Preparing Construction Supply Chains for Blockchain: An Exploratory Analysis

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Abstract

Blockchain, a peer-to-peer controlled, distributed database structure, has the potential to profoundly affect the current business transactions in the construction industry through smart contracts, cryptocurrencies, and reliable asset tracking. The construction industry has often been criticized for being slow in embracing emerging technologies and not effectively diffusing those technologies through its supply chains. Often, the extensive fragmentation, traditional procurement structures, destructive competition, lack of collaboration and transparency, low-profit margins and human resources are shown as the main culprits for this. As Blockchain makes its presence felt strongly in many other industries like finance and banking, this paper investigates how to prepare construction supply chains for Blockchain technology through an explorative analysis. Empirical data for the study were collected through semi-structured interviews with 17 subject experts and focus groups. Alongside presenting a SWOT (strengths, weaknesses opportunities, threats) analysis, the paper exhibits the requirements for and steps toward a construction supply structure facilitated by Blockchain.

Keywords: Blockchain, Smart Contract, Supply Chain Management, Project Management, SWOT

1. Introduction

1.1 Digital transformation in AEC

Digitalization is seen by policy makers as a key strategic solution to the architecture, engineering and construction (AEC) industry's well-known problems (e.g. low-productivity, low value-for-money, poor health and safety and quality performance, frequent disputes etc) (Linderoth 2016; Jacobsson et al. 2017; Lavikka et al., 2018). Alongside presenting promising opportunities for the development of the industry, for instance, though task automation (Matthews et al. 2015), data-driven decision-making (Gerbert et al. 2016), and collaborative value creation with new forms of interaction, improved information sharing and transparency among stakeholders (Schober and Hoff 2016), there are also serious arguments underlining the gaping digital divide between small and large companies (Dainty et al. 2017), questioning organizational readiness in the AEC industry for digitalization, whether digitalization has delivered its promises (Khosrowshahi and Arayici 2012; Miettinen and Paavola, 2014), and emphasizing problematic matters around data privacy, trust and intellectual rights in data-rich environments (Sadeghi et al. 2015; Ahmed et al. 2017).

Under these circumstances, distributed ledger technologies (DLTs) including blockchain are increasingly being investigated as a potential solution to address many of the challenges hindering the AEC industry's performance such as transparent collaboration, secure and traceable data storage and retrieval, smoother business transactions with less disputes and safeguarded privacy and intellectual property rights (Li et al. 2018b; Penzes, 2018). This paper presents the initial findings of a research project aiming at understanding the potential and problems associated with the blockchain technology for the AEC industry through primary data from 17 interviews with subject experts. and secondary data from the literature. Following a detailed literature review on the blockchain technology and its potential use in the AEC industry, the research method and initials findings in the form of a SWOT (Strengths-Weaknesses-Opportunities-Threats) table are presented and discussed.

1.2 Blockchain technology

Blockchain is a peer-to-peer, distributed data structure that allows for the chronological recording and secure storage of transactional data (Li et al, 2018a). Blockchain's first application was introduced in 2008 by Satoshi Nakamoto, a pseudonym for an individual or a group, in a white paper on Bitcoin, the world's first cryptocurrency (Nakamoto, 2008). A blockchain is essentially an encoded digital ledger that is stored on multiple computers on a public or private network. Blockchains consist of nodes situated upon those networks which utilize some common communication protocol—each node on the network stores a copy of the blockchain and a consensus function is implemented to verify transactions to preserve the immutability of the chain (transactions cannot be changed) (Bashir, 2017). These nodes hold a copy of encrypted data blocks (records) chained to one another through hash codes (Swan, 2015). Therefore, each block is connected to the one before and after it, and each block is then added to the next in an irreversible chain and transactions are blocked together—hence the term 'blockchain' (see Figure 1)

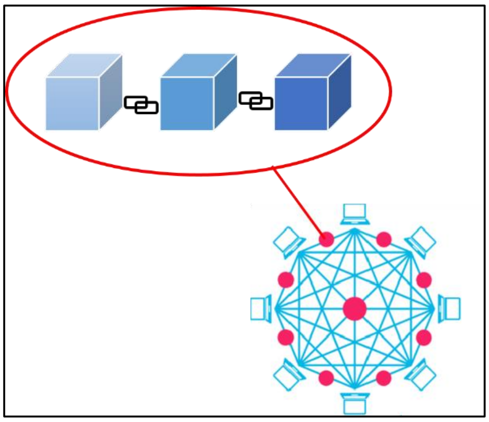

Figure 1: Encrypted and chained data blocks are distributed over multiple nodes in Blockchain

When a new transaction is created, the details of the transaction are broadcast to the network for validation and verification. If a consensus is reached by the nodes that the transactions in the block are valid according to a governance protocol, the block is appended to the blockchain and each node's copy of the blockchain is updated accordingly (Chang et el. 2017; Karafiloski and Mishev, 2017). Once these blocks are collected in a chain, they cannot be changed or deleted by a single actor. No single party or intermediary controls the data and the entire data infrastructure is visible to all parties. Within public blockchains, every transaction is 'permissionless' and users can remain anonymous. The network typically contains an incentivizing mechanism to encourage participants to join. Bitcoin and Ethereum are examples of public blockchains. Within permissioned blockchains participants need to obtain an invitation or permission to join. Access is controlled by a consortium of members (consortium blockchain) or by a single organization (private blockchain). Data security, cryptographic data encoding, distributed data storage and consensus mechanisms, anonymity, data auditability/traceability, resilience and fault-tolerance are the blockchain keywords (Ben Hamida et al., 2017).

1.3 Application of blockchain technology in AEC industry

It is evident that potential application of blockchain in the AEC is wide and varied. As the technology is still maturing, most of the applications in the literature are still conceptual with the discussion being not about ‘what do we need blockchain for’, rather the focus is on ‘how can blockchain improve this’ (BRE, 2018). Some of these potential application areas for the industry are facilitating collaboration and trust between stakeholders, peer-to-peer commercial transactions, digital passports, proof-of ownership and rights, supply chain traceability, smart contracts, faster planning and design processes, digital twins,, lower transactional and financial costs, proof of provenance, reduction of human error and improved Internet of Things (IoT) applications (Heiskanen, 2017; Kinnaird and Geipel, 2017; Turk and Klinc, 2017; Li et al., 2018a, 2018b; Penzes, 2018).

Blockchain has also potential to solve some pressing issues and obstacles to building information modelling (BIM), in particular issues around confidentiality, disintermediation, provenance tracking, multiparty aggregation, interorganizational recordkeeping, non-repudiation, traceability, data ownership and intellectual rights, change tracing etc. (Klinc et al, 2017; Turk and Klinc, 2017). Wang et al, (2017) proposed blockchain-enabled applications to improve the current processes of contract management, supply chain management, and equipment leasing.

Alongside those potential applications, several challenges facing the adoption of the blockchain technology by the AEC industry were also underlined in the literature (Bocek et al., 2017; Koutsogiannis and Berntsen, 2017; Ksehetri, 2017; Li et al., 2018b); authentication of data input in the immutable blockchain structure, legal gaps, unreliable and insufficient bandwidth capacity, human errors in coding of smart contracts, potentially enabling unethical and criminal activity, blockchain interoperability issues, significant energy consumption requirements by the nodes, exchange rate volatility in the cryptocurrencies, lack of organizational readiness, resistance to change and insufficient skilled human resources for blockchain.

So far, the use of blockchain in construction has been limited. Some are using it to store sensor data from buildings in a trustworthy and distributed way (Graphic, 2017). There were also speculations that Ethereum could host BIM applications (Salmon, 2017). The use of blockchain in co-housing projects has also been suggested (Lohry, 2017). Hultgren and Pajala (2018) examined how the blockchain technology can support supply chain transparency and material traceability in the construction industry along with identifying its potential consequences. Some blockchain-focused initiatives aiming at a wider adoption and investigation of the technology by the AEC industry has recently been set up (e.g. UK’s Construction Blockchain Consortium).

The study addressed the following research question: “How can construction industry leverage the potential of blockchain technology across the supply chain?”. To this end, the study sets the following research objectives:

- To identify the key players of a blockchain-enabled construction ecosystem.
- To understand the main strengths, weaknesses opportunities and threats of deploying blockchain technology in construction.
- To develop propositions for transformations (e.g. in skills, procurement and business models) needed in both the demand and supply chain of construction to deploy blockchain technology.

- 2. Research Method

The study follows an interpretative research philosophy and critical realism to understand how blockchain technology could impact construction and facilitate supply chain management. (Maxwell and Mittapalli, 2010). Critical realism is consistent with mixed methods, recognizes that complete objectivity against data is impossible and attempts to establish contextual validity (Shannon-Baker, 2016). The study is explorative in nature aiming to set directions for future research and application in blockchain-based supply chain management in construction.

There were two main sources of data: primary and secondary data' both of which qualitative in nature. Primary data were collected from semi-structured interviews with 17 subject matter experts. The experts were selected based on their professional background. Specifically, the sampling criteria included: (a) familiarity with blockchain technology, (b) engagement with digital technologies in construction, (c) professional experience in construction or technology space. No restriction was set as to the geographic location of the participants. The recruitment or the experts took place via professional connections, snowballing effect and contacts from social media.

Table 1 contains a description of the profiles of the interviewees, their background as well as the setting of the interviews. Secondary data were collected through desk research by reviewing ten recent industry and policy reports on the topic of blockchain technology introduction to construction. Table 2 shows the sources of these industry and policy reports.

Table 1: Identifiers (ID) and profiles of interviewees and duration of interviewees.

ID	Position	Organisation	Industry	Location	Interview type	Interview duration
1	Director	BIM consultancy	Construction	London, UK	Face-to-face	38 minutes
2	Director	Entrepreneur	Technology	London, UK	Face-to-face	35 minutes
3	Founder	Non-profit	Construction	Washington DC, USA	Face-to-face	50 minutes
4	Principal	Architecture & Law	Construction	London, UK	Face-to-face	42 minutes
5	Reader	University	Higher Education	Cardiff, UK	Face-to-face	75 minutes
6	Consultant	AEC Consultancy	Construction	Berlin, Germany	Face-to-face	52 minutes
7	Consultant	AEC Consultancy	Construction	Glasgow, UK	Face-to-face	58 minutes
8	Consultant	AEC Consultancy	Construction	Manchester, UK	Face-to-face	60 minutes
9	Director	Law Consultancy	Construction	London, UK	Face-to-face	43 minutes
10	Director	Law Consultancy	Construction	London, UK	Face-to-face	43 minutes
11	Senior Consultant	Design and Consulting firm	Engineering and Construction	London, UK	Skype meeting	38 minutes
12	Director	Blockchain Development	Construction	Paris, France	Skype meeting	42 minutes
13	Vice President	Blockchain Foundation	Construction	Washington D.C., USA	Skype meeting	36 minutes
14	CEO	Blockchain Technology company	Construction	London, UK	Skype meeting	37 minutes
15	Senior Researcher	Research Institute	ICT	Gothenburg, Sweden	Skype meeting	67 minutes
16	Head of VDC Infrastructure	Infrastructure	Construction	Jönköping, Sweden	Face-to-face	30 minutes
17	Sustainable Development Responsible	Project development and construction	Construction	Gothenburg, Sweden	Skype meeting	22 minutes

Table 2: Industry and policy reports on blockchain technology in construction.

Issuing organisation	Year	Main focus	Resource
Arup	2017	Smart cities, circular economy, tokens and engineering	Link
CDBB	2018	Smart contracts	Link
Deloitte	2017	Commercial Real Estate	Link
Digital Catapult	2018	Market research on industry status	Link
ENSTOA	2018	Smart contracts	Link
ICE	2018	Smart cities	Link
PwC	Text	Energy production and consumption	Link
FICCI- PwC	Text	Smart contracts, payments, procurement and asset management	Link
Thomson Reuters	Text	Construction and Real Estate	Link
WEF	2018	Environmental sustainability	Link

- 3. Empirical Findings

3.1 SWOT analysis

The findings from the primary and secondary data were recorded, interpreted, analyzed and grouped in the SWOT analysis format. SWOT analysis can be used to evaluate new technologies or directions for an organization or an industry (Andersen, 2007; Gould, 2012). Table 3 illustrates the SWOT analysis of the use of Blockchain in the AEC industry.

Table 3: SWOT analysis based on the empirical data about blockchain technology in construction.

Strengths	**Weaknesses**
Technical - Increased security in data storage and retrieval - Increased data traceability - Increased data transparency - Smooth handover of data - Data interoperability ***Ecosystem*** - Demonstrable outcomes in other sectors, e.g. FinTech and LawTech - Clear and time-stamped accountability chain - Immutability and tamper-less ledger of transactions - Able to skip the intermediary (middlemen) - Authenticity of product, certificate and information - Tokenised ecosystem (utility or security token) consisting of solution engineers is a potential use case.	***Structures*** - Private blockchains are more prone to be modified/hacked. - Robust data validation (proof-of-stake) systems are necessary - Private blockchains cannot communicate with each other at the moment. - Scalability of blockchains ***Skills*** - Lack of awareness at senior management level - Lack of skilled human resources. ***Industry Adoption*** - Lack of blockchain-based commercial or procurement frameworks - Lack of substantial exemplary use cases. - Lack of a legal foundations/regulations. - Lack of industry standards for blockchain - Insufficient evidence on the business case - Perceived high-risks and hesitation - Lack of incentives for smaller players
Opportunities ***New applications***	**Threats** ***Public action***

- The Internet of things (IoT) will be of the prime beneficiaries of blockchains - Blockchain can facilitate creating decentralised common data environments ***Industry adoption*** - Blockchains may be the trust layer just above the internet for digital transactions - Blockchain may accelerate digitalisation in the industry - Blockchains can facilitate various applications in commercial, supply chain and operations management in construction - Reduced commercial transaction costs - Information resilience (opportunity): blockchains' immutable nature will render information resilience a key subject in the industry ***Competition*** - SMEs can form trust-based commercial/procurement frameworks on blockchains SMEs can receive credibility and visibility from participating in blockchains,. ***Business environment*** - Stronger government involvement to legitimise the implementation and usefulness - Faster financing and allocation of payments in projects - Protection of Intellectual Property (IP) Rights - Increase in capital movement and investments - New Business model enablement - True sharing economy	- Energy management and use - Powerful organisations' and governments' trying to dominate and control the blockchain environment ***Technology Maturity*** - Limited view to the technology - The current "noise" and hype - a too optimistic picture of the technology ***Acceptability*** - Information resilience (threat): blockchains' immutable nature increases systems' sensitivity to low-quality information. The need for trust won't disappear but will shift focus to information input. - Lack of governance in peer-to-peer transactions - Lack of involvement from professional institutions in policy-making - Traditional culture and lack of innovativeness ***Competition*** - The existing digital divide between larger organisations and SMEs may worsen. - As a disruptive technology, increasing data transparency and peer-to-peer transaction possibilities may annoy some third party intermediary organisations and service providers in the industry that may lead them to trying to undermine or control the technology.

- 4. Analysis and discussion

4.1 Strengths

The known strengths of Blockchain were underlined by the interviewees as well. Blockchain is a distributed ledger, storing mathematically encoded and chained data blocks over multiple nodes for increased data security, traceability, and transparency. This creates a clear and time-stamped accountability chain, facilitating the authentication of a product, service, transaction, document (certificate) and information. Alongside these generic benefits, it was underlined that a smooth data handover and, for public blockchains, data interoperability between different applications can be attained for the AEC industry. There also exists some encouraging Blockchain outcomes recorded (e.g. FinTech and LawTech) in other industries for the justification of the technology's potential. Its potential ability to create a true sharing and peer-to-peer (P2P) economy will eradicate the need for third party middlemen and intermediaries that are nicking from the value generated between the service provider and the buyer.

4.2 Weaknesses

Some interviewees underlined that the full-potential of blockchains could be realized over public blockchains only as private blockchains are not much different than distributed databases in terms of data safety. They are more prone to unsolicited data modifications and manipulations in that sense. Further, public blockchains cannot communicate with each other at the moment. However, senior management in the AEC industry might opt for private blockchains for the sake of "better" or "centralized" control of their blockchain applications over faster transaction rates. This is also relating to the current lack of awareness at senior management level. Senior management in the

AEC industry should be correctly informed of advantages and disadvantages of public and private blockchains. The dissemination of blockchains will necessitate the adoption of robust data validation systems and procedures in the industry as data authentication will gain more prominence. The number of transactions that public blockchains can handle per second is currently limited due to the limited size of allowable blocks for safety concerns. This brings the question of blockchains' scalability provided their use is to increase substantially in the near future alongside smart cities and digital twins. Lack of skilled human resources that have a solid understanding of the AEC industry and blockchain development in different disciplines in the AEC industry (e.g. law, engineering, construction management etc.) is another major concern. It is evident from the literature review and interviews that the absence of blockchain-based commercial or procurement frameworks and governance mechanisms for the AEC industry is a barrier before the operationalization of the technology. In parallel to this, there are currently no substantial exemplary use cases in blockchain based asset tokenization, supply chain management, procurement etc. in the AEC industry. Gaps in legal regulations supporting blockchain-based supply chain and procurement mechanisms are hindering factors, which leads to a situation where there is insufficient evidence on business gains for the industry. Alongside the non-existence of industry standards for blockchain, the perceived high-risks and hesitation associated with the immaturity of the technology prompt AEC management to adopt a "wait-and-see" policy toward the Blockchain technology. For smaller companies specifically, the lack of incentives for blockchain adoption is a serious barrier.

4.3 Opportunities

Blockchains are envisioned to constitute the trust layer just above the Internet for all sorts of digital transactions in the AEC industry. Internet of things (IoT) based applications will be of the prime beneficiaries of Blockchain in this arrangement, particularly in facilities management, smart cities, digital twin creations, procurement and material and physical/digital component supply management. Also, blockchains can facilitate creating decentralized common data environments (e.g. blockchain-based cloud BIM platforms) for organizations, towns, cities and regions in the future as a trusted intermediary for two-way communication. Consequently, Blockchain may accelerate the digitalization agenda in the industry through overcoming some significant digitalization barriers associated with trust, transparency, data traceability, intellectual property rights and record keeping. Also, more robust precautions/procedures for information resilience will need to be in place as a key concern for data input of desired "quality" due to blockchains' immutable nature. The interviews confirmed the true potential of Blockchain in facilitating smart contracts, e-procurement, creating secure electronic identities and records for construction organizations (proof of work), electronic or physical asset tracking (e.g. for circular economy), collaborative procurement arrangements, crowdfunding (e.g. communities directly funding construction projects), secure peer-to-peer data transactions for commercial or operational purposes. (e.g. enabling BIM processes by reducing commercial disputes). Smaller organizations can form trust-based commercial/procurement frameworks on blockchains between each other to compete with larger organizations. They can also receive credibility and visibility from participating in blockchains (e.g. rating and assessing collaborators in projects). In line with this, new business models and the existing relational contracts, and partnering/alliancing arrangements will be supported by a Blockchain base, transparent commercial backbone. Project financing and transaction costs will reduce significantly, which will also help with the inclusion of smaller organizations in project delivery. On the commercial front again, faster financing and allocation of payments in projects can be realized through Blockchain, which will help organizations record more manageable cash flows. A stronger government involvement to legitimize the implementation of Blockchain is expected in the near future with increasing attention to the technology. Cross-border/regional capital movement and investments in the AEC industry may gain momentum due to the transparency induced by Blockchain.

4.4 Threats

With the extension of the use of Blockchain and the number of nodes involved in data transactions, energy requirements to maintain the system will also increase exponentially. This will further deteriorate the already poor sustainability records of the AEC industry. The lack of governance in peer-to-peer Blockchain transactions may lead to commercial disputes or exploitations. The current lack of involvement and *laissez-faire* approach to blockchain by policy makers in the AEC industry may further contribute to this lack of governance situation. The existing digital divide between larger organizations and smaller organizations may worsen. Smaller organizations may have to be excluded from blockchain-based supply chain arrangements, if they are not sufficiently prepared. With powerful organizations' trying to dominate and control the blockchain environment, a blockchain elite –just like the data elite today - can emerge. Also, as a disruptive technology, increasing data transparency and peer-to-peer transaction possibilities may annoy some third party intermediary organizations and service providers capitalizing on the status-quo in the AEC industry, leading them to trying to undermine or control the technology. The current "noise" and hype on Blockchains draw a too optimistic picture of the technology with many overarching promises that may lead to disappointments in practitioners when faced with realities – the technology is still maturing with operational issues. Limited view to the technology mostly around the popular cryptocurrencies or commercial arrangements will hamper blockchains' potential. The information resilience requirement can be a treat as well as an opportunity in the future as blockchains' immutable nature will increase organizations' and supply chains' sensitivity to low quality data. The need for trust will not disappear but will shift focus to data input and resilience. The notorious traditional culture and slow take-up of innovations are seen as threats before Blockchain as well like many other technologies and emerging concepts in the AEC industry.

5. Conclusions

Blockchain has recently gained significant attention from the construction industry. As a disruptive technology, it offers immense strengths/opportunities and possesses serious weaknesses/threats at the same time. The initial findings of a research project aimed at understanding the current issues associated with creating Blokchain based construction supply chains were presented and discussed in this paper using primary and secondary data. The findings are mostly in line with the recent literature investigating the implementation of Blockchain in the AEC industry. In that sense, more research is needed to better understand the specific roles and responsibilities of stakeholders (e.g. governments, policy makers, clients, larger and smaller organizations, suppliers, end-users etc) to overcome the identified threats and weaknesses of the technology. Also, detailed requirement analyses are needed to realize and operationalize the strengths and opportunities of Blokchain for the industry. Alongside those more conceptual discussions, a Blokchain use case around those opportunities is needed for a better understanding of the implementation of the technology in the AEC industry.

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