Blockchain in construction – hype, hope, or harm?

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Abstract

Business and public interest and investments in digital ledgers, smart contracts and virtual currencies such as bitcoin, has skyrocketed. Blockchain is indeed a hyped technology – and should therefore raise healthy skepticism. During construction production, projects and the involved companies take on a disintegrated economic flow and allocation of economic resources; these include supplies of materials and services, payments, accounting tasks, and other economic decisions, that are often treated second-hand by site management, subcontractors, transport companies, retailers and material suppliers. Within such a situation, blockchain technologies can maybe create value for stakeholders in handling this economic flow and integrating it with other information and material flows. So, in this sense, blockchain represents a hope for construction; however, this paper critically scrutinizes blockchain for construction, in trying to answer the question whether it indeed constitutes hope, or it is harmful. The paper will report from an ongoing study and development project aiming at implementing a blockchain prototype for digitalized construction logistics at a large building site. A literature review, undertaken in several iterations from May 2018 to summer 2019 and following the emergence of the hype for blockchain, reveals visions and a few prototypes of related systems for construction. Theoretically, the paper adopts a sociomaterial approach, appreciating that blockchain is as much about social interaction and development of trust, as it is about digitally facilitating economic transactions. Several critical issues threatening to jeopardize the adoption of blockchain are analyzed in the paper, such as the protection of the economic data during transactions, permission access control which only allows a few people to enter the system while still requiring a minimum of trust between those already inside the system, and possible financial speculation on the utilized cryptocurrencies. The way construction stakeholders can mitigate such issues, thus enabling blockchain to become a realized hope rather than harming the sector, is discussed. Probably the largest risk relates to unrealistic hopes of full transparency in open blockchain systems, potentially making the systems too vulnerable to external intervention and even speculation. Permissioned systems with some level of hierarchy appear to be a feasible compromise solution mitigating the potential harm.

Keywords: Blockchain, construction logistics, construction supply chain, security, trust.

1. Introduction

Blockchain, initially conceptualized as the technology underlying bitcoin (Singhal et al., 2018), has been increasingly hyped due to the skyrocketing of business and public interest and investments in digital ledgers, smart contracts and virtual currencies (Wiatt, 2018). In social interaction terms, blockchain is a team technology that facilitates collaboration to counter business challenges; in technical terms, it is a shared, decentralized, and distributed digital ledger replicated across unique nodes representing interacting entities (such as organizations or individuals) (O'Leary, 2017; Penzes, 2018; Singhal et al., 2018; Verhoeven et al., 2018), and can serve as a peer-to-peer value transaction system (O'Leary, 2017; Verhoeven et al., 2018), with no need for the transactions' in-between verification, security and settlement through trusted intermediate third-parties (Singhal et al., 2018; Verhoeven et al., 2018). The database stored on each such digital ledger is append-only, and every new entry is permanent, immutable, and replicated across the nodes (Swan, 2015; Singhal et al., 2018); each new entry is added as a "block" in the chain, it stores a finite set of transaction-related data of a fixed size, and is orderly connected with the previous blocks (Verhoeven et al., 2018). The transaction history follows the chain of blocks, resolves the transactions by holding both the present and the relative historical information, is shared across the nodes, and can only be updated through consensus and validation, utilizing algorithmic methods such as "proof-of-work", "proof-of-stake" and "proof-of-authority" (O'Leary, 2017; Penzes, 2018; Singhal et al., 2018; Verhoeven et al., 2018).

Aside bitcoin, potential applications of blockchain are continuously being investigated; such investigation also points to blockchain's disruptive aspects (Konstantinidis et al., 2018), like its potential as a process performance measurement tool (Kuhi et al., 2018; Ye et al., 2019), and a catalyst for the establishment of a digital ecosystem with the Internet of Things (IoT) (Woodhead et al., 2018). For the construction sector, there has been research on blockchain solutions both for the theoretical understanding and deriving of methodological frameworks on process re-engineering (e.g. see the suggestions in Barima, 2017; Turk & Klinc, 2017; Wang et al., 2017; Kamenetskii & Yas'kova, 2018; and Li et al., 2019b), and for the practical development and implementation of relative applications (e.g. see the applications investigated in Mathews et al., 2017; Wang et al., 2017; Mahmod & Hinton, 2018; Navadkar et al., 2018; Penzes, 2018; Gerber & Nguyen, 2019; and Nguyen et al., 2019).

Among the relative research efforts and focusing on on-site construction logistics and supply chain management, the disintegration of the material and economic flows has been identified as persistent (Shin, Chin, Yoon, & Kwon, 2011), and its potential resolution with the implementation of blockchain has been indicatively investigated, but not systematically in – among others – Wang et al., 2017; Dobrovnik et al., 2018; Lanko et al., 2018; Li et al., 2019b; Penzes, 2018; and Rubio et al., 2018. With the integration of the material and the economic flows through blockchain, a holistic overview of the full construction logistics can be facilitated, through the fostering of trust, transparency and traceability in the relative transactions, enhancing of the deliverables' quality appraisal, facilitation of supply chain stakeholders' collaboration, optimization of constructability (as it is positively impacted by a holistic view on logistics, supply chain integration, and trusted cooperation between stakeholders (Kifokeris & Xenidis, 2017)), and creation of value for the interested parties. Such a creation of value could even formulate new digital business models – namely, digital transformations of the background and processes of organizations in order to create, deliver and capture value (Beck et al. 2017; Konstantinidis et al., 2018).

The creation of such value and its culmination into the relative digital business models tackling the flow disintegration in construction logistics through the use of blockchain, constitute a hope for the construction sector, following the hype with which blockchain solutions are being currently approached. In this paper, and trying to investigate the hands-on realization of such a hope through lessons-learned from other relative examples, a targeted literature review on blockchain-related visions and prototypes for the construction sector, is conducted. However, to also consider issues threatening this realization, thus rendering such a solution a potential form of harm instead of hope, a complementary targeted literature review identifying relative jeopardizing factors, is conducted. For this dual identification, the paper draws on a sociotechnical approach (Orlikowsky, 2016), which entails that the development of digitalization is an intertwined social and technical process, since sociotechnical theories highlight the way technology is co-shaped with practice. Following is the discussion on the research findings and the

role of the construction stakeholders in facilitating the realization of the hope and the mitigation of the harm, and the conclusions of the current research effort.

2. Blockchain: a sociomaterial perspective

As mentioned in the introduction, blockchain is a digital technology that can be potentially implemented in a number of building processes in a diverse manner (see, for example, in Barima, 2017; Turk & Klinc, 2017; Penzes, 2018; Gerber & Nguyen, 2019; and Nguyen et al., 2019). However, the largely non-systematic approach on most of these possible implementation efforts reveals that they are largely rather visions, with only a few actual applications leading to working prototypes, which can later lead to the corresponding adoption in use (see, for example, the ones mentioned in Penzes, 2018; Gerber & Nguyen, 2019; and Nguyen et al., 2019). "Vision" refers to the first and the beginning of the second level of the maturity and technology readiness scale for applications (Gerber & Nguyen, 2019), namely "concept" and "demonstration"; "prototype" refers to the completion of the "demonstration" and the commencing of the third level of the scale, namely "commercialization"; and "adoption" refers to the completion of "commercialization", the final level of the scale, which translates into use in praxis.

To better analyze the gradual embedding and interaction of blockchain in and with building processes and practices, we propose the conversion of the maturity and technology readiness scale into the three aforementioned levels of vision, prototype, and adoption into use. This conversion is compatible with the fact that in the current effort, we mobilize the sociotechnical approach for our research on blockchain for construction in general and building logistics in particular, which entails that the development of digitalization is an intertwined social and technical process (Orlikowsky, 2016). We focus on the sociotechnical approach defined as sociomateriality, which emphasizes the way digital technologies are co-shaped with practices (Bader & Kaiser, 2017; Orlikowsky, 2016). In more detail, from the lens of sociomateriality, the social and the material parts of digital technologies are inseparable (Orlikowsky, 2016). For the particular case of blockchain for building logistics and supply chain management, the sociomaterial scope leads to the perspective that blockchain cannot be understood separately from the building logistics processes themselves, nor their practical realization from vision to prototype and adoption into use. Thus, in this context, the primary unit for blockchain research is not individual entities with well-delimited boundaries and attributes, but rather phenomena materially embedded in practice (Orlikowsky, 2016).

A key aspect of the sociomaterial perspective in the aforementioned context is the discussion on the autonomy-control paradox (Bader & Kaiser, 2017; Zuboff, 2019). While blockchain advocates the claim that the fundamental aspects of the technology itself generate trust and security, it is possibly more sociomaterially precise to understand these generated phenomena as a coexistence of control and autonomy. Blockchain provides overall transparency through generalized and decentralized control, but on the same page, it appears to reduce the autonomy of the single actors represented by the nodes of the blockchain network (Bader & Kaiser, 2017; Zuboff 2019).

3. Blockchain visions and prototypes for construction

As introduced in the first section of the current paper, the integration of the material and the economic flows through blockchain can bring about a holistic overview of the full construction logistics process, through the fostering of trust, transparency and traceability in the transactions within the flows, the enhancing of the deliverables' quality appraisal, the facilitation of supply chain stakeholders collaboration, the optimization of constructability, and the creation of value for the interested parties – which can then be culminated into new digital business models for the construction supply chain actors implementing such a system. Trying to investigate the hands-on realization of such a hope, we apply a sociomaterial lens in a targeted literature review on blockchain-related visions and prototypes for the construction sector.

In the vision level, Gerber & Nguyen, 2019, and Nguyen et al., 2019, have identified the following market areas and their associated technologies which can be integrated with blockchain solutions to facilitate the corresponding projects and create value for the relative actors:

- Cities – the associated technologies are utilized for the procurement and supply chain management, and the IoT-integrated smart city.
- Energy – the associated technologies are utilized for energy microgrids, electric vehicles' power sharing, smart meter billing, clean energy sources, and renewable certificate tracking and trading.
- Property – the associated technologies are utilized for smart contracts for real estate, title records, lease agreements and automated payments, and property data management.
- Transportation – the associated technologies are utilized for ride hailing, car sharing payments systems, material passports, and biometrics to enable gateless borders.

In Penzes (2018), there have also been identified areas and relative technologies with the potential of hosting integrated blockchain solutions. Some of them, like procurement and supply chain management, corresponded to the ones mentioned above; in addition, other identified areas and technologies included maintenance survey, site management record keeping, smart contract-governed site working hours register and payment systems, design package submissions through smart contracts, on-site health and safety incident registration, and material tracking for improved sustainability. In addition, in Li, Greenwood and Kassem (2019a), a systematic literature review has been conducted on conceptual models and practical use cases regarding blockchain and digital ledger solutions in the built environment, discretized in the areas of smart energy, smart cities / sharing economy, smart government, smart homes, intelligent transport, Building Information Modelling (BIM) in construction management, business models, and organizational structures.

Apart from the cases of visions, there are also certain examples for construction sector-related blockchain solutions that have reached the point of prototype, thus offering a richer understanding on the actual realization of such systems. Notable among such prototypes are the following:

- BIMCHAIN (Mathews et al., 2017; Penzes, 2018; Gerber & Nguyen, 2019, and Nguyen et al., 2019): this prototype is within the market area of cities, and the application areas of BIM coordination and smart asset management. The proponents of BIMCHAIN argue that blockchain can facilitate security, liability, transferability and live data collection; acting as a digital immutable ledger in BIM-supported processes. It allows the project to be mapped and tracked at every stage, thus establishing ownership of models and tracking incremental improvements and changes during the design stage. The related data can be internally and externally controlled and relied upon, increasing transparency and trust, and reducing corruption, inefficiencies, and contractual disputes. To bring about such benefits, BIMCHAIN can act as a legally binding tool, with the aim of high-quality and accountable BIM products. Within BIMCHAIN, smart contracts can be drawn up and payments are automated to ensure that the related actors are committed to achieving their stated outcomes. A market-ready product is expected in 2019.
- Circularise (Gerber & Nguyen, 2019, and Nguyen et al., 2019): this prototype is within the market area of cities, and the application area of circular economy. Within it, blockchain solutions can allow the effective and reliable tracking of materials and components throughout the whole supply chain. Considering the reusability of materials and components as part of their lifecycle, such blockchain-enabled tracking can continue in perpetuity. The manufacturers, recycling agencies, and clients, can consistently and confidently monitor the circularity of their products. In this vein, Circularise, an open and distributed communications protocol, offers an open-source distributed communications protocol for a circular economy, thus allowing information exchange throughout the supply chain and facilitating transparency around product and material histories and destinations.
- SiteSense® (Gerber & Nguyen, 2019, and Nguyen et al., 2019): this prototype is within the market area of cities, and the application area of cash flow construction management. Blockchain can connect all project stakeholders, allowing each actor to track progress and automate payments according to completed work packages. Thus, construction progress can be more effectively monitored, and any cash flow problems mitigated. As a related solution, SiteSense® utilizes blockchain in a cloud-based project site field tool setting to monitor, categorize and maintain relevant resources and documentation. The list of transactions is stored in a private blockchain accessed only by the related stakeholders.
- Blockchain tool for real estate transactions and mortgage deeds (Gerber & Nguyen, 2019, and

Nguyen et al., 2019): this prototype is within the market area of property, and the application area of sale and asset transactions. This tool is piloted by Sweden's land registry authority, Lantmäteriet, and other partners. It connects sellers with real estate agents and buyers and integrates information on land registry and bank accounts. Recent demonstrations of the tool include identifying verification processes, approving and executing digital agreements, and exporting finalized legal contracts. Thus, the process of signing the purchase agreement through the registration of the sale can be facilitated to last only a few days or even hours, instead of four to six months.

- Shipment tracking solution by Maersk and IBM (Gerber & Nguyen, 2019, and Nguyen et al., 2019): this prototype is within the market area of transportation, and the application area of freight tracking and logistics. This venture aims to digitize trading workflows and end-to-end shipment tracking. Within the system, each stakeholder can track the progress of items throughout the supply chain, and check customs documents, bills of lading and other freight data. The role of blockchain is to ensure a secure, well-documented data exchange and transparent repository, and reduce the cost of cumbersome manual paperwork.

The lessons-learned of these visions and especially prototypes for the potential of blockchain-enabled construction logistics with integrated material and economic flows, approached from a sociomaterial angle, will be investigated in the discussion featured later in this paper.

4. Threats to the adoption of blockchain for construction logistics

There can be several jeopardizing factors threatening the adoption of blockchain for construction logistics with integrated economic and material flows. Central among them are the ones regarding the security aspects of blockchain technology itself, which are investigated in Kareem et al., 2018; Penzes, 2018; Sklaroff, 2018; Underwood, 2018; and Veuger, 2018. These threats can be discretized into the following issues: (a) lack of trust of the stakeholders among themselves and in the adoption of blockchain, (b) the disruptive nature of this technology can be viewed with discomfort, and extreme opinions even regard it as a fad, (c) the anonymity of the nodes in the distributed network can lead to illicit activities (e.g. in the purchasing and on-site delivery of material and equipment), (d) the cryptocurrencies used can cause the loss of real-value grasp and can be an object of financial speculation, (e) breaches in the system cryptography can lead to immediate and unrecoverable losses of virtual funds (however unlikely and/or extremely costly in computational means this may be) – as opposed to the potentially retrievable fiat currency funds, and (f) the automated processes can be imbued with such inflexibility that they could even lead to loss rather than creation of value for the stakeholders (e.g. in the case of transactions between the main contractor and the suppliers and subcontractors across the supply chain). Moreover, blockchain is considered by some researchers as ambiguous regarding the value created by implementing the relative solutions – especially for construction logistics – (e.g. in Li et al., 2019b), and as cumbersome to implement without the simultaneous implementation and support of other types of infrastructure as well, such as BIM and IoT (Ye et al., 2019). Many of these threats are also identified in studies of other application areas than construction (Hackius & Petersen, 2018; Khong & Escobar, 2017).

In Penzes (2018), a survey among industry leaders further recognizes barriers in blockchain adoption for construction, divided between early challenges (regulatory uncertainty, lack of trust among users), and obstacles expected to be met in 3-5 years (cost of implementation, question of how to start, and lack of governance). In the same effort, some more dedicated sector-related challenges are identified, such as unmovable organizational vested interests, cultural organizational structures, narrow profit margins, and industry fragmentation. Moreover, Li et al. (2019a) identify as key challenges possibly threatening the adoption of blockchain in the construction industry issues on authentication of data and connectivity, coding of smart contracts, energy consumption of the mining process of proof-of-work blockchain protocols, exchange rate volatility, interoperability, legal constraints, possible malicious attacks, and the industry-wide readiness of adoption and resistance to change. Difficulties in the market adoption of blockchain, misconceptions regarding what it is and how it can be used, and the currently non-existent legal regulations framing its use, are identified by Poszler et al. (2019), as especially detrimental for blockchain implementation for, specifically, logistics and supply chain

applications, including the ones related to the construction sector.

Coupled with the challenges are the potential limitations of such an implementation, as identified both during and after the literature review and through discussions with practitioners in the Swedish construction sector. At this point, there is little widespread understanding of the blockchain technology within the construction sector (and especially construction logistics), and the correspondingly dedicated and/or knowledgeable practitioners are few (Barima, 2017; Li et al., 2019a). This can lead to the need of outsourcing the development process of blockchain prototype to blockchain technicians, who may not necessarily be familiar to the particularities of construction logistics. Furthermore, cryptocurrencies may be increasingly accepted for transactions in parts of the construction industry, but they are not accepted by all; and they cannot be avoided in the first place, since they are essential for the function of the blockchain itself. Finally, an always present challenge is the stimulation of the respective actors into adopting a new digital business model utilizing blockchain (Barima, 2017).

5. Discussion: lessons-learned and the role of construction stakeholders

When reviewing the emerging knowledge on blockchain in construction, it is clear that the processes in an around building logistics actually represent a possible field of blockchain implementation, especially for the realization of a solution of blockchain-enabled construction logistics with integrated material and economic flows. However, the lessons-learned from the visions, prototypes, threats and challenges connected to the implementation of blockchain for the construction sector (in general) indicate that a lot of ground has yet to be covered for an actually realized, commercialized and adopted application. The visions are interesting and show potential, but cannot really be assessed until they reach a higher level of technological readiness and maturity; the prototypes may be on track for such a step of development, but most have not reached that just yet; and the threats and challenges still need to be tackled, with some of them being particularly acute in the construction industry (e.g. the low level of knowledge on related technologies among construction-oriented practitioners). Things can be even more tentative for construction logistics in particular, since a business case for the application required to support the implementation of a blockchain system appears to be barely established – if not still absent. The related stakeholders are under these circumstances prone to blocking changes due to a focus on shorter-term impacts (Cooper, 2018).

Therefore, it is crucial to focus on the issue of value creation for all interested parties and stakeholder groups across the supply chain, and to present them with the benefits of blockchain implementation to both themselves and the wider sector (Cooper, 2018). For this, it should be considered that the potential applications may involve more than just agents of the construction industry in specific, as well as different levels or stakeholders within the built environment sector; thus, future work on the development of related blockchain solutions should focus on the value propositions to each stakeholder at each and every phase of the utilization of such a solution (Cooper, 2018). Mapping all stakeholders and interactors within a blockchain-induced solution for construction logistics (especially one seeking to integrate the two main supply chain flows, namely the material and the economic one) and engaging with these groups from the beginning, would optimize the creation and demonstration of the value for each (Cooper, 2018), while also helping to overcome the aforementioned threats and challenges.

The insights mentioned above are in line with the sociomaterial take on the blockchain adoption for construction logistics, as well as the existence of the control-autonomy paradox. For such a perspective, taking as an example the state of the construction sector in Sweden, certain set-ups of stakeholders can be largely identified: (1) large contractors integrating building logistics services internally, to overcome transaction issues and maintain full power over the material supply and economic flows; (2) clients employing small independent logistics consultants to facilitate different interests in the logistics setup, and (3) third-party actors such as construction equipment or industrialized housing suppliers, offering dedicated digital logistics solutions.

These set-ups represent different corresponding business models and forms of collaboration between the participating stakeholders; but rather than viewing these set-ups as technical choices between rational and discernible modes of operation (something recurrent in operations management

and business economics), through the sociomaterial approach they are understood as different sociotechnical solutions involving specific distributions of power. The first set-up signifies a more traditional power balance. The second introduces a neutral (in terms of interactions and power distribution) facilitator of the logistics flows; the role of these facilitators is usually signified according to the clients' power and prerogative. The third set-up emanates from strategic moves of companies operating in a field tangential to the construction logistics themselves, and commencing their gaining of influence. In all set-ups, the corresponding operational frameworks are not only influenced by the process of knowledge exchange (Gustavsson, 2018), but also constitute a type of a power and control-autonomy struggle coupled with the considerations of adopting a disrupting digital technology.

Hence, adopting blockchain solutions integrating the material and economic flows within new digital business models for each set-up, should also consider these dimensions and the way they can be addressed by all related stakeholders – and also all the issues emanating from and connecting to those dimensions. In terms of security, for example, large urban construction sites can suffer from theft in material supplies. It is thus underlined that internal trust among participants in a blockchain, in which there is limited or no centralized control, should be facilitated. In this vein, it might be necessary to set up a permissioned access control system and implement a set of processes to protect the blockchain from external threat and mitigate the potential of it constituting a harm. In addition, the issue of integration may involve technical interoperability bottlenecks, changes in work practices and organizational re-engineering. The initial placement of a blockchain solution to integrated building logistics would probably be on top of an information infrastructure consisting of a series of different systems connected to accounting, project planning, quality control, access control, and site planning; then, the adoption of common standards (e.g. for the structuring of digital ledgers), may be in order.

6. Conclusions

Blockchain adoption for construction logistics may bring about optimized ways to tackle problems in the field, especially when discussing solutions integrating the material and economic flows across the construction supply chain as a dimension of a new digital business model – an issue of disintegration that has been identified as recurrent, and the tackling of which could bring about a holistic overview of the full construction logistics process, foster of trust, transparency and traceability in the related transactions, enhance the deliverables' quality appraisal, facilitate the supply chain stakeholders' collaboration, optimize constructability, and create value for the interested parties. Lessons-learned from visions and/or actually operating prototypes of relative solutions in other construction-related contexts – such as urban development, maintenance survey, site management record keeping, smart contract-governed register and payment systems, smart contract-governed design package submissions, on-site health and safety incident registration, material tracking for improved sustainability, smart energy, smart cities and the sharing economy, smart government, smart homes, intelligent transportation, Building Information Modelling and construction management – indicate a strong potential for the adoption of blockchain in construction logistics. However, there are also threats and challenges in such an adoption, like the lack of trust of the stakeholders, speculation on the cryptocurrency value, loss of funds, misconceptions on its use, and ambiguous value creation for the interested stakeholders.

A sociomaterial perspective can help in understanding blockchain's potential, and also the aforementioned challenges and threats, and their coupling with the actual organizational set-ups of the stakeholders collaborating across the supply chain (e.g. contractors encompassing logistics competences, or clients employing third-party logistics consultants). Moreover, it can facilitate the understanding of these matters not only as technical choices between rational and discernible modes of operation, but also as different sociotechnical solutions involving specific distributions of power – something essential when having stakeholders with often conflicting interests, as the ones in construction logistics and supply chain management. By taking these dimensions into account, it can be deduced that the matter of adopting blockchain for construction logistics is something far more complex than just tinkering around a new technological solution. In conclusion, there should be a continuous and significant effort in research, implementation and testing of prototype applications of blockchain solutions for construction logistics (especially when tackling the integration of flows such as the material and economic ones), to reach a point of certainty regarding the feasibility of such

solutions. The adoption of a technology as blockchain should be carefully approached, so as it can be realized as a hope for the construction sector, rather than cause harm following a hasty implementation due to the hype surrounding a buzzword.

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