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EXPLORING APPLICATIONS OF BLOCKCHAIN TECHNOLOGY IN THE CONSTRUCTION INDUSTRY

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Blockchain provides a secure decentralized information management system that can solve many common problems facing the construction industry. The loose structure of the construction industry, the way that public and private projects are tendered, and the supply chain system it uses for material and service delivery provide unique challenges and problems. New information technology management systems such as BIM and RFID are used to address some of these issues, though not completely. Blockchain technology can be used to further improve the information management systems in construction, provide more automation and mitigate many possible legal conflicts by default. Implementation of blockchain technology in the construction industry can also result in the use of smart contracts with fewer administrative struggles, improve the flow of the project, material, and service delivery, and increase the security and currentness of BIM or project documents. This study aims to explore the applications of blockchain technology in improving the construction industry's information management systems. It is concluded that not only the blockchain technology has potential in addressing some of the common problems in the construction industry but also it is adaptable to the construction industry structure and the way it is practiced. Thus, blockchain technology is a viable option for adaptation in the construction industry.

Keywords: Smart contract, Information technology, Supply chain management, BIM, Circular economy, Facility management.

1 INTRODUCTION

The construction industry is often critiqued because of its inefficiency and low productivity. The disaggregated structure of the construction industry, its sequential nature where works need to be done in a sequential and chain resembling system, and the number of stakeholders with different interests involved in each project are named as root causes of its problems. Coordinating all the necessary tasks, contract administration, handling claims, and supply chain management through manual paperwork is proved to be troublesome and inefficient. Blockchain is an information technology that inherently adapts to these structural problems. Blockchain can provide a direct solution to each of these problems or provide a comprehensive platform where project design and management happens in a blockchain backed Building Information Model (BIM) integrated with a self-enforcing smart contract supplied by vendors chosen and managed by a blockchain network in a larger scale of circular economy. This technology is capable of bridging the lack of trust between the stakeholders (Mathews *et al.* 2017), automate a lot of currently manual processes,

provide a secure and reliable infrastructure for collaboration and information exchange while increase transparency and provide a reliable chronological record keeping.

Blockchain is an implementation of distributed ledger technology, where peers are the data storage nodes. In such a system, the information is shared with everyone completely and verifiably with complete traceability and chronological order. The technology itself is free and implementing a blockchain system is far cheaper than any other shared database system such as common cloud solutions. There have been three generations of blockchain so far, that is, Blockchain 1.0 for digital currency, Blockchain 2.0 for digital finance, and Blockchain 3.0 for digital society. Blockchain 1.0 is solely regarding the decentralize transaction of money and payments. Blockchain 2.0 works in a more general way and covers transactions related to any kind of asset. For instance, smart contracts and smart properties are examples of the second generation's implications. Blockchain 3.0 goes beyond the concept of asset transaction recording and covers areas such as government, health, science, and culture. Blockchain implementations in supply chain management and banking systems show it is highly secure and reliable (Morabito 2017). Public, consortium, and private blockchains provides different information management systems frameworks that can address different needs based on the level of openness and access it is needed (Morabito 2017). A public blockchain is accessible by anyone, and the data can be read or be written by any user, whereas, in a private system only the selected few can access the system. A hybrid or consortium blockchain allows exchange between separate blockchain networks. The absence of administrative power in blockchain and the power of crowed over the data validity is the source of its power.

Blockchain is identified by Wang *et al.* (2017) as one of the tools that can help to overcome the acknowledged lack of trust and inadequate information sharing technologies in Architecture, Engineering, and Construction (AEC) industry (Lau and Rowlinson 2010). Blockchain, due to its working system, would eliminate the need for trust between the parties or the need for confrontational contractual relationships due to the lack of trust. Five areas of blockchain technology's applications in the built environment sector is investigated in this study. Namely, smart contracts, supply chain management and circular economy, BIM, facility management, and sustainability. Finally, the challenges of using blockchain technology in the built environment sector are discussed, and directions for future research are suggested.

2 SMART CONTRACT

A smart contract can be defined as a computer program consist of if/then statements dividing the work into smaller measurable work packages and automating the process of compliance and payment (Lamb 2018). The conditions where each work package or milestone is considered complete is defined, and the completion of each one would trigger the predefined compensation automatically. This approach of breaking the project into smart contracts would provide a new type of work breakdown structure, which would help all the stakeholders to better understand their obligations, requirements, and liabilities as well as how other work packages is going to affect theirs or vice versa. As a result, a better holistic view of the project before execution and also during execution would be provided, where the real-time progress of the project can be tracked and provide a well-recorded track of developments during project execution. Controlling the contract governance with a computer program would decrease the number of uncertainties involved in project execution as the outcomes and the triggers to each outcome is completely predefined and expected. Signing off payments would become automatic dependent on the proof of work and compliance and reduce the need for administrative support in that aspect of the work. The if/then system would ultimately reduce the disputes from contract stipulations as the

conditions and compensations of the work is clearly stated by if/then statements and is governed automatically by a computer program. Blockchain can be the platform for implementation of smart contracts as a digital protocol. The information recorded in blockchain would clearly show who is responsible for what work at what time. Any tempering and change in the project data would make that block of information invalid, and it is fully traceable to the party at fault. In other words, the data recorded in the blockchain network is secured and tempered proof.

The underlying assumption of construction contracts is that most of the rights and obligations of stakeholders are against each other. This environment is in direct contrast to the new collaborative project delivery methods, such as BIM requires. The shared data environment provided by blockchain would allow a seamlessly automated compliance evaluation and provide an instrumental data record for dispute resolution. Consequently, using smart contracts and blockchain would eventually change the landscape of use of escrows, liens, and other sorts of bonds in the construction industry. Smart contracts provide extreme transparency and Potentially reduce the number of conflict points and also provide an unalterable track of project progress which can be used for conflict resolution in case it becomes necessary.

Cryptocurrencies such as Bitcoin are suggested to be used as the form of payment or collaterals in smart contracts (Cardeira 2015), but it is not necessary and not practical with current fluctuations in cryptocurrencies values. Payments and collaterals could still be hard currencies handled through banks by integrating existing payment accounts and the blockchain network. The end result would be a reduction in the number of people involved in contract administration and a better record keeping of the procedures followed. Reduction of intermediary parties and paper processes such as payment applications would increase the efficiency of the industry, not because of the increase in productivity but because it would smooth the administrative process such as compliance and financial procedures and automate many of the processes involved, which would increase the speed of project governance. Ultimately, such a system would smooth the project delivery process and provide a transparent and traceable payment system. Auditing the project cost, progress, labor practices, and any other project's record would be much faster and more reliable compared to the conventional project delivery systems. Consequently, the industry would become more efficient and inherently more ethical. The increased transparency would also result in better accountability and better project governance.

Implications of blockchain in construction and contract administrations go beyond the scope of smart contracts. Issues such as temporal equipment lease (Wang *et al.* 2017) and temporal insurance policies (Kakavand *et al.* 2017) are already being discussed where the user only pays for the time construction workers are present at the job site, and the validity of this and other conditions under question can be securely verified through blockchain network. Having a complex construction project executed though smart contract and blockchain might not be feasible in the near future (Gabert 2018). However, the viability of the concept is evident and implementing such a system in simple projects or subcontracts would be an appropriate first step to evaluate its performance in the real world.

3 SUPPLY CHAIN MANAGEMENT AND CIRCULAR ECONOMY

The decentralized and fragmented structure of the construction industry's supply chain very well pair with the decentralized ledger system of blockchain. Blockchain can provide the infrastructure needed to securely and reliably advance material traceability (Hultgren and Pajala 2018, Petersson and Baur 2018) and promote the circular economy (Rudolphi 2018). Smart contracts can play a role in supply chain management and material tracing too. Both supplier and buyer can be assured that they are going to get compensated for their money/product by using a

smart contract. As a result, the purchase could happen more directly between the source and the end user without the need for local suppliers. The payments can be sequential and proportionate to the status of material/product delivery, and the final payment could be tied to the final inspection/commission of the material/product.

There is also a high potential for integrating internet of things or RFID tags with blockchain to provide real-time material monitoring system resulting in better site management practice and increase in construction efficiency. Using a blockchain network for supply management would help vendors to easily show their certification of identity from authorities. The buyers can easily validate those certifications of identity and also see the track record of the vendor to check their reputation and capacity from previous works. As a result, a buyer and a vendor without knowing and trusting each other can engage in a transaction.

On a grander scale, a true circular economy is achievable through blockchain. When a raw material is extracted, its information can be stored on a blockchain network, storing its source and characteristics. Then producers can use that network to order and obtain their raw materials. Each order is also stored, and it is traceable that each product consists of what raw materials from where. This chain of information continues to the end user who is buying the product and installing it in their project, which would increase the material transparency in the construction industry. Furthermore, during the lifetime of a product when maintenance is necessary or if there is a question regarding its source or its materials' source it is clearly traceable. There will be a chain of information from raw material source to factories, vendors, sub-contractors, contractors, and the final project. That would allow a fully transparent material usage in the industry, where planning for reusing of materials are possible through pre-planning and current knowledge of materials status and their background.

4 BIM

The introduction of BIM to the AEC industry provided a shared data environment where all the information is stored in a shared project file. The location and maintenance of this shared data environment presented a new challenge. Blockchain technology is a promising solution to such a problem (Turk and Klinc 2017). An always current distributed ledger system with high security, which can be used as an infrastructure for maintaining up to date BIM models during the project Lifecycle between the involving stakeholders. BIM provides a single project environment where all the information regarding the project is created and stored there. Blockchain provides a single platform to maintain and update that project environment and connect it with the reality of site work. This would provide a time-stamped, tampered proof data. The peer-to-peer structure of blockchain aligns well with the collaborative way that a BIM model is developed by different stakeholders, and ultimately, it would improve collaboration. The tampered proof track record of changes to the model by each user can be used to find a party at fault in design or miscommunication. Any change to the model is recorded and communicated to other people linked in the blockchain network. Consequently, the BIM related claims during the project lifecycle can be solved much more natural.

Connecting a project's BIM model to a smart contract would need an information system to link project elements to reality and reflect the project progress on the model. Blockchain can be used separately or in adjunction of governing the smart contract to link the BIM model to the smart contract and update the BIM model according to the project progress. The smart contract program can be applied to the BIM model elements and linked to the project's reality through blockchain. As a result, the actual construction should match the model to get compensated. If the contractor finds a clash or an error, he can send a change order or RFI, and it would be

securely time stamped and recorded. The granular work progress can be tracked on the model with or without reality capture technologies. The inspection process can be done by manual inspection or automatically through reality capture technologies such as 3D laser scanning or Lidar. The end result would be a streamlined contract administration and better project governance.

5 FACILITY MANAGEMENT

Integration of blockchain and BIM or Building Maintenance System (BMS) would provide a reliable integrated system which can provide the complete history of the project and also trace every detail of the building to its source (Mathews *et al.* 2017). Furthermore, this integration can stretch to the future and use smart contracts when maintenance is needed to automatically place a work order and upon the verification of completeness, release the payment to the contractor. The concept of Decentralized Autonomous Organization (DAO) is introduced as an organization, which is governed via multiple smart contracts. A DAO can be attributed to a building through its lifecycle where everything from design and construction to operation, maintenance and demolition is done by smart contracts cohesively and autonomously. Blockchain is one of the few technologies can bear the burden of supporting such complex interactions through time. Longitudinal health record (Angraal *et al.* 2017) is an example of a similar concept from a different industry.

6 SUSTAINABILITY

The material transparency discussed in supply chain section would have an impact in sustainability in areas such as whole life cycle cost, carbon emission estimates, and raw material verification. For instance, the designers or users can make a sustainable choice by using material traceability through blockchain up to the source of any product's raw materials. Typically, the supply chain would provide the specific information required by the clients. A blockchain platform would enable not only the direct suppliers to provide the required information but also the indirect suppliers such as the raw material providers to a prefabrication factory can also put their information in the database for more accuracy and verifications. This process would provide consistent and structured asset information. This database can be used not only for decision making during the design, procurement, and construction but also would be beneficial for the post-occupancy management of the facility. A blockchain network can also help energy management on a grand scale to achieve a smart grid (Mengelkamp *et al.* 2018). First, both energy consumption and production should be tracked using a blockchain. Then, this could provide a basis for a better supply and demand control and ultimately a true dynamic pricing for energy.

7 CONCLUSION

Successful implementation of blockchain in other industries such as accounting, financial technology, and commodity market shows the viability of this technology. Blockchain can hypothetically provide a platform for supporting the link between the physical world and the digital one. It can also cover the whole Lifecycle of a project from material sourcing, contract administration to the operation, maintenance, and eventually demolition and material reusability. Blockchain would help to smooth the project development processes and reduce the need for intermediary parties. One necessary step for this technology to become prevalent is becoming prevalent as much as possible so the software providers would enable their software to use push

and pull data by integrating with blockchain. A common standard and template for each application area is crucial. Thus a loosely structured industry such as construction can use this system. Consequently, everybody in the supply chain would be able to input their data and use the other stakeholders' input in a meaningful manner. One important issue raised in this study is while cryptocurrency can play a role in each discussed section, it is not necessary to be part of the system and blockchain can be used regardless of the cryptocurrency state.

The disaggregated structure of the construction industry makes it a suitable match for using blockchain. However, this loose structure is a disadvantage in implementing innovation and new technologies. This problem is more noticeable when a grand scale change is requiered. As a result, the administrative gap within the industry is a hindrance to blockchain technology implementation in this industry. Even though computer aided design and BIM is digitizing the construction industry, there is an apparent gap between the framework envisioned in this paper and the current state of digitization of the construction industry. A looped two-step approach is necessary to, first study the industry to find the requirements and applicable areas. Then, the second step is to test the viability of the solutions and adjust the framework based on the empirical findings. This study is a contribution to the first step, which is going to be followed by testing each explored area with test cases in future works.

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