2021 European Conference on Computing in Construction
Online eConference
July 26-28, 2021

BLOCKCHAIN USE CASES ACROSS ENTIRE LIFECYCLE OF A BUILT ASSET: A REVIEW

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ABSTRACT

Blockchain is a key enabling technology towards the 4th industrial revolution of the construction industry. The aim of this paper is to map uses of blockchain technology across the various phases in the lifecycle of built assets. Of interest to this paper is a new classification of blockchain solutions in combination with other key enabling technologies, like Building Information Modelling and Internet of Things. The literature indicates that blockchain shows high potential for solving challenges across the entire lifecycle of a project and has an especially high potential to influence and possibly improve management in the Operation and Maintenance phase.

INTRODUCTION

The Architecture, Engineering and Construction (AEC) industry is well known for its low productivity, and slow adoption of process and technology innovations. In 2016 AEC industry in Europe was ranked as the second least digitised sector, only above agriculture (Agarwal *et al.*, 2016). Construction industry is highly project-based and characterized by high level of fragmentation and decentralisation, with most businesses being Small-Medium-Enterprises (SMEs). At the same time, projects are very unique with little repetition and high complexity (Maciel, 2020). For this reasons, the digitalisation of the AEC industry is a complicated and slow process.

Advancements in Building Information Modelling (BIM) are the basis for digital transformation of AEC industry (Mathews *et al.*, 2017). The United Kingdom (UK) is one of the world's leading countries in BIM adoption. Since mandating BIM for all public projects in 2016, the number of practices using BIM increased from 54% to 69% in 2019, after a slight drop from 71% in 2018. That means that even in the UK more than 30% of practitioners are still not using BIM (NBS, 2019). At the same time, recent survey shows that only around 9% of projects in Germany are developed using BIM and only 52% of companies have ever used BIM (PwC, 2019). Slow adoption of BIM might be caused by low client demand, lack of training and expertise, high costs (NBS, 2019), existing data processing and mostly analogue exchange methods (Nguyen *et al.*, 2019). Many scholars claim (Mathews *et al.*, 2017; Nguyen *et al.*, 2019; Penzes, 2018) that blockchain technology could provide a catalyst for BIM in reaching its full potential as it eliminates the problem of trust. Maciel (2020) believes that blockchain-enabled BIM might be the key to the digital transformation of the AEC and push it towards the 4th industrial revolution.

The purpose of this paper is to provide a new classification system from the perspective of lifecycle management through a methodological review. The research question that this study addresses is: to what extend is blockchain technology useful across lifecycle phases of a built asset and what are the inter-relations between blockchain use cases, BIM and Internet of Things (IoT).

RESEARCH METHOD

Although blockchain is relatively new technology its innovative character has drawn the attention of many researchers around the world. There are already several literature review studies (Erri Pradeep *et al.*, 2019; Götz *et al.*, 2020; Hunhevicz and Hall, 2020; Kim *et al.*, 2020; Kiu *et al.*, 2020; Li *et al.*, 2019; Nawari and Ravindran, 2019a; Perera *et al.*, 2020; Turk and Klinc, 2017; Wang *et al.*, 2017; Ye *et al.*, 2018) and industry reports (Gerber and Nguyen, 2019; Kinnaird and Geipel, 2017; Nguyen *et al.*, 2019; Penzes, 2018) about possible blockchain applications in AEC industry. In this paper we will classify blockchain applications from the above-mentioned literature by using meta-analysis method.

Firstly, the principles of blockchain will be briefly explained and then its potential applications in AEC industry will be identified. Afterwards, a classification of blockchain use cases according to their integration with BIM and Internet of Things (IoT) technologies and their relevance for each lifecycle phase of a building project will be presented. Finally, the challenges of blockchain implementation will be discussed.

BACKGROUND

Blockchain is a Distributed Ledger Technology (DLT) and was first introduced in the white paper by Satoshi Nakamoto (2008) as a base for the world's first cryptocurrency named Bitcoin. DLT is a database of transactions which is stored in a network on multiple nodes simultaneously, making it therefore decentralised and unchangeable

(described as immutable). A highly resilient network protocol and consensus mechanism enable all participants of the network to interact with each other in a peer-to-peer manner and thus there is no need for intermediaries and a third party controlling the network. All interactions are cryptographically secured and added to an immutable record of transactions which is then a single source of truth (Perera *et al.*, 2020).

Blockchain is often described as a powerful and disruptive force that can transform the industry and drive the economy on a global scale, as it creates an entire new paradigm for building data collection (Kinnaird and Geipel, 2017; Mathews *et al.*, 2017). The invention of blockchain and the impact it may have on the world has even been compared to the invention of the Internet (Kinnaird and Geipel, 2017; Maciel, 2020; Nguyen *et al.*, 2019). Blockchain has already had a disruptive impact on banking, finance, insurance, health, and education sectors and as discussed herein, may have the potential to transform AEC industry (Kim *et al.*, 2020; Nguyen *et al.*, 2019). Construction projects might be seen as an ideal test case for blockchain implementation as they are involving often numerous stakeholders with high degrees of distrust, requiring a trustworthy, independent, open and secure record of information (Mathews *et al.*, 2017).

Since the emergence of Bitcoin – the first use case of blockchain technologies, known also as Blockchain 1.0 – it was understood that blockchain could have diverse applications beyond cryptocurrencies. Blockchain 2.0 was introduced in 2015 with Ethereum being an alternative platform to Bitcoin (Nawari and Ravindran, 2019a). One of the most fundamental and disruptive innovations enabled by blockchain 2.0 were smart contracts which are digital programs requiring no middlemen, that execute defined terms automatically once predefined conditions have been met. Decentralised Autonomous Organisations (DAOs) are a special type of smart contracts, which resembles a form of an organisation working on a blockchain. Unlike traditional organisation they exist only in the blockchain and therefore have no CEO, board of directors or headquarters (Kinnaird and Geipel, 2017). Applications based on a blockchain that are not run by an intermediary are called DApps. DApps enable direct user interaction with the blockchain, usually through web user interfaces (Hunhevicz and Hall, 2020).

Blockchain 3.0 aims to improve the biggest shortcomings of previous versions such as transaction time, scalability, and ease of implementation (Nawari and Ravindran, 2019a). The next version - Blockchain 4.0, additionally will leverage upon the advantages of integrating Artificial Intelligence (AI) which will enable the system to make decisions and act without direct need for human intervention (Kiu *et al.*, 2020). Blockchain technology is still evolving, and there might be a range of possible applications which are still to be discovered.

BLOCKCHAIN APPLICATIONS IN AEC

A report from Institute of Civil Engineers (Penzes, 2018) indicates that blockchain can tackle problems such as lack of accountability, transparency and efficiency in construction industry. According to Mathews et al. (2017) *'Blockchain's core strength is that it can provide a solution to the problem of trust'*. Blockchain-powered smart contracts may help to solve serious problems of late or withheld payments in construction projects which often lead to project failures and disputes between stakeholders (Wang *et al.*, 2017). Penzes (2018) identifies three potential areas of blockchain applications in construction industry: Payment and Project management, Procurement and Supply Chain Management and BIM and Smart Asset Management.

The concept of blockchain-based platform for payment and contract management is one of the most valuable applications of blockchain in the construction industry (Kim *et al.*, 2020). Such a platform could be used through the whole lifecycle of a project to enable transparent and effective collaboration on every level between all stakeholders (Gerber and Nguyen, 2019). Application of smart contracts ensures that every action, like automatic initiation of payments, always happens according to contractual terms, therefore eliminating the problem of late payments. Also a selective-transparency in payment records in blockchain based data model is possible when needed. For instance, sensitive financial information can be shared privately between two contracting parties, while non-sensitive payment-related information can be seen by all project participants (Das *et al.*, 2020).

Payment management is not the only opportunity for application of blockchain technology. It may revolutionise the current supply chain management by improving its integration, co-ordination and logistics (Kinnaird and Geipel, 2017). Blockchain technology can also be a solution for managing BIM models through the whole lifecycle of a building project. Both BIM and blockchain share the ability to serve as a single source of truth (Di Giuda *et al.*, 2020). Blockchain enables an immutable record of changes of a BIM model as well as immutable record of ownership of a model or of a digital component (Gerber and Nguyen, 2019). For managing BIM models a Decentralised Common Data Environment (DCDE) was proposed, instead of traditional central cloud-based storage (Kinnaird and Geipel, 2017; Nawari and Ravindran, 2019a)

Li *et al.* (2019) have outlined other potential applications of blockchain technology for the built environment such as smart energy, smart cities, sharing economy, smart government, intelligent transport and business models. For the scope of this review paper, these applications will be omitted in the classification, as they cross over into other sectors.

Hunhevicz and Hall (2020) summarised all blockchain use cases in AEC industry into 7 categories: Internal use for administrative purposes, Transaction automation with

smart contracts, Immutable record of transactions, Immutable record of assets/identities, Coins/tokens as payment for incentive scheme, Decentralised applications (DApps), Decentralised Autonomous Organizations (DAOs). Wang et al. (2017) proposes another new use case for asset management which is blockchain-enabled equipment leasing platform. Another recent systematic literature review from Kiu et al. (2020) classify blockchain use cases in a similar manner to Penzes (2018), but with two additional categories. Firstly, real estate management which includes previously mentioned use case for record of property ownership, for example blockchain enabled land title registry. Secondly, funding management which is a relatively new proposal for a blockchain-enabled crowdfunding platform to raise funds for certain projects (Kiu *et al.*, 2020).

BLOCKCHAIN, BIM AND IOT

Both industry and academia reports (Kinnaird and Geipel, 2017; Ye *et al.*, 2018) indicate that blockchain, BIM and the IoT are three technologies which are currently having a profound impact on the AEC industry. It is difficult to analyse the benefits of a single technology, as they are complementary to each other and it is their interaction that enables new applications in AEC industry (Ye *et al.*, 2018). In this section (and in Figure 1) a classification of blockchain use cases according to the integration of blockchain, BIM and IoT is presented.

The biggest advantages that integration of blockchain to BIM collaboration can offer are: an immutable record of changes of a digital model, assigning responsibilities to all stakeholders according to their roles and transparent record of data entries and ownership in BIM model. Through blockchain features such as decentralisation, immutability of decisions and files, and protection of intellectual property some of the shortcomings of centralised BIM implementations could be tackled (Dounas *et al.*, 2020). Linking BIM to blockchain enable the ability to track project progress and worked hours (Penzes, 2018).

Blockchain technology can solve the limitations and risks of IoT data, such as vulnerability of central database, need of third controlling party or risk of data leakage (Ye *et al.*, 2018). As a more and more devices, in transportation, infrastructure, energy, waste or water, become connected, there will emerge a need for a trusted system able to process all transactions between those devices (Nguyen *et al.*, 2019). Internet of Things will need a blockchain-enabled Ledger of Things (Kinnaird and Geipel, 2017). One of the most often mentioned use cases of IoT and Blockchain integration in construction industry is tracking of supply chain logistics and record of maintenance and operations data (Qian and Papadonikolaki, 2020).

A vision of a real-time Digital Twin can become reality thanks to the integration of BIM, IoT and blockchain technology. At its basic level a Digital Twin is a digital representation of a built asset and their processes. Integration of BIM, blockchain and IoT has the potential to turn Digital Twins to live and always updated source of information which may even operate autonomously through smart contracts (Götz *et al.*, 2020). Another application which utilizes all three technologies is verification of activities and installation tasks on the construction site (Di Giuda *et al.*, 2020).

Kinnaird and Geipel (2017) introduced a concept of the Blockchain of Circular BIM Things, which combines the use of blockchain, BIM and IoT with the concept of the Circular Economy, which can be defined as *'a system that aims to create a more efficient and environmentally-friendly economy through the re-use and recycling of materials'*. Finally, the integration of these three technologies enables a secure, transparent and convenient Decentralised Common Data Environment (DCDE), where BIM information and IoT data can be managed and stored (Tezel *et al.*, 2020; Ye *et al.*, 2018).

BLOCKCHAIN ACROSS LIFECYCLE STAGES

The Association for Project Management (APM) defines 6 lifecycle phases of a project which are: Concept, Definition, Implementation, Handover and Close, Operations and Termination (Naybour, 2012). The RIBA Plan of Work 2020 organises the lifecycle of building projects into eight stages: Strategic Definition, Preparing and Briefing, Concept Design, Spatial Coordination, Technical Design, Manufacturing and Construction, Handover and Use (RIBA, 2020). For this work, and based on both the APM and RIBA lifecycle concepts, we will simplify the lifecycle of a built asset into 5 phases:

- Preparation Phase,
- Design Phase,
- Construction Phase,
- Operation & Maintenance (O&M) Phase
- Termination Phase.

In this section we will discuss how blockchain can support continuous use of digital information across the entire lifecycle of a built facility. A classification of use cases from recent literature according to their appropriateness in each lifecycle phase is presented in Figure 1.

Whole Lifecycle

Numerous blockchain applications are relevant during the whole lifecycle of a built asset. Especially the idea of a Decentralised Common Data Environment (DCDE) is important for the entire lifecycle of a built asset, as it facilitates continuous collaboration between all participants of a project and ideally works as a single source of truth for all project information. Therefore, it is vital that DCDE upholds data security, quality, privacy and integrity standards, which can be secured by blockchain (Nawari and Ravindran, 2019a). Using a blockchain platform means a perfect notarisation and synchronisation of documents during the whole project lifecycle. A blockchain records every creation, deletion, and updating of files, knows exactly the origin of every information and enables

their authentication and data provenance (Wang *et al.*, 2017).

Most of the use cases of transaction automation with smart contracts, like triggering payments or contract deliverables, self-executing contract administration and automated data/information sharing (Hunhevicz and Hall, 2020) are possible to implement in every phase of a project. An idea of shared Project Bank Accounts and insurances between multiple, independent stakeholders during the whole project was described as a good use case for blockchain implementation (Das *et al.*, 2020; Li *et al.*, 2019). As blockchain is a base for Bitcoin, Hunhevicz and Hall (2020) consider payment in cryptocurrencies in AEC industry a worthwhile use case to consider.

Cryptocurrency coins or tokens can also have another use than only for financial purposes. Mathews et al., (2017) propose the use of an #AECoin as a token to provide incentives over the whole building lifecycle. Project contributors would be rewarded with tokens for bringing valuable and long-term solutions to the project. This would create a win-win situation for both project owner and project participants, as they could build their reputation based on their rewards (Mathews *et al.*, 2017). A blockchain platform would enable managing identities for reputation of people or firms for clear and trustworthy identification which could support stakeholder selection process. Based on digital identities Decentralised Marketplaces for Products and Services could be established using DApps (Kinnaird and Geipel, 2017).

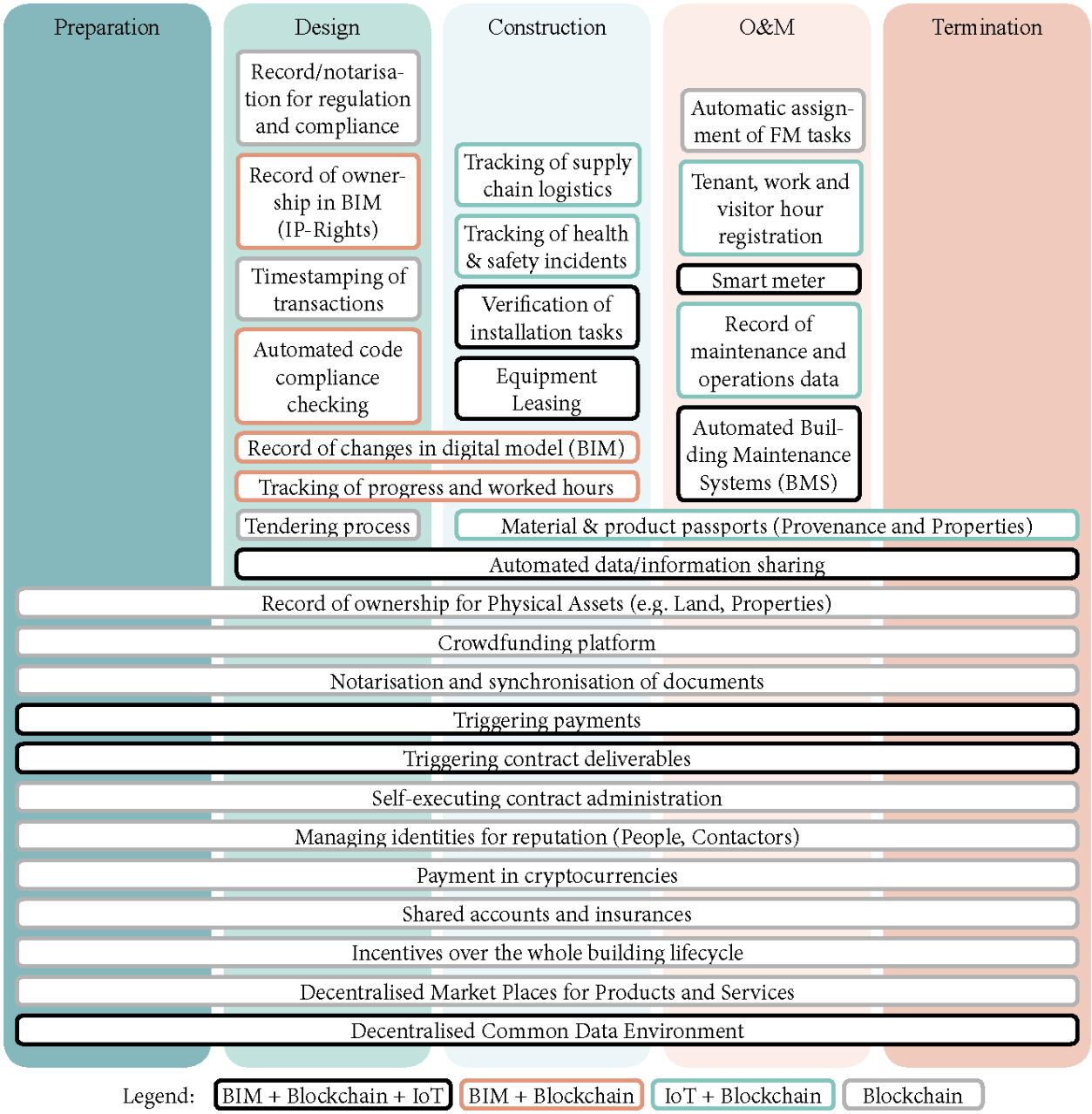

Figure 1 Classification of blockchain use cases for all lifecycles of a building project, author's representation.

Preparation Phase

Typically, in the beginning of building projects, the use of digital tools is limited. However, even before the first BIM models are created there is a high potential for blockchain implementation. In order to use the advantages of applications described in the previous chapter from the very beginning and throughout the project it may be necessary to define all future data needs for DCDE. Blockchain enabled record of ownership, especially in cases such as land property, could significantly ease and speed up the process of purchasing land in the first steps of the project (Kiu *et al.*, 2020). Some projects such as new landmarks for a country or a city typically requires raising significant funding from investors. Blockchain enables the initiation of a safe, transparent platform for crowdfunding, which can be traced by anyone in later stages of a project (Kiu *et al.*, 2020).

Design Phase

The design phase is a process of continuous development of design models where collaboration among stakeholders is essential. Blockchain enables the ability to store an immutable record of changes that all participants make to a BIM model (Di Giuda *et al.*, 2020). Thanks to timestamping of transactions and tamper-proof guarantee the record is transparent and easy to follow. A cryptographically secure digital signature protects data provenance as well as the metadata such as timestamps or author information (Turk and Klinc, 2017). At the same time, the record enables stakeholders to publicly prove the ownership of Intellectual Property (IP) rights for whole BIM model or a singular component such as Revit families (Erri Pradeep *et al.*, 2019). Ability to prove IP rights during collaboration between stakeholders would enhance trust and be a big step towards enhanced BIM collaboration (Nawari and Ravindran, 2019a). Blockchain mechanism can be also used for decentralised design optimisation conducted by both human or artificial intelligence agents (Dounas *et al.*, 2020).

As the design process starts, a blockchain system can start recording all interactions between all stakeholders (Yang *et al.*, 2020) as well as worked hours and submitted deliverables defined by different design packages. Based on that a smart contract can be prepared to initiate automatic payments whenever defined milestones are achieved or deliverables are submitted in time (Penzes, 2018). Blockchain enabled design process ensures an immutable record of changes using any type of data, including documents, pictures, videos or BIM, in the same time enhancing trust and accountability between all project participants (Yang *et al.*, 2020). Blockchain technology would also be very advantageous in tender procedures. All the tender documents, such as the information models presented both by the client and by the bidders, could be stored in an immutable way. This would eliminate any possible operational ambiguity and ensure effective and fair competition (Di Giuda *et al.*, 2020).

Nawari and Ravindran (2019a) introduced Automated Code-Checking and Compliance (ACCC) Framework for the automation of the Building Permit Process in post-disaster recovery. In their system the architect sends a BIM model for review to a building authority which is then verified and processed by a smart contract. Removal of an overseeing third-party could lead to significant savings by removing processing fees, diminishing paperwork and shortening the time needed to issue building permits. Moreover, such a platform provides transparency and secure network services without interruption which is especially important in the process of rebuilding after a disaster (Nawari and Ravindran, 2019b). Nevertheless, it is not hard to think how this solution could be applied on regular projects.

The aforementioned examples show that blockchain has the potential to address many challenges during the design phases by clarifying liabilities, increasing the reliability of information and improving the security of information flow (Erri Pradeep *et al.*, 2019).

Construction Phase

One of the most significate impacts that blockchain may have on the construction phase of a building is how it can change the supply chain logistics and management. According to Qian and Papadonikolaki (2020) blockchain has three main applications in the supply chain: tracking with help of Internet of Things (IoT), contracting through automation and application of smart contracts, and transferring of cash flows. These applications of blockchain can significantly enhance trust and transparency between participants and increase effectiveness and security of supply chain management (Qian and Papadonikolaki, 2020; Tezel *et al.*, 2020). Integrating innovative technology such as blockchain into construction logistics will force organisations to innovate and change their business models, as the roles of individuals and internal business structures will change (Tezel *et al.*, 2020). Kifokeris and Koch (2020) proposed a model for independent construction logistics consultants which ensures integrated economic, material and information flow, improves process management, increase productivity and in the same time facilitates consultant's competitive advantage. Each component or material used in the project can be registered with a unique ID on the blockchain platform, creating a possibility for a digital identification – Material and Product Passports. They enable tracking of each component from production, through the supply chain and its installation until it is reused or recycled (Penzes, 2018). Such a blockchain-based system for procurement would provide all stakeholder with transparent information about all the fabrication and design specifications, transportation and installation details and production and procurement details (Yang *et al.*, 2020).

The concept of triggering payments by smart contracts can be applied not only in the supply chain management. As in design phases, where submission of design packages triggers smart contract, construction tasks are the

triggering smart contracts (Penzes, 2018) For example, when a construction project reaches a specified structural level, such as frame stage, lock-up stage etc, an automated payment from project client to the general contractor could be triggered by execution of the smart contract. Consequently, based on the contract conditions, all related payments, stipulated as smart contracts between the general contractor and their subcontractors or suppliers, could be automatically activated (Wang *et al.*, 2017). Activities at the physical delivery, such as verification of installation tasks, could also be coded into a smart contract and consequently trigger payments (Di Giuda *et al.*, 2020).

Leasing heavy equipment, such as cranes or loaders instead of purchasing them is becoming an increasingly frequent option for contractors. The traditional leasing process is often inefficient and time-consuming due to a large amount of paperwork which needs to be done. Moving the leasing process to a blockchain platform could speed it up significantly, as all steps such as insurance and payment would be combined in one platform. Implementation of IoT sensors would enable automatic tracking and recording of operational status of the equipment such as electricity consumption, daily usage and abnormal breakout events (Wang *et al.*, 2017).

Operation and Maintenance (O&M) Phase

Götz et al. (2020) identified many use cases of blockchain and smart contracts for O&M phase. Blockchain technology could be a solution for storing operational data and storing maintenance, access, and activity metadata. Smart contracts can be used for automatic regulation of building systems, smart meter solution for water, energy and grid providers, automatic assignment of tasks for facility managers, tenant, work, and visitor hour registration, ID verification, additional work claims, enabling predictive planning for maintenance, and smart scheduling. A blockchain-enabled Digital Twin could support processes and decisions (both strategic decisions making and on-field daily asset management) in a wide range of asset management activities (Götz *et al.*, 2020). A verified record of maintenance and operation data is essential for facility managers. Thanks to blockchain the quality of the data from the IoT services can be appropriately verified and adjusted to contractual requirements.

In order to provide facility managers a digital model, a sufficient BIM framework is required from the inception of the project (Götz *et al.*, 2020). COBie (Construction Operations Building Information Exchange) models defining data exchanges from the design and construction phases could be enhanced, or replaced by a blockchain-enabled platform (Kinnaird and Geipel, 2017).

Ye et al. (2018) proposed an automated Building Maintenance System (BMS) in the form of a Decentralised Autonomous Organisations (DAOs) which could collect data from IoT sensors and record them in the blockchain enabled Digital Twin. In case of a failure of some component the DAO could respond to this event according to the scheme of the smart contract. The proposed system could automatically write a damage report, connect a designated service provider, or purchase a new component without need for a human action (Ye *et al.*, 2018).

Tracking of supply chain logistics is also relevant in the O&M stage. A blockchain system records the history of the supply chain from the raw material preparation to offsite manufacturing, transportation, site construction, and until the final commissioning. Furthermore, Product Passport gives overview about all information of each installed product. As those information are always authentic and non-editable, in case of a serious defect of a product, the responsible party can be quickly identified and confirmed without tedious arguments (Wang *et al.*, 2017).

Termination Phase

Reliable provenance of materials is crucial for sustainability and responsible sourcing in the industry as the reuse and recycling of materials can depend on the certified material specifications (Penzes, 2018). A Data record from the whole lifecycle of an asset and Product and Material Passports provide knowledge about every element of a building and therefore allows for a sustainable reuse and recycling of materials. As we mentioned earlier, blockchain technology could be a significant step in the move towards adoption of Circular Economy principles in AEC industry (Nguyen *et al.*, 2019).

DISCUSSION

This study presents an alternative classification of blockchain use cases in the AEC industry to further the research on the topic. Our classification affirms that blockchain may be advantageous at all lifecycle stages and facilitates the advancements of BIM and IoT. As seen in Figure 1, blockchain and BIM use cases are mostly relevant in the Design phase of a project, while blockchain and IoT integration is applicable in Construction and O&M stage. As most of the literature presents theoretical use cases rather than practical implementation of blockchain technology in the industry (Tezel *et al.*, 2020), further research should focus on prototypes and case studies. The development of blockchain enabled DCDE is especially important, as it is intended as a base and a single source of truth during the entire lifecycle of a built asset.

Transaction automation with smart contracts is relevant in all lifecycle phases of a built asset. The contents of a smart contract may be adjusted to deliverables of any lifecycle phase and trigger payments between any participants of a project. Despite this, a major challenge for the implementation of smart contracts is the lack of legal implications, lack of regulations, the complexity of coding them and transaction longevity (Li *et al.*, 2019; Tezel *et al.*, 2020). The idea of coins/tokens as payment for incentive scheme in construction industry was also proposed by various authors, however, it is questionable whether payments with cryptocurrency would be accepted.

One of the most elaborated area of blockchain adoption in the literature is Supply Chain Management, which

occurs during the Construction phase. It might be caused by the relevance of this topic to other industries which are generally much more advanced in the adoption of technological innovations. During the Design stage BIM models are intensively developed, therefore the collaboration between multiple stakeholders is essential. Blockchain is often described as a hope for advancement to BIM Level 3, which is the base for the 4th industrial revolution of the industry. However, the integration of those two technologies is facing many challenges such as poor technological state of the industry, lack of skills, interoperability and scalability problems (Li *et al.*, 2019; Tezel *et al.*, 2020).

Blockchain use cases in the O&M phase have the potential to disrupt the whole FM sector. As the amount of project information increases with each lifecycle phase, the O&M phase contains the greatest amount of information which needs to be managed by facility managers and therefore the need for blockchain implementation is very high. The integration of BIM, IoT and blockchain technologies is essential to achieve the goal of a real-time Digital Twin and automatic BMS. Implementing such a blockchain based Digital Twin in FM practice could have a profound effect on the effectiveness and sustainability of buildings during their whole lifecycle.

CONCLUSION

Blockchain technology is rapidly evolving and may have a disruptive influence on the AEC industry, as it already has in other sectors. This paper has described the basic principles of blockchain technology and listed recent advances in implementing blockchain in the AEC industry. A wide range of possible use cases were identified and classified according to their integration with other technologies and their relevance in each lifecycle stage.

Recent literature indicates that blockchain technology shows great potential for solving challenges faced by the construction industry across all lifecycle phases of a built asset and has an especially high potential in the O&M phase. Integration of BIM, blockchain and IoT may provide new opportunities for the Facility Management sector and should therefore be further explored in future research. Also, the development of blockchain-enabled DCDE is highlighted as a very important step to achieve the goal of a real-time Digital Twin, which can become a single source of truth across the entire lifecycle of a built asset. A recommendation for future research to focus on practical case studies was also expressed in this paper.

ACKNOWLEDGMENTS

The work presented has been a contribution to CBIM European Training Network funded by the European Union's Horizon 2020 Programme under the Marie Skłodowska-Curie grant agreement No 860555.

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