LEVERAGING SMART CONTRACTS IN BUILDING INFORMATION MODELING (BIM) FOR UNIFIED PROJECT EXECUTION: A THEORITICAL FRAMEWORK.

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ABSTRACT: *Over time, several procurement methods have been adopted to facilitate the successful delivery of construction projects with minimal financial losses in order to offer maximum value to clients. In recent years, the Integrated Project Delivery (IPD) procurement model has been introduced for better overall financial performance. In this model, every member of the project team has a stake in overall profit or risk irrespective of the extent of their roles and change orders and correction of errors and omissions are managed effectively with minimal contractual disruptions. This paper aims to address some of the previously cited barriers in earlier scholarly work, and it proposes a conceptual framework that integrates two novel concepts towards tackling technological and financial barriers in adopting IPD namely, BIM and Smart Contracts (SC). A framework is developed for a BIM-blockchain-IPD whereby the BIM model is integrated with blockchain technology, thereby acting as an immutable and transparent information repository and a platform for interdisciplinary collaboration in Architecture, Engineering and Construction (AEC) projects. The smart contract feature of blockchain technology offers an automated equitable distribution of risk and reward amongst project stakeholders based on agreements at project inception. Thus, the research contributes to a more efficient project delivery method by avoiding information asymmetry amongst stakeholders through a tamper-proof, BIM-enabled Common Data Environment (CDE). The proposed framework is validated with qualitative analysis of information obtained based on AEC industry procurement workflows.*

KEYWORDS: *Integrated Project Delivery, Smart Contract, Blockchain, BIM, AEC, Common Data Environment.*

1. INTRODUCTION

The American Institute of Architecture defined Integrated Project Delivery (IPD) as “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction” (AIA California Council, 2007).

Integrated Project Delivery can be broadly categorized as a type of relational project delivery arrangement (RPDA), developed to generate a cooperative and trustful climate for project implementation that requires an honest and open communication for establishment of a trustful relationship (Lahdenpera, 2012). One key element in this form of procurement process is an early integration of the project team at inception. The early integration of different project participants has a main influence on the optimization of the design and therefore also on the construction as processes become more consistent with less rework (Heidemann & Gehbauer, 2010).

This paper conceptualizes a scenario where blockchain technology, through smart contracts can be integrated with BIM to facilitate integrated project delivery, towards an improved procurement process. It begins with a terse review of relevant literature under a few thematic headings. Then, diagrammatic workflows are used to illustrate a theoretical framework and the interconnected networking of project stakeholders. After which, a use case scenario of a procurement workflow using smart-contract enabled BIM for IPD is used to describe the framework.

2. LITERATURE REVIEW

Project delivery methods continuously evolve to address the specific needs and concerns at the times and each method has implications on the cost, schedule and quality performance, albeit how much performance is typically affected is still unclear. (Sullivan, Asmar, Chalhoub, & Obeid, 2017). Various project delivery types have been used in the AEC industry globally such as Design Bid Build (DBB), Design-Build, Design Build Operate and 4) Construction Manager at Risk (Roy, Malsane, & Samanta, 2018). Lahdenpera (2012) highlighted six (6) key features of RPDA or a cooperative delivery approach namely; a cooperative culture, team formation, administrative consistency, commercial unity, planning emphasis and operational procedures (Lahdenpera, 2012). In collaborative projects, stakeholders must have a high level if shared understanding with respect to cooperation, control and coordination to achieve mutually desired outcomes. (Ali & Haapasalo, 2023). However, the complexity

Referee List (DOI: 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Oluwatoyin Lawal, Nawari Nawari, *Leveraging Smart Contracts in Building Information Modeling (BIM) for Unified Project Execution: A Theoretical Framework.,* pp. 352-359, © 2023 Author(s), CC BY NC 4.0, DOI 10.36253/979-12-215-0289-3.34

of construction and the multiplicity of stakeholders and their interests raises the probability for disputes and conflicts. Alaloul et al (2019) described construction as a fertile seedbed for disputes. (Alaloul, Hasaniyah, & Tayeh, 2019). Kumar et al (2020) highlighted 14 factors which lead to dispute in construction in order of hierarchy, stating that ambiguous language of contract was the most influential factor, which may also lead to opportunistic behavior, delayed response to decisions and unrealistic expectations, which may in turn lead to poor communication between project partners, culminating together with other factors to cause payment delays and eventually project cost overrun (Kumar Viswanathan, Panwar, Kar, Lavingiya, & Jha, 2020).

2.1 Challenges and Limitations of Integrated Project Delivery

Construction supply chains have remained contested, fragmented and highly adversarial because of the conflicting nature of demand and supply (Cox & Ireland, 2002). Kahvandi et al (2019) highlighted for limitation categories for the use of IPD on projects namely; contractual, environmental, managerial, and technical ones and resolving contractual challenges is very effective in resolving environmental, managerial, and technical challenges. (Kahvandi, Saghatforoush, ZareRavasan, & Preece, 2019). In less developed construction sectors like Nigeria, practitioners are aware of IPD but not as proactive towards its application, of which technological, legal, financial and cultural issues are hindering its widespread adoption (Ebekozien, Aigbavboa, Aigbedion, Ogbaini, & Aginah, 2023). Similarly, lack of interest amongst stakeholders involved in the construction supply chain and negative perceptions about the efforts, risk and expenses required in implementing IPD are observed limitations to its use (Durdyev, Hosseini, Martek, Ismail, & Arashpour, 2020).

2.2 Smart Contract Solutions for Construction

Smart contracts (SC) are contract clauses written in computer programs that will automatically self-execute when predefined conditions are met. They consist of transactions essentially stored, replicated and updated in distributed blockchains (Zheng, et al., 2020). The construction industry worldwide is known for its adversarial working relationships which exist between the stakeholders (Phua & Rowlinson, 2003). Young-Ybarra & Weirsema (1999) found trust to be the only component of social exchange theory that had a positive effect on flexibility of strategies (Young-Ybarra & Wiersema, 1999) Pishdad-Bozorgi (2017) explored trust dynamics on real world IPD projects and both case studies used in the research confirmed that IPD was more effective in building trust than traditional delivery method (Pishdad-Bozorgi, 2017).

2.3 Blockchain and BIM in Construction

The AECO industry began to actively deploy BIM on projects in the early and mid-2000s (Jung & Lee, 2016). In a scientometric review, Liu et al (2019) mentioned that research in the field of BIM has been developing continuously and has completely subverted the traditional operation mode of AEC industry, while attracting more researchers' attention at the same time (Liu, Lu, & Peh, 2019). Lawal & Nawari (2022) proposed a BIM-blockchain unified ledger to provide traceability for building components for a more auditable real estate valuation. (Lawal & Nawari, 2022). One of the most commonly researched blockchain applications in AEC is its integration with BIM for improved workflows and processes amongst construction stakeholders, thereby fostering improved collaboration. (Nawari & Ravindran, 2019) (Zhang, Doan, & Kang, 2023). BIM adds one or more additional dimensions to traditional design approaches which is the information layer that describes physical properties of building components. Innovations to the blockchain-BIM integration has made it possible for a shared platform like BIM to provide security of sensitive data either through a confidentiality minded framework (Tao, et al., 2022) or by using lightweight blockchain-as-a-service prototypes in the case of emergency construction projects (Tao, et al., 2023). Applications of blockchain-BIM are prevalent in pre-construction stage for secure and traceable control of design documentation, however, as the maturity level of both technologies increase, this integration will cut across project lifecycles.

3. THEORETICAL FRAMEWORK

The use of Building Information Models (BIM) for generation of information has become widespread in the Architectural, Engineering and Construction (AEC) industry in the past decade. BIM also refers to the virtual process and workflow that encapsulates all aspects, disciplines and systems of a facility or asset within a unified virtual model to facilitate a more accurate and efficient real-time collaboration (Azhar, Khalfan, & Maqsood, 2012). BIM is a revolutionary technological development that is rapidly reshaping the AEC industry and transforming the way we build, and the AEC industry have pushed stakeholders to use BIM extensively in a streamlined and integrated manner over the building lifecycle (Liu, Lu, & Peh, 2019). BIM helps to discover collisions which

usually occur during construction in a high number and therefore, the team is able to resolve those already during the design phase. A huge amount of time, rework and redesign can be eliminated (Heidemann & Gehbauer, 2010).

The image in figure 1 shows an interconnected loop between all project stakeholders and between stakeholders and the BIM model, which is housed in a cloud-based Common Data Environment. Earlier studies have proposed a Common Data Environment (CDE) for secure data storage of digital assets, interdisciplinary coordination, management, and versioning of information containers (Sreckovic, et al., 2021) (Wang, Wu, Wang, & Shou, 2017) (Pishdad-Bozorgi, Yoon, & Dass, 2020). Figure 1 below is a diagram of interrelationship between all project stakeholders. A cloud-hosted blockchain CDE which is the agreed information repository that records all additions and alterations to the contained information, is used to house a shared BIM model. Blockchain provides a decentralized, automated and secured financial platform which enables multiple parties to control and track financial transactions (Elghaish, Abrishami, & Hosseini, Integrated project delivery with blockchain: An automated financial system, 2020).

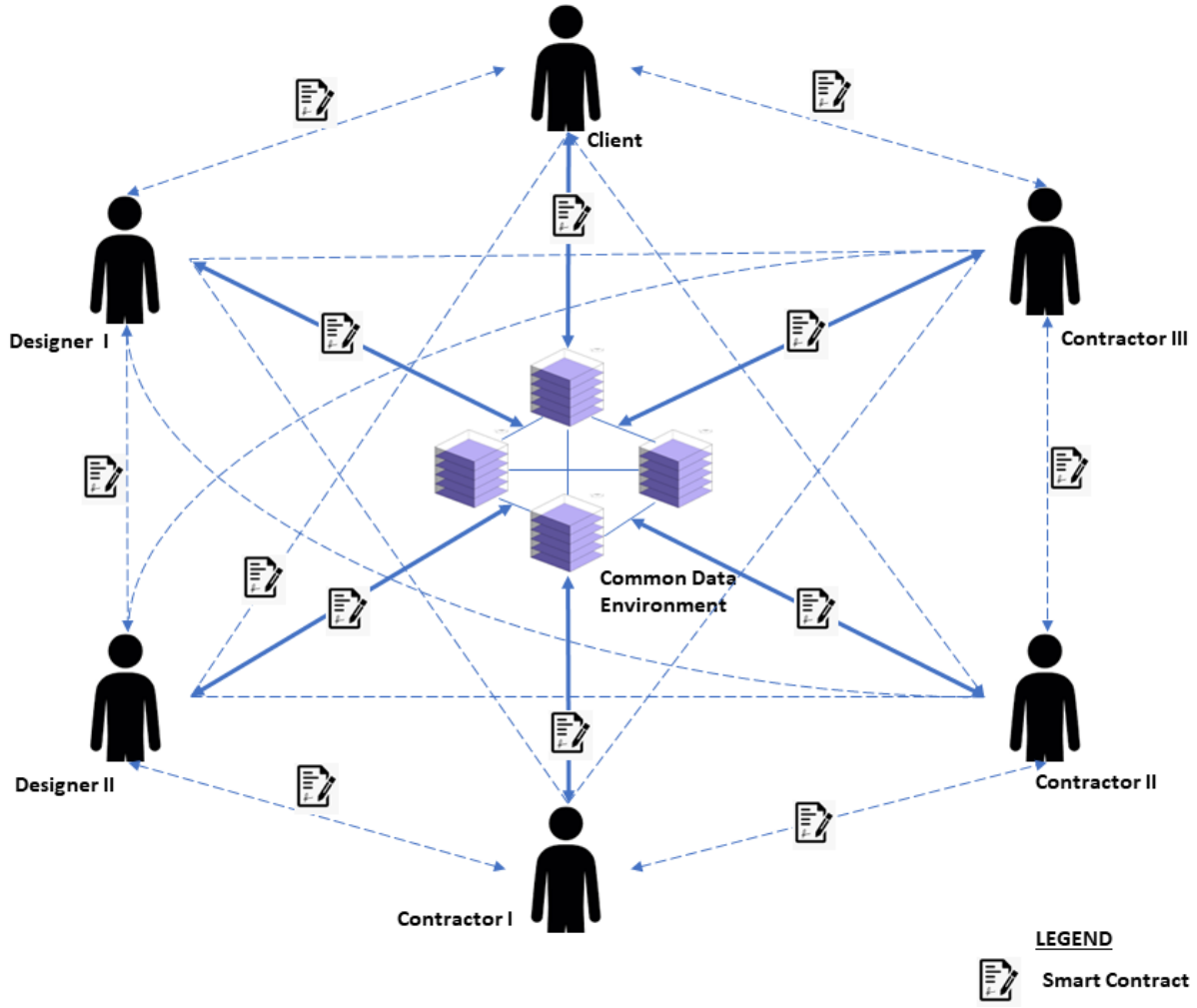

Figure 1: Network of project team and BIM model, with smart contracts managing the interrelationships

The CDE connects to a front-end interface wherein all participants are visibly interconnected and smarts contracts embedded between every interconnection act as triggers to automate and record the transition to a new phase of engagement once certain conditions / project milestones are reached, as confirmed by the BIM and a physical model twin contained in the CDE. The physical twin is derived through the use of IoT and BIM. The emergence of IoT has transformed the way data is shared across various sources (Barricelli, Casiraghi, & Fogli, 2019). Digital Twins refer to the process of merging the virtual world and real world, and has become a widely accepted tool in the Architecture, Engineering, and Construction (AEC) industry due to its ability to enhance cross-disciplinary collaboration (Sahal, Alsamhi, Brown, O'Shea, & Alouffi, 2022). The linear flow of information and smart contract deployment referred to in Figure 1 is shown below in Figure 2.

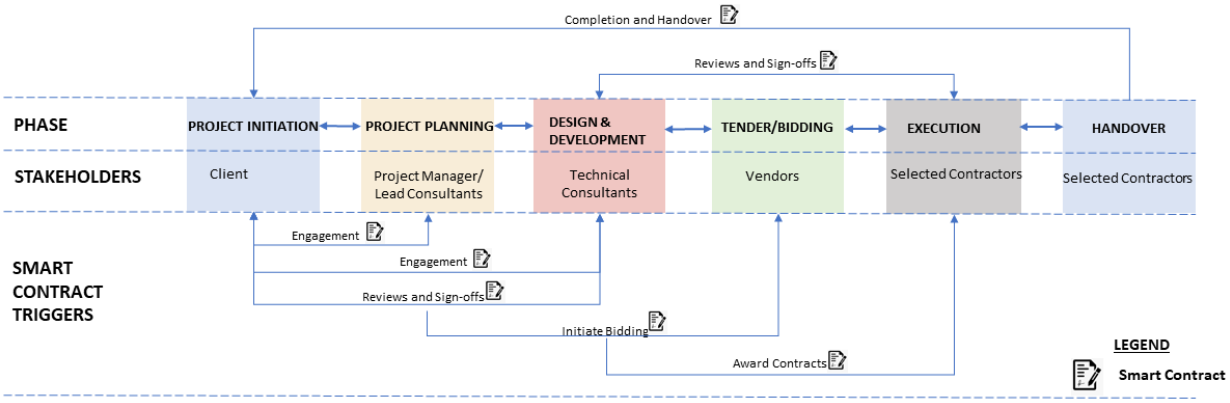

Figure 2: Linear Information Flow in Integrated Project Delivery

Smart contracts are deployed at instances where a client 1) engages a new service provider, 2) reviews and signs off on information, 3) initiates a bidding process, 4) appoints a contractor and also when consultants 1) review and sign-off on documents and procedures submitted by contractors and 2) signs off on construction at project completion.

4. USE CASES

The use case scenario will be discussed under to main headings; 1) BIM-enabled Integrated Project Delivery and 2) Smart Contract Payment Method through BIM Monitoring.

4.1 BIM-Enabled Integrated Project Delivery

The ability of BIM to replicate physical scenarios throughout the building lifecycle makes it suitable for collaborative workflows. BIM and IPD are process innovations that are driven by technology and reconfigure social relationships (Rowlinson, 2017). Existing literature suggests that BIM and/or IPD can dramatically enhance project performance from conceptualization through building management, and ongoing operations. (Ilozor & Kelly, 2012). This scenario leverages the abundance of research in BIM and IPD. The Project Manager (PM) or Lead Consultant (LC) creates the initial BIM model and shares it with the client, other consultants and all the contractors as they join the project. The PM/LC acts as the network administrator throughout the project. All changes as well as milestones are securely recorded in the back-end interface using the smart contracts and these milestones are visible to all members of the project team, so every party knows what stage every aspect of work is. Contract administration is enumerated under section 4.2 using the principle of Common Pool Resource (CPR). BIM-based solutions for IPD have also been proposed to enable accurate cost estimation at project inception when little information is available on the front end (Elghaish, Abrishami, Hosseini, & Abu-Samra, 2021)

4.2 Smart Contract Payment Method Through BIM Monitoring

Common-pool resources are systems that generate finite quantities of resource units so that one person's use subtracts from the quantity of resource units available to others (Ostrom, Gardner, & Walker, 1994). Hunhevics et al (2020) suggested that the governance of a Common Pool Resource (CPR) scenario was a useful guide to future research and applications of blockchain in construction. (Hunhevicz, Brasey, Bonanomi, & Hall, 2020). This phase of the use case deploys the combination of the BIM model, the model's physical twin on site using IoT technology to implement Digital Twins as discussed earlier, and the CPR as illustrated in Figure 3 below. The diagram below is a blow-up of the CDE shown in Figure 1.

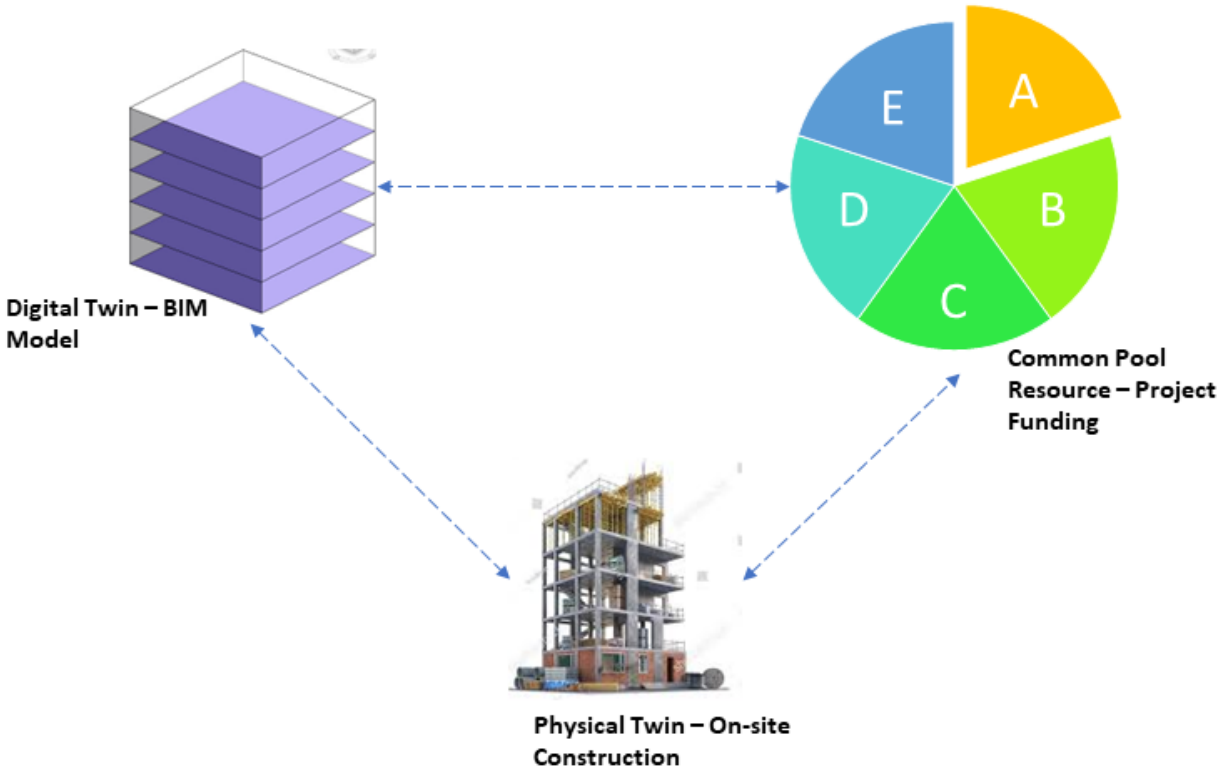

Figure 3: Components of the Common Data Environment

Earlier sections have shown how workflows of several project stakeholders can be integrated. However, contract administration, clarity of contract language and timely payment disbursement are some of the factors which make traditional procurement methods cumbersome. In this instance, the human component of contract administration and payment disbursement are eliminated by depositing project funds in an escrow account, otherwise referred to as the CPR. The CPR acts as a third-party agent except that it is not triggered by any one individual. Once a contract milestone is reached by any of the project stakeholders, the digital twin pair of the BIM model and the IoT powered construction communicate with the CPR to trigger a smart contract between the client and the corresponding project stakeholder. Payment is automated to such stakeholder based solely on the attainment of an earlier agreed milestone.

5. CONCLUSION

This research has built upon a preponderance of academic endeavors in the field of BIM, Integrated Project Delivery, Blockchain, and Smart Contracts within the AEC industry. With recent academic interests in the use of BIM at the forefront of some of the most cutting-edge innovations in construction and deployment of smart contracts to facilitate payment in construction projects. Beginning with a terse literature review which discussed general scholarly efforts around Smart Contracts and IPD, the literature review was broken down into thematic areas like challenges and limitations of IPD, Smart Contract (SC) solutions for construction and blockchain-BIM integration in construction. A theoretical framework was proposed which situates all stakeholders in an interconnected loop and in connection with the blockchain-enabled BIM simultaneously. The BIM is shared through a Common Data Environment (CDE). The linear flow of information/instruction in this form of IPD is also illustrated. Two use case scenarios helped to visualize the applicability of this framework. The first uses a BIM-emabled IPD where the shared BIM model facilitates the construction-phase collaboration amongst the project team whereby the Project Manager or Lead Consultant acts as a network administrator and changes are recorded using Smart Contracts. The second use case deploys SC payment method through BIM monitoring. In this case, a Common Pool Resource (CPR) warehouses the funds required for the project and BIM monitoring such as IoT-enabled Digital Twin can be synchronized with CPR and SC to trigger payment instructions once physical progress corresponds with the pre-coded digital milestone on the BIM model. Although this concept offers a solution to streamline construction workflows, further research is required to elucidate on the algorithmic workings of smart contract deployment in a BIM-enabled IPD.

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