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TOWARDS A RESEARCH AGENDA FOR SMART CONTRACT ADOPTION IN LESS TECHNOLOGICALLY ENABLED CONSTRUCTION ENVIRONMENTS: A SYSTEMATIC LITERATURE REVIEW

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Smart contract (SC), a tool created for technologically enabled environments (TEEs) is poised to tackle the obsolescence within and inefficiencies of the traditional environments in construction. Generic considerations of SC are predicated on ideal TEEs, in spite of the slow pace of technology adoption in the construction industry. This is indicative of the fact that, quite a lot of less TEEs(LTEEs) still do exist in construction. But how should SC in construction be implemented within the LTEEs remains largely unknown, thereby creating the potentials for a research agenda within the LTEEs. This paper conceptualizes the state of the art of SC research in construction. A systematic literature review was undertaken to explore the ontology of SC in construction and applying the theory of technology adoption, the paper further characterized the ontological considerations into two domains i.e. TEE and LTEE. The outcome of this investigation revealed that under the LTEE perspective: existing research is challenged at addressing SC related issues; third parties are indispensable; and that the block-chain technology is most suitable for implementing SC. The findings provided information on how SC can be implemented in less technologically enabled environment. To conclude, the paper suggests that SC in construction research should be approached from a hybrid perspective whereby third parties (e.g. consultants) would still have prominent roles in contractual transactions as opposed to the fundamental principles of SC e.g. autonomous processes, and elimination of third party participation.

Keywords: construction, smart contract, technologically-enabled environment

INTRODUCTION

SC has revolutionized the norm of traditional contracts in the construction industry. Studies show transactional transparency, independent processes and security of

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payments in SCs which addresses major problems with progress payment in construction projects (Hamledari & Fischer, 2020; Ahmadisheykhsarmast & Sonmez, 2020; Li & Kassem, 2019; Alharby & Moorsel, 2017; Bartoletti & Pompianu 2017). SCs are contracts that are written in computer codes and operate on a block chain (BC). SC automatically verifies, executes and enforces a contract based on the terms written in the code (Wang, Yuan, Ouyang, Ni, Han & Yue-Wang, 2019; Cardeira, 2015; Natanoshi 2009). SC is an efficient and reliable means of payment used for automated execution of contract conditions needed to redeem the inefficient traditional payment system in the construction industry. In SCs, payment is made at an instantaneous effect which is largely unobtainable via the traditional contracts (Mason, 2017). The main attribute of SC according to Ahmadisheykhsarmast & Sonmez, (2020) is the provision of security of payment for construction works without incurring administrative costs or requiring intermediaries such as Architects and Quantity Surveyors (QS) in a traditionally procured construction contract. SC in an idea TEE uses big data sensors such as drones and reality capture cameras to monitor work progress and effect payment upon completion of tasks.

Despite the move towards technology advancement in the Construction industry, a lot of LTEEs still exist causing poor adoption of SC technology in the industry. Specific problems that researchers have solved in SC can largely be categorized into two –method and technology. 'Method-related 'problems reveals non established systems for implementing SCs while the 'technology 'problems indicated costs, crypto currency fluctuations, data capture/preparation time and accuracy of input data generated by reality capture technologies (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2020).

Existing research on the use of SC technology to expedite payment in real time construction projects were done with reality capture technologies at the construction sites to confirm work done before automating on-chain payment. In LTEEs, SC technology might be impracticable hence an introduction of a human component is inevitable.

The traditional payment system requires inputs from both the Architect and Quantity Surveyor (QS) during the certification process which are usually complex in nature. These third party consultants are fundamental to progress payment and their quality assurance functions cannot be performed by technologies in use in the LTEEs. Hence, SC methodology would have to be modified to accommodate third party interaction.

There are currently no attempts in literature made to implement SC based on the contractual provisions governing construction contracts. Hence, this research hybridizes SC using block chain (BC) technology and the traditional payment system to cater for the peculiarities of construction projects by introducing a synergy between project consultants and SC technologies such that the consultants can play prominent roles in contractual transactions as opposed to the fundamental principles of SC e.g. autonomous processes, and elimination of third party participation projects.

LITERATURE REVIEW

This section is divided into five sections to provide detailed information on the general concepts and applications of SC as found in literature. The first section discusses SC applications, the second section explored SC technologies, third section considered SC limitations, fourth section discussed SC features in TEEs and LTEEs and the fifth section looked at various interactions of SC in TEEs and LTEEs.

SC applications

Researchers have dwelt on one major aspect of SC namely: progress payment of construction works (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2020; Li & Kassem, 2019; Mason, 2019; Alharby & Moorsel, 2017, Cardeira, 2015). Over the years, the construction industry has experienced unsteady flow of payment for construction projects in real time. Payment has been a lingering problem in the construction industry and one of the top causes of disputes on site (Ahmadisheykhsarmast & Sonmez, 2020). Researchers have covered payment in three areas namely: Factors, Effects and Measures (Ahmadisheykhsarmast & Sonmez, 2020; Thanuja & Olabode, 2020; Li, Greenwood &Kassem, 2019; Peters, Subar, & Martin, 2019; Mohammad, Suman, Harum & Hasim, 2018; Hansen, Rostiyanti & Purnomo, 2017; Niazi & Painting, 2017; Ramachandra & Rotimi, 2015). The factors identified have been summarized into: Contractual issues, and financial issues (Peters et al., 2019; Hansen et al., 2017; Niazi & Painting, 2017; Ramachandra & Rotimi, 2015). The effects of late payment practices have led to negative cash flow for main contractors and delayed payment of subcontractors where as poor payment systems have caused destruction of trust between contracting parties and abandonment of contracts (Ahmadisheykhsarmast & Sonmez, 2020; Thanuja & Olabode, 2020; Peters, Sabar & Martin 2019; Li, Grenwood & Kaseem 2019; Mohammad, Suman, Harum & Hasim 2018; Niazi & Painting 2017; Ramachandra & Rotimi, 2015). Quite a number of proposed measures to payment exist in literature, the common one been: creating a feasible form of financial security at the outset of a project which formed the basis of the argument in this paper (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer 2020; Moumita et al., 2020).

It has become evident that the traditional system cannot address the inefficiencies of payment problems for construction works (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2020). Hence, there is a paradigm shift to an automated system which supports the new normal ushered by the pandemic. SC with features such as transparency, security of payment, autonomous transaction and guaranteed execution is the new deal (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2020; Brydon & Wang, 2018; Cardeira, 2015).

SC Technologies

Blockchain (BC) technology

BC is a way of storing records of value and transactions; a database (Gates, 2017). Most transactions between people require an intermediary (e.g banks) to provide trust, security and to facilitate transactions. BC technology removes the need for an intermediary, allowing people to transact directly and promote trust and assurance with each other (Gates, 2017; Mason, 2017). In order for a transaction to be processed, it is grouped with other transactions and added to a new block on

top of the previous block in the chain. Each block refers to the previous block number, linking them together in a chain. The chain of blocks in the BC links all the way to the first block on the chain thereby ensuring security. SC with BC technology transfers ownership of securities (lien rights) into the BC. A party (the contractor) is expected to perform some tasks on a certain date, once the SC verifies the completion of the task, it enforces the contract automatically by paying the contractor. The set out conditions are spelt out and imputed into the chain (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2020; Gates, 2017; Mason, 2017).

Decentralized Apps (DAPPS)

These are apps that are open source, not controlled by one person or entity and runs across a distributed BC. DAPPS has no central server; instead users connect to each other through peer to peer connects (Gates, 2017). A web of interconnected SC can be used to create a fully autonomous organisation which is capable of carrying out functions similar to the traditional organisation.

Reality Capture Technology (RCT)

Robotic reality capture machines such as camera equipped unmanned aerial vehicles (drones) are machines used to document progress of tasks on site whose outputs are fed into the SC to value the percentage of works done and enforce payment accordingly (Hamledari & Fischer, 2020). The relevance of this technology to SC according to Hamledari & Fischer (2020) is argued to bridge the gap between the on and off chain realities, a limitation of using only the BC technology. Secondly, RCT captures the physical reality exactly as it is thereby introducing objectivity into the valuation of works and ensuring consistency across the chain as only reliable data are imputed.

SC Limitations

Despite the potential advantages of SC, there are specific limitations of SC that researchers have identified which include: costs of acquiring RCTs, fluctuations of crypto currencies, data capture and preparation time, vulnerability (cyber attack) and misinterpretation of input data (if data are captured wrongly) (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2020; Li & Kassem, 2019; Nanayakkara & Perera, 2018; Alharby & Moorsel, 2017; Kosba, Miller, Shi, Wen, Papamanthou & Hawk, 2016; Luu, Chu, Olickel, Saxena & Hobur, 2016; Natoli, & Gramoli, 2016; Zhang, Cecchetti, Croman, Juels & Shi, 2016). These limitations are arguably bearable compared to the magnanimous challenges of the traditional payment system which subjects valuation of works to the interpretation of the valuer. Additionally, the discrepancy of the wrongly captured data affects only the timing of a minor fraction of the payment but not the entire valuation (Hamledari & Fischer, 2020).

Cost:

Acquiring RCT in LTEEs is capital intensive. The average cost of a drone with minimal gadgets is about N1, 500,000 (in Nigeria) which is a little too much for an average client in both public and private sectors. With digital cameras and a good smart phone, project progress can be captured with reasonable accuracy which offers a cheaper alternative.

Fluctuation of crypto currencies

SC utilises special currencies known as crypto currency for payment common ones being bitcoin (BTC) and ethereum (ETH). The primary difference between BTC and ETH is that BTC is mainly used as a distributed ledger for financial transactions while ETH is designed to be used as a distributed computing platform for running applications (multiple facets). Employers might incur losses due to fluctuations in the exchange rates of crypto currencies. The current exchange rate of ETH/NGN is 731,839.08 while BTC/NGN is 22,498,522.85 (Morningstar, 2021). A large amount of buying demand from an employer for a mega project is likely to lead to a rapid appreciation of ETH making this a limitation for adoption in large scale projects (Ahmadisheykhsarmast & Sonmez, 2020).

Data capture and preparation time

According to (Hamledari & Fischer, 2020), data processing time using digital images takes about 14 minutes excluding the data capture time from site. From processing to payment might take some days. Despite the ease of this process compared to the traditional payment system, for projects where time is of essence, there may be a need for a quicker technology.

Vulnerability of SC platform

Researchers have analysed the vulnerability of SC and categorised them into security and privacy issues. Cyber attack is a common phenomenon with technological inventions. According to (Dika &Nowostawki, 2020), "Reentrancy" which relies on the interaction between two SC is viewed as the most common severe vulnerability of SCs. This permits one SC interacting with another SC to retrieve multiple information from the interacting SC which can be used to defraud that SC if there is an incomplete interaction between them. Transaction origin, timestamp dependence, external calls, unchecked send-bug, etc other vulnerabilities identified by (Dika &Nowostawki, 2020) that limits the adoption of adoption of SC.

Misinterpretation of data

The accuracy of data fed into the SC is important in achieving best payment practices. According to (Hamledari & Fischer, 2020), a 5% inaccuracy was detected in the input data arising from the misinterpretation of a painted wall as a plastered wall. The implication is that 5% of the misinterpreted element was paid either too early or later. Although, this inaccuracy exists, it still offers a better result than the traditional format where the inspector might be biased.

Features of SC in TEEs and LTEEs

Automated Process

The ability to enforce a contract upon the completion of certain tasks without any human intervention makes SC desirable in the new normal for contracting. Researchers reveal that the instantaneous potential of SC can be largely seen in its ability to save cost and time of projects as well as improving project performance (Mason, 2019; Bartoletti & Pompianu, 2017; Mason, 2017). This also eliminates the inefficiencies of managing hard copy documents.

Compatibility with other technologies

A. **Building Information Modelling (BIM)**: There is recent improvement in the adoption of BIM in the CI. Although BIM provides a yardstick against which smart contracts can align, Mason (2017) opined that SC should run solo so as to generate thousands of "straightforward contracts executed by high performance". The argument is that if SC relies closely on BIM to operate, then there are chances of centralization of operations due to the issues with BIM adoption complexities across its levels (level 3: a single shared project model) which opposes the fundamental principles of SC.

B. **BC technology**: BC is a distribution of database among a continuously growing list of transactions in units of blocks linked together and secured from tampering and breakage. BC offers enhanced speed of transactions with the potential for the real-time instant transfer (Gates, 2017). Researchers revealed that BC has the potential to change almost every industry in the world due to its transparency of transactions, removal of intermediaries and decentralization of operations (Lauslahti, Mattila & Sepppala, 2017). SC works best on BC technology because it operates automatically without a central authority. Once the conditions written into the SC are met, payment is made and released and if not met, payment is withheld. Hence, series of activities/ sub contracts in a project can be linked together in a SC but operates independently. The beauty of SC with BC technology is that a uniform view and record of transactions are maintained throughout the chain and irrespective of the amount of new instructions fed into the block, the system remains intact.

Third party elimination

One of the attributes of SC is the elimination of a central control/ command. The decentralized nature of SC permits individual activities to operate independently without the authorization of a central command. This promotes objectivity and transparency and eliminates bias. It also improves the speed and accuracy of works as each component is structured to monitor progress and dispense value automatically once a completion command is triggered.

Real time progress and records

With the RCT upon which SC operates with, real time progress and records of daily tasks are captured using drones and big data sensors positioned strategically at different points on the construction site. Information is managed and disseminated across the block and progress of works can be tracked with ease. According to Hamledari & Fischer, (2020), a robotic reality capture machine was used to capture physical site progress while the SC dispenses payment when tasks were accomplished. This was used to make payment to seven subcontractors without relying on a centralised control mechanism. The subcontractors did not have to apply for payments because payment was made automatically once the SC confirms data received. The major challenge the researchers encountered using this approach is the data capture and preparation time which delayed payments for a few days.

Interactions between TEEs and LTEEs

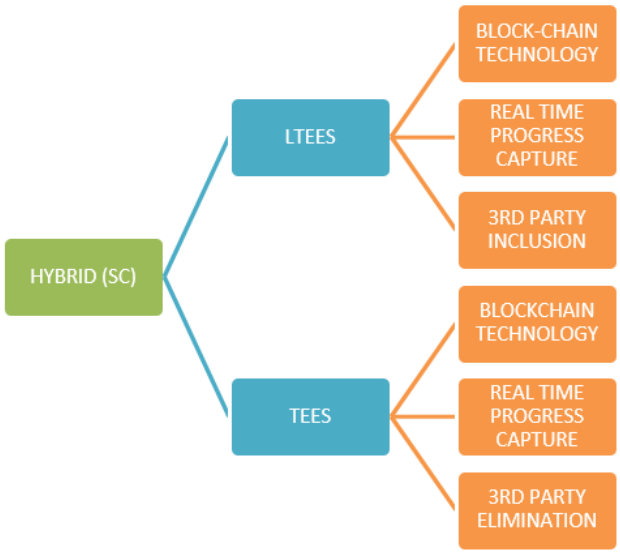


Figure 1: Interactions between SC environments

In LTEEs, technological advancement is at embryonic stage, hence full automation is unlikely and the inclusion of consultants for project supervision and endorsement of payment becomes inevitable. The study therefore, proposed a hybrid SC payment system to suit the complexities of the construction industry. In the proposed hybrid SC payment system, the contract is written as codes in the SC. Upon collection of data from site using digital cameras/ smart phones which is fed into the SC for verification of completed tasks. A consultant in the block-chain values and approves due amount to be paid to the contractor/supplier. SC verifies completed transaction and payment is made. Series of sub contracts can be written in blocks and added to the BC, such that many activities are going on concurrently without interference and progress of works can be viewed by everyone on the block. Hence, eliminating inaccurate progress report and delayed payment.

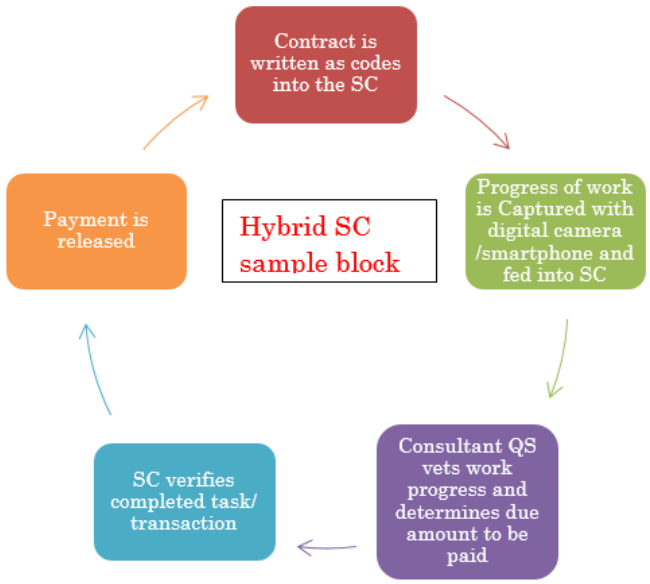


Figure 2: Hybrid smart contract block

CONCLUSION

SC can be used to overcome the inefficiencies of the traditional payment system which has plagued the Construction Industry (CI) over the years. Advancement in technology in the Construction Industry has made the need for SC evident as it encourages minimal physical site interactions, transparency of transactions, and speedy delivery of projects. However, how SC should interact in LTEEs remained unknown. This study provided information to bridge the cap by establishing a hybrid SC payment system for adoption in LTEEs which will be tested in life projects as part of an ongoing PhD research work. The study also supports (Mason, 2019) on the semi-automation of SC in the CI for best practices. Major limitation of the study is the poor technical experience of construction consultants which can be overcome by awareness/training of consultants in technological skill acquisition/software development. The study is recommended for adoption in medium-sized public projects.

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