication in order to collaborate effectively.

![Figure 7 Collaboration barriers chart](source: made by authors)
The previous investigation shows that the individuals are willing to share information and engage in openwork enlivenment environment. However, Figure 8 shows that the multidisciplinary corporate techniques are not equipped to handle the challenges of an AEC future design project. Nevertheless, it stands on a moderate level of preparation to deal with current obstacles and complexity.

4.2.2. BIM's Core Capability: Essential Collaboration

The preponderance agreed that collaboration is the essential core of BIM practice. In fact, by integrating intelligence and efficiency into project execution and connecting teams and processes at every step of the project, BIM is altering the way projects are delivered across sectors. Furthermore, this promotes cooperation and coordination, which are essential components for igniting meaningful and comprehensive collaboration among project participants and stakeholders. Refer to Figure 9.
Figure 10 shows the importance of collaboration is growing exponentially with the future innovative projects that need complex coordination and enhanced tracking. Collaboration is a strategy that the construction industry has historically failed to embrace, but one that has been repeatedly proved to be hugely advantageous to the business (Tao et al., 2022).

4.2.3. Blockchain's Impact Across Industries: A Reliable Truth Source for AEC

The literature highlights Blockchain as a transformative technology across industries, with numerous potential applications in the BIM environment to boost efficiency and cohesion in the construction sector, such as in the digital economy, procurement, and smart management. The questionnaire posed four questions to gauge Blockchain's utility in modernising the AEC industry: Does it enhance collaboration? Can it securely record and distribute changes? Will it establish a single source of truth? Does it ensure transparent project management?

Out of the participants, only 29% had Blockchain expertise. Delving deeper, 9 out of 31 participants were experts, with 60% being moderately knowledgeable and 80% being proficient. No participant was fully versed, reflecting the nascent nature of Blockchain in the AEC sector. The results revealed: 90% of experts believed Blockchain would improve collaboration (Figure 11). A majority agreed that Blockchain would securely manage data updates (Figure 12). 44% felt strongly that Blockchain could create a single source of truth for the BIM environment (Figure 13). There was general consensus on Blockchain ensuring tight-knit and transparent project management, as depicted in Figure 14.
4.2.4. WBS Capabilities Across Industries: Enhancing AEC Project Efficiency

Taking into consideration just 42% of the participants has Work Breakdown Structure WBS expertise, which only 13 participants out of 31 were experts which divided between 4 participants are component knowledge around 60%, and 9 participants are proficient around 80%, none of the participants is 100% expert due to various roles within the AEC industry, where this knowledge is not required for all positions. Firstly, 85% of the WBS expert has found that WBS would track all project stages and activities, where 46% has strongly agreed, and the other 38% has agreed (See Figure 15). Secondly, WBS will surely track all updates and changes to the project plan and lifespan. Referring to Figure 16, only one proficient expert has strongly agreed, and over 8 competent experts has settled this idea.
Fourthly, as Figure 17 illustrates, 44% strongly agreed that Blockchain would help the BIM environment create one source of truth, where around 33% agreed, and Hardly 22% were neutral about this idea. Finally, 22% of the proficient expert strongly agreed that WBS would help to identify the impact of each change, other 44% agreed, 22% were natural and 11% disagree. None of competent experts strongly agreed, however, roughly 50% agreed, 25% were natural, and 25% disagree. Check Figure 18.

**Figure 17** WBS identify changes impact
*Source: made by authors*

**Figure 18** WBS enhance management
*Source: made by authors*

### 4.2.5. Integrating Blockchain & WBS for AEC Collaboration

Despite the fact that the framework is founded on three pillars of knowledge: blockchain, work breakdown structure, and building information modelling (BIM), only the Blockchain expertise level will consider it, where it is the crucial component in determining the framework’s value. Considering just 29% of the participants has blockchain expertise, which only 9 participants out of 31 were experts which divided between 4 participants are component knowledge around 60%, and 5 participants are proficient around 80%, none of the participants is 100% expert due to the Blockchain subject in AEC industry still a novice.

**Figure 19** Importance of follow up
*Source: made by authors*

**Figure 20** Blockchain support WBS
*Source: made by authors*

Firstly, 66% of the Blockchain expert has strongly agreed about the necessity to track and follow up the project updates, where the other 33% where equally divided between agree, disagree, and
strongly disagree (See Figure 19). Secondly, Blockchain would certainly fortify the planned WBS. Referring to Figure 20, just 11% has strongly agreed, and 44% expert has settled this idea, and 44% were unbiased to this concept.

![Blockchain will help prevent the clashes](image1)

![Blockchain for automated collaboration](image2)

Thirdly, as Figure 21 illustrates, nearly 22% strongly agreed that Blockchain would help to prevent clashes within the BIM environment, same as 22% agreed, on the other hand, 44% were neutral about it, and 11% disagree, this issue in particular requires further examination and clarification to demonstrate how it will benefit the workflow by preventing clashes and improving coordination, which may include conducting interviews or doing case studies. Finally, 40% of the proficient expert strongly agreed that Blockchain would be the cornerstone to automated collaboration, and the other 60% agreed. 50% of competent experts strongly agreed, an additional 50% agreed. Check Figure 22.

4.2.6. validation of the developed Framework.

All the questions of the fourth section of the questionnaire were designed to help validate the framework. However, question number 23 will provide a direct point of view regarding the benefit of Blockchain & Smart technology to the AEC industry. Evidently, the responses were mainly in favour of this allegation that Blockchain will execute the project in an exemplary manner with the help of other innovative technologies: such as smart contracts. As Figure 23 shows, most of the responses were positive. Reciprocally, on previous questions, the respondents slanted in favour of agreeing on the potential benefit of implementing Blockchain in BIM to evolve the industry. Identically, Participants with less expertise yet familiarity with the topic tilted the odds in favour of blockchain that could promote the BIM environment in the AEC industry with the help of intelligent technologies.
4.2.7. Development of the enhanced Framework.

Although the framework is built on three pillars of knowledge: blockchain, work breakdown structure, and building information modelling (BIM), the questionnaire includes questions regarding BIM level 3, which is an essential factor to the framework's success. Considering just 49% of the participants has BIM L3 expertise, which about 15 participants out of 31 were experts which divided between 7 participants are component knowledge around 60% , 6 participants are proficient around 80% , and 2 participants are proficient around 100% . Refer to Figure 24. These Figures were unexpected and highly positive, indicating that the industry has already laid the groundwork for integrating BIM level 3. By comparison, the literature analysis was sparing with resources, focusing exclusively on the Digital Built Britain (DBB) Level 3 Building Information Modelling - Strategic Plan. In addition, there was a lack of data on whether the industry has endorsed BIM L3 to go forward with implementation plans and adopt it.
As Figure 25 is illustrating the majority approving that BIM Level 3 "L3" adoption will be influential in the AEC industry, throughout the BIM lifecycle from inception through to facilities management and then refurbishment. Secondly, 40% of the L3 expert with different levels of knowledge has strongly agreed that BIM L3 would provide a rooted platform for enhancing collaboration. at the same time, the other 60% were approved of the concept, plus the participant with less expertise has shared the same views. (See Figure 26).

This qualitative question will concentrate on the areas in which BIM L3 will be the most efficient and bring the greatest value. As illustrated in Figure 27, the most essential elements for implementing BIM L3 are a sustainable effort that avoids duplication or wastage. Additionally, flexibility, where BIM L3 expands flexibility by providing a single online source of information that can be accessed at any time, from any device, resulting in increased efficiency and more sustainable energy, as well as a reduction in project complexity.

![Figure 25 BIM L3 influence the AEC industry](source)

![Figure 26 BIM L3 enhance the collaboration](source)

![Figure 27 BIM L3 impacts](source)
4.3. Enhanced BWBs Framework

Following the completion of the findings and validation of the framework, the participant shed light on the significance of BIM level 3 and its opportunities to the industry in terms of increasing flexibility efficiency, conserving energy and effort, and overcoming future complexity.

As a result, the framework was improved to stress the need for BIM level 3 in order to accomplish automated collaboration. Additionally, the concept of BWBs cannot be achieved without implementing the forthcoming BIM maturity level; hence, blockchain technology requires a cloud-based platform; conversely, BIM level 3 requires a safe, robust online technology such as the Blockchain to secure the project data and exchanges. Refer to Figure 28.

The BIM L3 is anchored on the Common Data Environment (CDE), the project team's core repository of data used to gather, organise and redistribute documentation, graphical models, and other non-graphical data in IFC format. A centralised archive of information improves interaction across members of the project team and aids in the elimination of repetition of effort and data inaccuracies.
4.4. conclusion

The central impetus behind the questionnaire was to measure the depth of the construction sector’s engagement with Blockchain technology and to understand its perceived advantages. With the rapid progression of technology, there is an increasing need for industries, including construction, to adopt digital solutions that enhance efficiency, collaboration, and offer strategic advantages. By distributing the questionnaire to experienced professionals within the sector, we hoped to gather nuanced views on the potential for decentralised data exchanges and the collaborative merits of BIM technology. The results from the questionnaire illuminated several intriguing dimensions of how digital data integration can serve as a catalyst. This not only facilitates smoother operations but also nudges the entire construction sector closer to a more holistic digital integration. The consolidated insights derived from the survey data underscored several pivotal findings and recommendations:

- **Collaboration**: The success of Building Information Modelling (BIM) is intertwined with robust collaboration, indicating that it’s at the heart of operational success.

- **Enhanced coordination**: The results underscored an evident and urgent need to amplify collaboration efforts and coordination mechanisms.

- **Work Breakdown Structure (WBS)**: The significance of a WBS in project execution was emphasised, spotlighting its role in ensuring streamlined operations.

- **Blockchain’s Role**: The potential of Blockchain in catalysing transparent collaboration emerged as a notable insight.

- **BIM Maturity**: Progressing to the next stage of BIM maturity was not only viewed as a natural evolution but was also resonated with positively by respondents.

Revisiting the core objectives of the questionnaire, the data reaffirmed the underpinnings of the proposed conceptual framework. Clear issues related to collaboration were identified, with a resolution leaning towards an integrated approach combining Blockchain and WBS. The BWBs framework, as interpreted from the responses, is anchored by three critical components: Blockchain, WBS, and BIM. However, a caveat was the emphasis on BIM maturity. The full potential of the BWBs framework is best harnessed at BIM L3, which becomes a critical benchmark for ensuring the success of the BWBs integration.

In conclusion, the contributions of this study extend beyond the immediate findings. They highlight the transformative potential of integrating Blockchain, WBS, and BIM within the AEC sector. By paving the way for a new paradigm of collaboration, our research not only addresses the immediate challenges of contemporary construction processes but also lays the groundwork for future innovations. It is a clarion call to industry stakeholders to embrace and adapt to these integrative technologies, fostering a construction sector that is not only more efficient and transparent but also prepared to meet the challenges and opportunities of the digital future.
5. References


