Informing implementation of distributed ledger technology (DLT) in construction: interviews with industry and academia

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Abstract

This paper reports on the outcomes of seven semi-structured interviews that were conducted over a one-year period with industry practitioners and academics to discover the potential for distributed ledger technology (DLT) in the construction industry. Five themes were arose from the interviews: challenges for construction; smart contracts and payments; Building Information Modelling (BIM), collaboration and information sharing; the design development process; and regulations and compliance. Adversarial pricing, payments and poor regulations were identified as key challenges where DLT could support solutions. Smart contracts can lead to automation of activities in general, however, for payments, new financial legislation will need to be enacted beforehand. Smart contracts are unlikely to replace traditional construction contracts. Information is likely to be shared more freely leading to better collaboration for BIM-based projects. Recording of the design development process on a distributed ledger will provide the *who did what, when* that is currently lacking in construction projects and the operation of built assets. The immutable and transparent nature of DLT will hold people to account and encourage better compliance with regulations. Consideration needs to be given to: compliance with the General Data Protection Regulation (GDPR), how payments will account for the Construction Act, and to what extent smart contracts can be implemented in activities that require judgement on whether reasonable skill and care has been exercised. Future research will include further interviews and extension of a framework for implementation of DLT in the construction industry.

Keywords: distributed ledger technology (DLT), blockchain, construction industry, thematic analysis, smart contracts.

1. Introduction

Distributed ledger technology (DLT) is a way of recording transactions securely and in a decentralised manner. Many people refer to DLT as 'blockchain' which derived from *the Blockchain*, the specific technology that started the decentralised ledger revolution in 2009 with release of the world's most prolific cryptocurrency, Bitcoin (Nakamoto, 2008). However, the Blockchain, an append-only chain of verified transactions (Dorri, Kanhere, Jurdak, & Gauravaram, 2017), is just one instance of DLT. Using the generalised term of blockchain in place of DLT, therefore, restricts its meaning to one type of DLT leaving out those such as IOTA's Tangle which is a directed acyclic graph (Popov, 2018).

The construction industry is rife with challenges that do not appear to have been solved since the first major state of the construction industry report in 1994, the Latham Report (Latham, 1994). It has been followed by similar reports in the same vein such as the Egan Review (Egan, 1998), the Farmer Review (Farmer, 2016) and most recently the Hackitt Review (Hackitt, 2018). The key issues cited in these papers include low productivity, poor collaboration and information sharing, lack of enforcement of regulation and compliance, and poor payment practices.

Two major events took place in 2017 and 2018 that caused the United Kingdom's (UK) Government to rethink its current construction industry practices. In June 2017, a breakdown in

regulation and compliance caused a spark from an electrical appliance in Grenfell Tower, West London, a high-rise residential building, to spread to a building-wide fire killing 71 people (Symonds & Ellison, 2018). There were myriad failures throughout the building that did not meet safety standards with many claiming that building regulations were unclear (Booth & Davies, 2018). In 2018, the then UK's second largest construction contractor, Carillion, collapsed as a result of a broken procurement system and adversarial profit margins when it failed to pay its £1.5bn worth of debt having only £29m in the bank (Thomas, 2018).

DLT has been discussed as a tool to support many solutions to these challenges through its immutable, distributed, decentralised ledger (Jennifer Li, Greenwood, & Kassem, 2019). Some suggest DLT is a solution looking for a problem (Risius & Spohrer, 2017). The construction industry needs to be very careful not to implement the new innovation simply because it claims to be able to solve some of its challenges; a full and comprehensive review should be conducted looking at the requirements of implementing DLT in construction as well as considering alternatives (J. Li, Kassem, Ciribini, & Bolpagni, 2019). In addition, attention should be given to how these areas should be reformed and how cultural change within the industry is to be addressed. DLT is not a standalone solution; it is a tool that, when coupled with other tools such as Building Information Modelling (BIM), the Internet of Things (IoT) and smart contracts, has the potential to support digital transformation of the construction industry (J. Li et al., 2019).

The aim of this paper is to present findings from a series of interviews that were conducted with construction industry practitioners and academics with an interest in and knowledge of DLT to assimilate current thinking around the technology with regards prospects, potential use cases for construction and appetite for adoption. The research presented in this paper has informed to date a framework for achieving readiness to adopt DLT in the construction industry and is a continuation of this line of work (Jennifer Li et al., 2019). Section 2 describes the methodology adopted for this study; section 3 presents the findings from the interviews and provides a discussion; and section 4 concludes the paper and proposes next steps for the research.

2. Methodology

Following a comprehensive systematic literature review conducted by the authors in 2018 (Jennifer Li et al., 2019), a series of semi-structured interviews were conducted with seven people from across the construction industry. Due to the limited research that exists on DLT in construction, this qualitative research aimed to support the findings from the literature review and contribute further to the discussion of how the technology can address some of the industry's biggest challenges. The purpose of the interviews were to understand the perception and potential of DLT in construction and how it might integrate with other technological innovations in use today; questions were structured accordingly.

The criteria for selecting the participants were: senior experts from within the construction industry with an understanding of the industry's key challenges; experience of engaging with different types of organisations across the industry from contractors at all tiers to public sector clients; and knowledge and understanding of the potential for DLT in the industry. Table 1 shows the profile of the participants. To provide a holistic view of DLT across the UK's construction industry, participants were located across the UK from organisations ranging from micro-businesses to industry associations and large contractors. They were identified from within the authors' professional networks using a snowball sampling approach. The interviews took place over a one-year period as proprietary knowledge of the authors grew and as developments and interest across the industry increased in general.

A set of questions specific to DLT in general and smart contracts in particular were devised based on findings from the systematic literature review (Jennifer Li et al., 2019). Due to the novelty of the topic being investigated, the interviews were allowed to evolve throughout their duration to adapt to the participant's level of knowledge, expertise and interest in the subject, to provide flexibility to the process and avoid suppressing potential findings that would otherwise have remained undiscovered. Processing of the data followed the six-phase approach to thematic analysis as in Braun and Clarke (2012). First, each interview was transcribed; second, the data were coded based on initial analysis; third, the data were categorised into themes across all transcriptions capturing conceptual differences; fourth, the themes were quality checked against the data and revised based on deeper analysis; fifth, the

themes were clearly defined; and six, the resulting categories were collated and interpreted for presentation in this paper to provide meaningful contributions to the field of DLT in construction.

Table 1: Profile of interview participants

ID	Role in the Construction Industry	Interview date	Duration
P1	Chief Executive of an industry association, barrister	Apr 2018	3hr 30m
P2	Head of construction and engineering in a national law firm	Nov 2018	50m
P3	Founder of a construction technology start-up utilising DLT	Dec 2018	2hr
P4	Senior Counsel of a global construction contractor	Dec 2018	30m
P5*	Professor in construction law at a Russel Group university	Dec 2018	1hr
P6*	Research Associate at a Russel Group university, architect	Dec 2018	1hr
P7	Director of an information management consultancy that uses Blockchain	Apr 2019	50m

**Participants 5 and 6 were interviewed together.*

3. Findings and discussion

A number of topics emerged from the interviews; while they are by no means exhaustive, they provide an interesting perspective on the potential applications of DLT for construction as identified by the participants along with some aspects for consideration in further research.

3.1 Challenges for construction

Any solution should first understand the challenges it is trying to solve. Many challenges to construction have been discussed in previous studies (Jennifer Li et al., 2019) and some are highlighted in the introduction of this paper. Initial discussions during the interviews involved clarifying some of the challenges in construction today that have the potential to be addressed in part by DLT. An overarching challenge offered is that, "*in the UK, the industry is very fragmented and is why the UK has one of the most expensive construction industries in Europe"* (P1). Both P1 and P2 highlight **adversarial pricing** where main contractors are "*undercapitalised and therefore using supply chain funds as cashflow to finance their businesses*" (P1), "*which means you are on a knife-edge all the time and it just requires a couple of things that tip you over the edge as Carillion showed*" (P2). *"Use of supply chain capital was a deliberate business policy used by Carillion. For clients to ensure against insolvency, they need to insist on different procurement procedures"* (P1). **Payments** *"is one of the most important things that really needs to be addressed"* (P6). P5 adds that, *"there are inefficiencies in the supply chain; arbitrary decisions, subjective decisions that delay payment, people who intervene, breakdowns in communication, a whole range of things that stop money passing down the supply chain. But also that interfere in the records of what have been provided".* And P7 explains that, "*construction contracts now are, literally, all stick and no carrot"* adding that, *"there's no incentive to over deliver, and all the risk is basically pushed down the supply chain".* Currently in construction supply chains, there is a reluctance to foster long-term relationships between main and sub-contractors due to the short durations of projects and physical distances between contractors. This results in poor information flows that provide little transparency and limited exchange of information and communication in general (Dallasega, Rauch, & Linder, 2018).

With regards **regulations**, P1 states another key challenge is "*lack of enforceability. People are not clear what it is they're enforcing and, therefore, can't hold people to account if they don't know who did what, when. There is lack of accountability".* This is mirrored by the key issues highlighted in the Hackitt Review (Hackitt, 2018).

These challenges are complex and overlap but are ultimately as a result of poor procurement practices that have been ingrained over many years and low profit margins that, before the global recession, encouraged main contractors to create business models around the use project funds to

finance their business. These practices have continued into times of austerity resulting in clients requiring more for less and top tier contractors pushing the financial burden down through the supply chain putting quality and safety standards in jeopardy. DLT has the power to instil better behaviours in the way projects and assets are managed throughout an asset's lifecycle through providing visibility and traceability to clients and users (i.e. occupants) holding organisations and individuals to account. However, new practices require new legislation, new technology and new processes to be developed and deployed before better behaviours are likely to be seen in the construction industry.

3.2 Smart contracts and payments

A smart contract is an if/then, self-executing, computer-coded programme (Cohn, West, & Parker, 2017). When running on top of a distributed ledger, they offer the potential to automate many different types of activities within construction projects. They have been discussed as having the potential to replace traditional construction contracts where, in the context of the Accord Project (2019), P7 explains, *"It's producing that contract language programmatically using a data model so you can then produce your traditional contract but you can then have a data model that you can then hang things off and do all the things you can do with a programming language".* However, this is contrary to the view of the legal participants interviewed for this study. P4 states, *"one of the things it's not going to do is completely replace [traditional] contracts, purely because there are elements which require subjective viewpoints, for example, whether someone exercises reasonable skill and care".* P2 asks how far subjectivity can be removed from traditional contracts adding, *"You have to basically write a contract that doesn't contain the word "reasonable" in it. You need an "unreasonable contract" because there is your subjective element".* P5 says, *"it's so unlike a conventional contract that I don't want our discussions to suggest that there's anything in there that looks like a normal contract".*

P2 offers that a *"hybrid contract"*, a blend of a traditional and smart contract, will be used in the future *"giving flexibility to any judgement, which is necessary…in the context of a marriage with the subjective elements of the contract".* P4 adds that, in time, there will be off-the-shelf smart contracts, *"readymade sets so you shouldn't have to start from scratch every time you go to a project because it'll require a combination of lawyers and the coders and the commercial teams all coming together saying, well, this is how we want it to work".*

With regards the uses for smart contracts, they are proposed as a tool to measure contract performance, *"things like payments, ordering materials, anything that requires no level of judgement"* (P4). Smart contracts remove the flexibility that is seen in traditional contracts so P5 believes they *"only come into play after we've frozen our design development. There's no space, once you're into the world of smart contracts, there's no space for design development. You're going to get what you're going to get and you're going to pay for it so if you haven't crystallised that and made all the necessary decisions and being sure there's no more provisional items, there's no more change, no more refinement, you know, you're not ready for smart contract transactions".* In addition, P4 expresses the need to consider the Construction Act where "*you can issue Payless Notices, Payment Notices, you can report money in certain circumstances. So, whilst you can build that into the coding, there'll need to be a stepped process, it won't be, if you get to this milestone, you get paid".*

While payments are not the only and indeed main use case for smart contracts, they are perhaps the most commonly discussed use case as a result of DLT being initiated by Bitcoin. There are factors to overcome before payments and cryptocurrencies can be implemented in construction contracts such as enactment of new financial regulations but integration with current payment systems could be realised in the interim and result in elements of construction contracts being automated in the near future. Coding of every eventuality in a construction project is not practical but coding of activities that result in progressing some contract requirements, particularly those not requiring judgement (i.e. proof of delivery of goods to site), could be seen in the near future and can be integrated into existing systems such as automated data input into information models via IoT sensors.

3.3 BIM, collaboration and information sharing

It has been discussed that the limited success seen by adoption rates of BIM to date (NBS, 2019)

is in part due to the industry's reluctance to collaborate and share information (Barima, 2017; Belle, 2017; Farmer, 2016). P1 states, *"The biggest problem with BIM Level 2 is that we are trying to apply a collaborative tool to a non-collaborative industry… People aren't sharing data which is what's causing the problems. It's trying to integrate processes using a digital mechanism on top of shaky foundations".* P4 believes that DLT will *"help in terms of information sharing because there isn't any doubt as to who gave what, when and, technically, you can say, well, we can trust the information provided because no one would have tampered with it".* However, P4 raises the issue of the General Data Protection Regulation (GDPR) where personally identifiable information is used as well as what happens when a contract is terminated and people have a 'right to be forgotten', their right to copyright and their right to the information contained within the distributed ledger. *"If they have a right to all the information being deleted, which is quite common, how does that impact your blockchain?"* (P4). While these issues must be considered before DLT can be successfully implemented and written into contracts for construction projects, P4 continues that "*it will certainly help exchange of information insofar as people have the technology to view it [and] the processes are put in place… Same as BIM when everyone was saying everyone's going to do BIM and everyone's going to work together in theory, but you have to actually implement it".*

With regards the legal aspects of construction projects, when coupled with BIM, DLT has the potential to reduce *"things like onsite variations, which are very time consuming, requests for information, any disputes as to gaps in information or discrepancies in information. Hopefully that would all become a thing of the past if you're using blockchain and BIM and all the other tools. You have very clear information that everyone can rely on and is complete at the point you start construction. Because what really takes a lot of time in construction is the uncertainties and the onsite variations and the arguments later on"* (P4). *"Version control in BIM at the moment is not that good and I can see that an aspect of BIM going forward is going to know exactly who did what and when, when we have a dispute about it. If blockchain offers us that opportunity, then that's going to be helpful"* (P2). P1's view is that, *"Lack of clarity and phraseology is the biggest problem with disputes. Smart contracts could reduce the level of disputes due to the language used and promotion of standardisation of contracts. Smart contracts are more difficult to amend than traditional contracts and offer far greater transparency. People will be much more aware of what's in the contract".*

In a previous paper, the authors proposed a conceptual approach to integration of DLT, BIM, IoT and smart contracts (J. Li et al., 2019); the interplay between each of these technologies is important in each of their abilities to effectively support construction projects. P4 sees them as "*tools to implement the contractual arrangement between the parties".* Which tool is used at which time will depend on what the contract requires but as P6 indicates, "*there's a need to…realise that they have an element of dependency too".* J. Li et al., (2019) provide a proof-of-concept for automating an installation task within a BIM-based project using IoT sensors and smart contracts that record transactions on a distributed ledger. Another example may not require the use of IoT where the trigger for a payment via a smart contract may come from human interaction rather than data sensors, particularly where judgement needs to be exercised.

3.4 Design development process

The design development process starts from concept of a construction project and tracks actual delivery through all of the changes and diversions from initial design to as-built state allowing visibility of the development and evolution of a project over the duration of the project. All participants raised a benefit of DLT as being the historical ledger that definitively says who did what, when and how. P1 believes that, if *"installed at the outset of the procurement process,"* it "*would give oversight of the delivery team and would give a massive boost to the regulatory system".* P3 and P5 see value in pinpointing the problem to drive accountability backed up by data. P7 discusses the reduction in disputes between contractors and suppliers due to the "*publicly available ledger [where] you can see what happened and when".* P6 adds that *"… the only way we get lessons learnt is by…knowing at what point we…diverted and whether that was a positive diversion or a negative one and maybe [DLT] is a way we can actually…do that and…learn better"* (P6).

This use case opens the door to driving other improvements in the design development process particularly around the drive for information *"that might be contracts, that might be other things that you can use to push for that information"* (P7) and may give *"rise to a much better record keeping system"* (P2). *"Smart contracts, hopefully, will create…a greater level of transparency that enables us very quickly to go back to source… We should look down the supply chain to origins and the integrity of what we're getting…we never get interested in sub-contracts and supply contracts but blockchain enables us to do so"* (P5) and that provides a much more robust system of traceability. Traceability is at the centre of the Hackitt Review (Hackitt, 2018) and based on the findings from these interviews, it is something that can drive better practices and delivery throughout the asset lifecycle. In addition, P7 identifies new uses of information produced during a construction project or operation of a built asset such as performance data of components that manufacturers may be willing to pay for in the future allowing them to move toward a more servitised business model where equipment is leased rather than purchased.

3.5 Regulation and compliance

One of the failures of the construction industry is poor regulations and enforcement as stated by the Hackitt Review (Hackitt, 2018). Its response to this is a 'golden thread' of information or a digital record that performs the purpose of traceability as discussed in the design development process section above. P1 describes DLT as having the effect of *"someone looking over your shoulder"* and the importance of having oversight from the outset of a project. *"Use of technology to bolster regulation would ensure there were repercussions for having the blockchain as a regulatory tool that would reverberate throughout environmental standards, procurement, delivery etc."* (P1). In addition, DLT can be used in identity management of building components or a "*passport*" that provides data upon request such as ratings against which to prove compliance with building regulations. P1 believes that DLT *"will lend integrity to building safety and accountability",* that it can make it easier to *"enforce the delivery processes to quality and safety standards"*, that it will force *"people to account in quality factors [and] will change how people operate".*

Although the Blockchain is 10 years old, being released alongside Bitcoin in 2009 (Nakamoto, 2008), academic research on DLT for use in construction only began in 2017 (Jennifer Li et al., 2019). Given its nascence for construction, P4 believes that regulations for DLT in construction will be driven from outside the industry (i.e. in Europe or by other industries such as fintech) but *"how applicable those regulations will be to [construction] and how they will interact with say, the Construction Act, and such will get complicated. I think there will probably be case law first, before regulation just by the nature of things"* (P4).

4. Areas for further consideration

To demonstrate clear outcomes of this study and to inform future research in the field of DLT in construction, a number of areas requiring further consideration that arose during the interviews have been tabulated in Table 2. Each area has been described briefly and suggested activities to support further investigations given. While this table provides clear areas for consideration based on the interviews conducted for this study, an extensive list of challenges and opportunities related to DLT in construction based on a thorough systematic literature review is given in (Jennifer Li et al., 2019).

Table 2: Areas for further consideration

Area for consideration	Description	Implications for DLT in construction	Suggested activities
Procurement processes	Appointment practices based on a lowest tender wins ethos put in jeopardy safety and quality standards of built assets; procurement is not digitised and therefore does not support technological advancement of the industry in its current state.	DLT (and other digital systems such as BIM) require digital input to function optimally. A move toward electronic, digitised procurement processes would give a boost to digital transformation that the construction industry requires.	Industry should take steps to digitise current procurement processes to result in computable documentation (i.e. exchange information requirements) that can be transferred directly into smart contracts and information models to speed up activities and support automation.
Poor payment practices	Payments can take up to 120 days to be processed from the main contactor to subcontractors which negatively affects the supply chain. Disputes around quality and scope often arise delaying payments.	Undisputable, validated and verified proof that work has been completed to specified requirements will force main contractors to pay sub-contractors quicker, especially if written into the contract by the appointing party.	Demonstrate proofs-of-concept through simulations and pilot studies to show how proof is recorded on a distributed ledger.
Lack of collaboration and information sharing	Poor trust relationships between contracting parties, issues around intellectual property rights (IPR) and current payment practices discourage parties to collaborate and share information throughout project delivery.	Proof-of-ownership and timestamping on a distributed ledger can alleviate many of the issues around IPR resulting in a change in trust and therefore generate more willingness to share information and collaborate.	Demonstrate proofs-of-concept to show parties how their IPR can be protected using DLT. Increased collaboration and information sharing will support better delivery of projects with fewer disputes between the parties.
Lack of enforceability of regulations	Current policies and processes are not sufficiently robust to check and ensure regulations are complied with.	Immutable recording of certifications and compliance with regulations will provide proof that projects and assets are compliant. The new system will encourage contractors to work to better safety and quality standards if their work is to be recorded forever.	Review current regulations and compliance guidance. Develop new policies and processes to create a more compliant and transparent environment surrounding built assets. Consider DLT as a platform for recording regulations and compliance.
Complexity of construction contracts and the extent to which they can be automated	Subjectivity based on human experience and judgement is required in the delivery of construction contracts. These elements are not yet automatable as artificial intelligence is not sufficiently advanced to replace human judgement.	Some aspects of construction contracts can be automated while others require a human to interject. While technology develops to the extent that these aspects can be replaced by AI, smart contracts can be used for those activities not requiring judgement.	Investigate how far traditional contracts can be automated using smart contracts accounting for the level of subjectivity required in the delivery of construction contracts. Develop standardised off-the-shelf smart contracts to speed up processes and be more accessible.
General Data Protection Regulation (GDPR)	GDPR gives individuals more control over personally identifiable data.	An immutable ledger is in direct contrast to GDPR's 'right to be forgotten" where individuals have the right to demand their personally identifiable data be permanently deleted.	Consider GDPR in any DLT-based solution that records personally identifiable data ensuring that the solution is compliant with the regulation.

The areas highlighted in Table 2 consider aspects of the construction industry that are much boarder than the context in which they are described in this paper. Each requires consideration regardless of whether DLT is considered as part of a solution to improve current practices or comply with certain regulations. DLT is not offered as a standalone solution to solve the construction industry's many challenges, however, it is offered as an option for consideration alongside alternative options to support digital transformation and reform of the construction industry.

5. Conclusions

The aim of this study was to engage with senior industry practitioners and academics from across the UK construction industry to identify potential drivers for implementing distributed ledger technology (DLT) in this complex industry. Seven semi-structured interviews took place over a one-year period and discussed the sector challenges that can potentially be supported by DLT. While it is not a standalone solution to these challenges, DLT can be part of the solution due to its unique characteristics of decentralisation and immutability holding people to account through traceability and visibility. Four topics were discussed with interview participants alongside the industry's challenges: smart contracts and payments; BIM, collaboration and information sharing; the design development process; and regulations and compliance. This is by no means an exhaustive list of DLT use cases and there are many overlaps within these topics but each has different requirements for a DLT-based system whether that be integration with other technologies (i.e. BIM, IoT and smart contracts), enactment of new legislation or new business processes, among others. Participants identified future use cases that could be realised as a result of the initial purpose of DLT, for example, more advanced uses of information beyond that of a digital record such as performance analysis of building components that a manufacturer might be willing to pay for and better record keeping.

Some aspects to be considered arose from the interviews including: how GDPR will affect information held in a distributed ledger; coding of smart contracts to account for The Construction Act with regards payments; and implementation of smart contracts where reasonable skill and care or judgement of a human are required.

The limitations of this research include: the limited number of interviews that took place providing a limited perspective of DLT in the construction industry; and four of the seven participants had a legal background which is likely to have skewed the findings toward their collective perspective.

The interviews presented in this paper were conducted alongside a study to develop a framework for the implementation of DLT in the construction industry (Jennifer Li et al., 2019), the findings of which informed the framework's development. Further research will involve additional interviews with industry practitioners and academics and the addition of public and private sector clients and asset users (i.e. building occupants) to ensure that the framework is applicable to all DLT use cases and for different types of projects; and to further extend the framework to include a roadmap to implementation of DLT for specific use cases at an industry scale.

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