Stakeholders' Perspective on Blockchain and Smart Contracts Solutions for Construction Supply Chains

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Abstract

The construction industry produces one of the most complex and substantially large structures such as buildings, bridges, dams and tunnels using lengthy, network structured and dynamic supply chains with multiple internal and external suppliers. Long and complex supply chains make it difficult to monitor compliance, provide ultimate assurance of the final product and often lead to increased cost with payment delays. The technology that underpins cryptocurrencies is known as blockchain. However, the capabilities of blockchain can be extended far beyond cryptocurrencies. It enables existing applications to be improved and new applications such as blockchain-powered election, healthcare, identity management, power grids, supply chain, property, smart contracts and so on. This paper aims to compute the stakeholders' perspective on blockchain and smart contracts in the construction industry. As the primary data collection methodology, an industry engagement workshop in the form of round-table discussions was conducted. Each round-table comprised of both academics and industry participants with different context from the construction industry. The table composition was four industry practitioners and two academics with the responsibility of moderating the discussion for all six groups. There were 57 responses, and 18 unique perspectives were identified. A word cloud was generated by using the frequency of responses to identify the density of each perspective. The key findings of the data analysis highlighted efficiency, trust, fair, security, transparent, accountability, compliance and standardisation were highlighted as the stakeholders' primary perspective on blockchain and smart contracts based solutions for the construction supply chain. Moreover, meantime highlighted construction industry requirements and drivers of blockchain and smart contracts are reconciled. So, the findings will help in implementing better blockchain solutions to the construction industry in future.

Keywords: Blockchain, Smart Contracts, Construction Information Systems, Supply chain Management, Stakeholders' Perspective

1. Introduction

The construction industry makes a significant impact to the global economy and global construction industry output was over than 10 trillion USD in 2017 (GlobalData, 2018, McKinsey Global Institute, 2017), and it is approximately 13 per cent of the global gross domestic product (GDP) (McKinsey Global Institute, 2017). The construction industry produces some of the most complex and largest objects such as buildings, bridges, dams, tunnels. The complexity requires the integration of many specialists and suppliers of products, components and sub-elements to construct a building or a structure (Ashworth and Perera, 2018) through multiple supply chains. Usually, the construction industry has lengthy, network structured, dynamic supply chains with a large number of internal and external suppliers (Cheng et al., 2001, Papadopoulos et al., 2016). The complex and low transparent present construction supply chains have a significant number of issues (Deming, 1986, Danuri et al., 2006).

The dawn of the Industry 4.0, has seen the development of the Financial Technologies (FinTech) and their applications. The most prominent of these is the developments in cryptocurrencies such as Bitcoin, Ethereum, Ripple, EOS and so on. The technology that underpins cryptocurrencies is known as blockchain which was invented a decade ago (Underwood, 2016, Efanov and Roschin, 2018). The blockchain is a mechanism to replicate, share, and synchronise data spread across different geographical locations such as multiple sites, countries, or organisations. Accordingly, the main property of blockchain technology is that there is no central administrator or centralised data storage mechanism (Walport, 2016). However, the capabilities of blockchain technology can be extended far beyond cryptocurrencies. It enables existing applications to be improved and new applications such as smart contracts, blockchain-powered election, smart power grids, smart property and so on (Buterin, 2017, Di Iorio, 2017, Iansiti and Lakhani, 2017, Underwood, 2016). The simple meaning of smart contracts is self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. Smart contracts permit trusted transactions and agreements to be carried out among disparate, anonymous parties without the need for a central authority, legal system, or external enforcement mechanism. They render transactions traceable, transparent, and irreversible. The code and the agreements contained therein exist across a distributed blockchain network (Alharby and Moorsel, 2017, Hans Rudolf, 2017, Luu et al., 2016, Silverberg et al., 2016). This research was an attempt to identify stakeholders' perspective on blockchain and smart contracts based solutions for construction supply chain concerns.

2. Literature Review

2.1 Construction Supply Chain

A supply chain is a network of different processes of multiple firms, which are linked as upstream (i.e., suppliers) and downstream (i.e., customers) to deliver products or services to ultimate consumer (Christopher, 1992, Mentzer et al., 2001). Supply Chain Management (SCM) concept flourished in the manufacturing industry (Shingo, 1988) and latest SCM systems are trying to absorb modern Information and Communication Technologies (ICT) such as cloud computing, social media, Internet of things (IoT), Artificial intelligence (AI), Big data, multichannel communication, data science and so on (Ross, 2015).

Supply chains of project-based industries such as construction have inherent uncertainties due to the complexities involved (Behera et al., 2015). Inherit dynamic and complex nature of the construction supply chains negatively impacts most of the stakeholders including client, contractor, sub-contractors, suppliers and others. The most adverse impacts are related to payments inefficiencies. Over and above the long payment settlement periods as stipulated in the contractual arrangements, there is a substantial amount further payment delays (Danuri et al., 2006) and a considerable number

of partial payments and non-payments observed in the construction industry (Ramachandra and Rotimi, 2011). Due to these payment inefficiencies, cost of finance is significantly increased to cover-up to delay risk. Furthermore, the complex low transparent supply chains are weakening the level of trust and security of deliverables (Deming, 1986, Danuri et al., 2006). Wong (1999) has discussed compliance issues in construction, especially subcontractors and small suppliers in the higher end of the supply chain provide little or no guarantee of quality and professional competence. Therefore, in the construction industry, the main contract has to oversee and ensure compliance with the client's requirements. Moreover, subcontractors and small suppliers have a significant impact on delays in the projects (Wong, 1999). Therefore, it is essential to address issues with adversarial relationships in the supply chain are fundamental in providing greater efficiency in the construction industry.

2.2 Blockchain and Smart Contract

The dawn of the Industry 4.0, has seen the development of the Financial Technologies (FinTech) and their applications. The most prominent outcome is cryptocurrencies such as Bitcoin, Ethereum, Ripple. The technology underpins cryptocurrencies is known as blockchain or digitalised distributed ledger (Underwood, 2016, Efanov and Roschin, 2018). However, the capabilities of blockchain technologies can be extended far beyond cryptocurrencies. It enables existing applications to be improved and new applications such as blockchain-powered election, power grids, supply chain, property, smart contracts and so on (Buterin, 2017, Di Iorio, 2017, Iansiti and Lakhani, 2017, Underwood, 2016).

The blockchain is a mechanism to replicate, share, and synchronise data spread across different geographical locations such as multiple sites, countries, or organisations. Accordingly, the main property of the distributed ledger is that there is no central administrator or centralised data storage mechanism (Walport, 2016). Blockchain contains records of transactions as a chain of data blocks that are shared with other members as shown in Figure 1. Each transaction is confirmed by the agreement of a majority of members for making fraudulent transactions. Once that confirmed by members and accepted by the blockchain, it can never be altered or deleted (Efanov and Roschin, 2018, Underwood, 2016, Gupta, 2017, Iansiti and Lakhani, 2017).

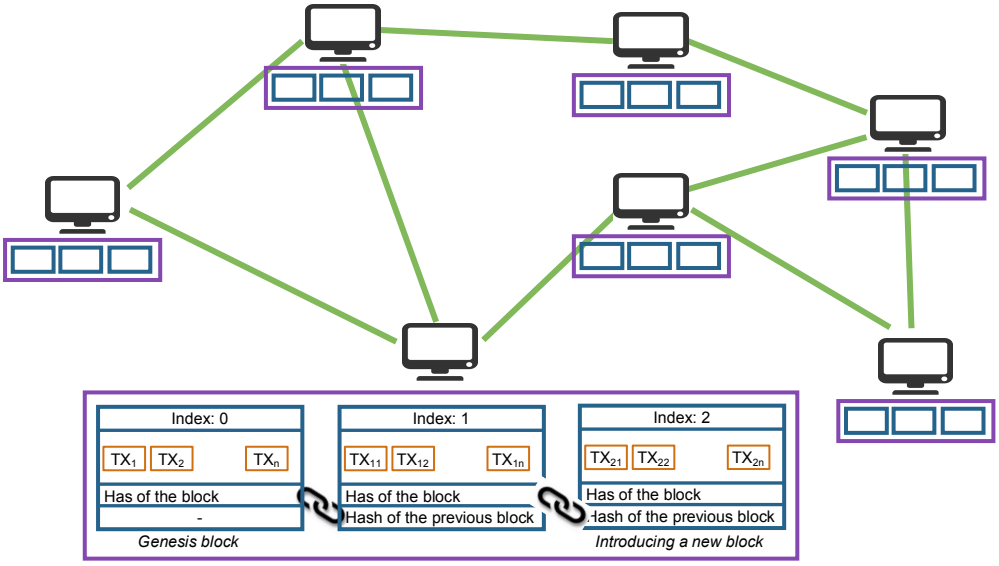

Figure 1: Blockchain network architecture

There are three main types of blockchain networks are public, private and consortium. The public blockchain is also called as permissionless blockchain, and it is open to anyone who wishes to participate as a member of the blockchain network. All the members of the network are allowed to access any data and read any transactions on the blockchain (Lewis et al., 2017). The private blockchain is also called as permissioned blockchain, and authorised participants can only join the

network (Martinovic et al., 2017). Consortium blockchain usually called as federated blockchains is partly private blockchain solution without a single owner (BlockchainHub, 2017). Common applications with low confidential data can use public blockchain platforms, private blockchain platforms are suitable for the enterprise-level secure application, and consortium blockchain platforms are suitable for the group enterprise-level application with a common interest (Hearn, 2016). Bitcoin, Ethereum and EOS.IO are public, and Hyperledger Fabric is private, and R3 Corda is consortium currently available famous blockchain platforms.

Smart contracts were first proposed in 1994 by Nick Szabo as a computerised transaction protocol (Hans Rudolf, 2017). The smart contract can be used to satisfy common contractual conditions including payment terms, liens, confidentiality without a central authority, or external enforcement and minimising malicious and accidental errors (Szabo, 1994). The simple meaning of smart contracts is self-executing contracts or set of rules with the terms of the agreement between buyer and seller being directly written into lines of code and exist across a distributed, decentralised blockchain network (Hans Rudolf, 2017, Luu et al., 2016, Silverberg et al., 2016).

Turing-complete is the key factor for creating a distributed application by using all the rich functions available in such programming languages (Luu et al., 2016, Li et al., 2017). Intentionally, Bitcoin has been designed with limited programming capabilities. So, it does not support for smart contact. However, Most of the modern blockchain or second generation blockchain networks such as Ethereum, Hyperledger Fabric, Quorum, Zen, Neo, EOSIO (Alharby and Moorsel, 2017, Luu et al., 2016) and many others support smart contracts where developers can build and run the various distributed applications called DApp on top of blockchain networks (Risius and Spohrer, 2017, Luu et al., 2016, Li et al., 2017). In other words, smart contracts are computer programs that run on blockchain networks and can automate various activities based on the conditions. Zhang et al. (2018) stated that "smart contracts can store data objects and define operations on the data, enabling development of DApps to interact with blockchains and provide seamless services to the application users" as shown in Figure 2. The smart contract provides better uniformity, accuracy, interoperability effectiveness, accountability, fraud resistance, integrity and many others compare with a traditional software solution. The most significant impacts from smart contract are self-contentedness, no-physicality and disintermediation.

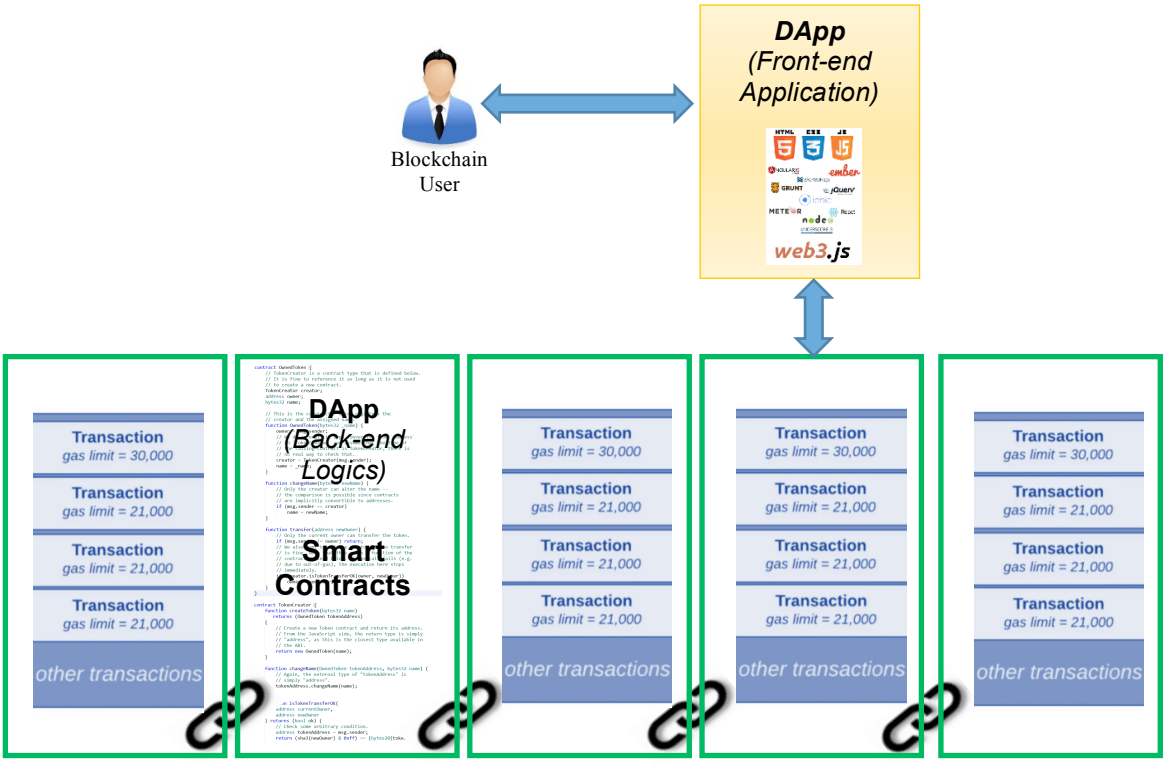

Figure 2: DApp and smart contracts in blockchain network

Five main properties of blockchain environment such as decentralisation, transparency, immutability, anonymity or pseudonymity and Turing-complete smart contracts provide high scalability and performance blockchain based systems have better decentralisation, anonymity, security, immutability, auditability, veracity, transparency, disintermediation and trust compare with traditional systems (Rodrigo et al., 2018). Most of the advantages enable with blockchain, and smart contracts based systems due to these key properties compare other systems. The best example of these features is cryptocurrencies, and it clearly shows a great extent of these features.

Three generations of blockchain application can be found during the last decade such as Blockchain 1.0 for the cryptocurrencies, Blockchain 2.0 for digital finance and Blockchain 3.0 for digital society (Swan, 2015, Zhao et al., 2016). Blockchain 1.0 or cryptocurrencies present market value is around USD 130 billion (Coin Market Cap, 2013) and blockchain 2.0 based smart contracts both got great success during the last couple of years (Lu and Xu, 2017). However, blockchain 3.0 or industrial applications are still in development level. Some blockchain based initiations are foreign aid, voting, transportation, food and agriculture, healthcare, logistic, retail, charity and microfinance. There is a great potential for blockchain and smart contract based applications for Construction and Built Environment such as property management, construction supply chain management, building information modelling, energy suppliers, carbon footprint and so on in the near future (Kinnaird et al., 2017).

3. Methodology

This research paper attempted to identify the stakeholders' perspective on blockchain and smart contracts based solutions for the construction industry supply chain issues. In order to obtain opinions and inputs, a representative sample of the Australian construction industry and academics were targeted. Centre for Smart Modern Construction of Western Sydney University held a roundtable event on 10th of July 2018 and accommodated 36 stakeholders of the construction industry. The participants can be categorised into three main groups of an equal number of participants as upstream and downstream members of construction supply chains, and construction industry and blockchain technologies-related academic from the university. Builders, manufacturers, suppliers, construction technologists, and so on represented upstream members of construction supply chains. Clients, consultants, architects, design engineers, project managers, legal advisors and so on represented downstream members of construction supply chains.

This research has four main steps;

i) Introduction to blockchain and smart contract technologies;
The director of the Centre for Smart Modern Construction of Western Sydney University presented blockchain and smart contract technologies for construction supply chain management. He introduced blockchain and smart contract technologies first. Then he discussed the current issues in the construction supply chain, what are the potential blockchain and smart contract technologies-based solutions, drivers and barriers of the technology.

ii) Roundtable discussion;
A total of 24 industry practitioners and 12 academics participated in the roundtable discussion. There were four industry practitioners on each of the six tables, and discussion was moderated by two academics in each table. Around one-hour time was given to the discussion session. During this time six members of each table deeply discussed current issues. Every group classified these problems into different areas such as trust, cash flow, compliance, assurance and so on and pasted in an A2 size paper by

using post-it slips. Then each group explained why they decided those areas. All the discussions and presentations were audio recorded for future reference.

As the next step each group came up with answers to "*What are the most appealing factors for you in the use of Blockchain and Smart Contracts considering its possibility of use in the construction supply chain?*" and their perspective on blockchain and smart contracts based solutions for those issues. Each group posted their answers to a word cloud activity which was produced by Poll Everywhere online solution and explained it.

iii) Data cleansing;
Before the analysis, four steps cleansing, and data moderation process was conducted.
a) Corrected spelling mistakes
b) Changed spellings to Australian English if somebody uses different spellings
c) Changed answers with few words into a single word
d) Replaced similar meaning answers with a better synonym

iv) Analysis and write the paper
As a final step, all the cleansed data was fed to a new word cloud activity on Poll Everywhere online system. Identified the highlighted stakeholders' perspective to construct the paper.

4. Research Findings

The roundtable event collected 57 responses for the stakeholders' perspective on blockchain and smart contracts based activity. There were 18 unique perspectives identified. Table 1 shows identified 18 factors and their number of occurrences. Efficiency, Trust, Fair, Security, Transparent, Accountability, Compliance and Standardisation are most appealing factors for stakeholders. All those highest ranked factors will be discussed in Table 1.

Table 1: Most Appealing Factors to Use Blockchain and Smart Contracts in the Construction Industry

Identifier	Appealing Factors	Number of Occurrences	Rank
AF01	Accessibility	2	6
AF02	Accountability	3	5
AF03	Adaptability	1	7
AF04	Automatic	2	6
AF05	Compliance	3	5
AF06	Decentralisation	1	7
AF07	Economical	2	6
AF08	Efficiency	9	1
AF09	Fair	6	3
AF10	Innovative	1	7
AF11	Reduplication	1	7
AF12	Reliability	2	6
AF13	Security	5	4
AF14	Simplicity	2	6
AF15	Standardisation	3	5
AF16	Transparent	5	4
AF17	Trust	7	2

AF18	Usability	2	6

Efficiency
Efficiency or its synonymous were proposed nine times by six roundtables, and it is ranked as the top stakeholders' perspective on blockchain and smart contracts based solutions. Almost all groups mentioned they want to improve their supply chain related efficiencies such as better good and service deliveries, payment settlements and supply chain based other operations. Li and O'Brien (1999) explained supply chin efficiency under four criteria; cost or profit, lead-time, delivery speed and waste reduction. Most of the roundtable event participants' expectation on blockchain and smart contracts based solutions will solve their supply chain efficiency issues at least to an acceptable level in the near future. Blockchain and smart contracts technologies provide great drivers to improve the efficiency of automation with non-physicality (Kinnaird et al., 2017).

Trust
Trust or its synonymous were proposed seven times, and it is ranked as the second stakeholders' perspective on blockchain and smart contracts based solutions. Deming (1986) stated that trust would reduce the cost and improve the quality of products and it is one of the key requirements of any successful supply chain. During the discussion and their presenting times, participants have highlighted that the construction industry faces a significant level of trust concerns due to their dynamic nature of supply chain, especially in payment settlement and quality of good and services. Study of adjudication cases of New South Wales, Australia shows that around 70% of the cases involved subcontractors as claimants and contractors as respondents (Brand and Uher, 2004) and especially higher nodes in supply chain expecting better trust mechanism for their payment settlement process. One of the great benefits provided by blockchain and smart contracts technologies is to improve trust among parties (Abeyratne and Monfared, 2016).

Fair
According to the Oxford English Dictionary - Fair is treating equally without favouritism or discrimination or without cheating or trying to achieve unjust advantage. Fair or its synonymous were proposed six times from six roundtables, and it is ranked as the third stakeholders' perspective on blockchain and smart contracts based solutions. From top to bottom of construction supply chain members expect fair arrangement between each other in areas such as fair profit and benefits sharing among each other than chunk for third-party finance and other organisations. Blockchain and smart contracts technologies provide fair outcomes for all the parties with high financial incentives (Kinnaird et al., 2017).

Security
Security or its synonymous were proposed five times, and it is ranked as the fourth stakeholders' perspective on blockchain and smart contracts based solutions. Security word has a broader meaning than just protecting something. A better secure system should address three aspects such as confidentiality, integrity and availability (Denning, 1999). Present day enterprise system users would like to have high information security level on their business information (Perera et al., 2012, Perera et al., 2013, Nanayakkara et al., 2013, Perera et al., 2014, Nanayakkara et al., 2015). Confidentiality describes only authorised people are allowed to access only allowed level of information but not others. Integrity describes nobody can illegally change data, and all the available data is 100% exact data should be there. Availability describes the system is available to access in agreed availability targets (e.g., 99.99%), and this is calculated against the system downtime. Security is a key outcome of blockchain and smart contracts technologies (Abeyratne and Monfared, 2016).

Transparent
Transparent or its synonymous were proposed five times from six roundtables, and it is ranked as the fourth stakeholders' perspective on blockchain and smart contracts based solutions. The complexity of the construction supply chain weakens transparency, and it leads to low trust products (Danuri et al.,

2006). This is a negative impact on the upstream members of the supply chain including suppliers and sub-subcontractors. Most of the higher node members of supply chain expect better transparent payments settlement mechanism than present traditional methods. Blockchain and smart contracts provide great transparency and create a trusted environment (Abeyratne and Monfared, 2016).

Accountability
Accountability was proposed three times from six roundtables, and it is ranked as the sixth stakeholders' perspective on blockchain and smart contracts based solutions. Three roundtables highlighted the importance of accountability between the organisations, simply describing as one organisation liable or answerable to another organisation based on their contracts or pre-agreement. Accountability will be one of the benefits of blockchain and smart contracts technologies from transparent systems (Kinnaird et al., 2017).

Compliance
Compliance was proposed three times, and it is ranked as the sixth stakeholders' perspective on blockchain and smart contracts based solutions from roundtable activity. One of the best examples of compliance issue with the material is Grenfell Tower disaster in the United Kingdom in 2017 (Preston, 2019). During roundtable activities, most of them highlighted compliance issues with the construction supply chain is a significantly important factor to solve. Kinnaird et al. (2017) proposed that the blockchain based supply chain will improve compliance.

Standardisation
Standardisation was proposed three times from six roundtables, and it is ranked as the sixth stakeholders' perspective on blockchain and smart contracts based solutions. The main argument from roundtable event participants was not about material or manufacturing standards. System standardisation is one of the import factors for enterprise level applications (Nanayakkara et al., 2014). They would like more supply chain standardisation such as payment terms, conditions and so on.

5. Conclusion

Based on comprehensive roundtable activity and with four steps methodology of this research, 18 unique perspectives from 57 responses were elicited. Figure 3 illustrates most highlighted factors such as Efficiency, Trust, Fair, Security, Transparent, Accountability Compliance and Standardisation and other next level perspectives such as Accessibility, Automatic, Economical, Reliability, Simplicity, Usability, Adaptability, Decentralisation, Innovative and Reduplication which were generated from all 57 responses by considering present construction sector issues and available information technology solutions.

Figure 3: Word cloud of stakeholders' perspective on blockchain and smart contracts based solutions

Three main conclusions can be derived from a comprehensive review of the outcome of roundtable discussion and word cloud events. a) The construction industry expects a better alternative to address unsolved issues by traditional information technology solutions b) The construction industry would like to focus on inter operate issues between other organisation without limiting to their internal

issues as a more dynamic nature of the industry c) Blockchain and smart contract based technologies can bridge most of the issues and expectations. As a concluding remark, authors believe that blockchain and smart contract powered solutions will significantly impact on enhancing the productivity of the construction supply chain in the near future.

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