Financing & Procurement
Working Group

Construction Blockchain Consortium

Blockchain & Construction Cash Flow

White Paper 1

Revision 1.0

About the CBC

The Construction Blockchain Consortium (CBC) was established to develop knowledge transfer, arrange commercial and academic presentations, assess and test commercial services and technology, conduct research, and drive policy, regulation and understanding of the consequences of Blockchain and other emerging technologies in the Built Environment. We also establish open source projects and encourage application developers to build proprietary technology and services for sustainable construction solutions.

In this first document of a series of white papers, we elaborate on the impact of blockchain in construction financing & procurement. Originally, we envisioned one document to cover the domains of financing and procurement. However, it soon transpired that the complexities of this intersection of multidisciplinary knowledge calls for topic analysis in order to retain the definition required to inform prospective technological applications.

Therefore, here we review current developments of blockchain technology relevant for construction smart contracts and assess its impact in the construction cash flow models and some of its procurement devices. This document aims to gather evidence with a view to shaping future policy and regulation in collaboration with the British Parliament.

Foreword

The built environment enables the rest of the economy and defines much of our quality of life. The sector embraces the overlapping sub-sectors of Property, Construction and Facility/Asset management and their related professional services which together represent 15-20% of GDP.

However, the sector suffers from major weaknesses and generally underperforms which results in many disputes. Business cycles are exaggerated, inhibiting the modernisation of investment and fragmenting supply chains. High risks and small profits disincentivise collaboration and focus minds on the capital stage of projects. Whole-life value is not a priority and the 'golden thread' of information about each asset is usually missing. It is widely considered that the business models of procurement and contracting are broken and open to disruption by better ideas.

This paper looks at distributed ledger technologies which might prove to be part of the disruptive potential. Some might increase trust and collaboration, move money better through the supply chain, improve asset performance and enable long-term availability of asset information. Disputes might be avoidable or resolved by data analysis. I commend the work done so far.

Richard Saxon, CBE
Chairman
Joint Contracts Tribunal (JCT)

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Acknowledgements

In 2017, Professors Alan Penn and Phillip Treleven proposed the idea of creating an initiative within University College London (UCL) to serve and guide the industry regarding the adoption of innovative data architectures such as distributed ledgers and blockchain.

Since our formation, the CBC has been grateful for UCL Innovation and Enterprise's support, both in the early stages of the Consortium's development and during the challenging times of COVID-19, which severely impacted our events agenda, including the now-rescheduled CBC2020 Annual Conference. Furthermore, the efforts of the professional services and academic staff at The Bartlett Faculty and its School of Architecture have been central to ensuring the CBC advances on a sound and sustainable footing.

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Executive Summary

In this first of the CBC's white paper series, we examine the applicability of blockchain in construction cash flow processes in relation to existing financial and legal frameworks. Originally, we envisioned one document to cover blockchain's applicability in the domains of financing and procurement. However, it soon transpired that this topic is very broad and could - and eventually will - constitute multiple white papers.

This document aims to inform policymakers, industry and academia about the feasibility of applying blockchain to address cash flow challenges in construction. The CBC looks forward to continuing its work with the All Party Parliamentary Group (APPG) on Blockchain and anticipates that the findings laid out in this document will have a role in the formation of government policy in this area.

In Chapter 1, we note that the complexity of construction projects and implications for cash flow starts from their outset given their financing from multiple sources, such as government-backed large infrastructure or public works to private funding of commercial real estate. We also raise that failure in projects may happen as a result of poor project execution and a number of common issues can arise, including cost overruns as a result of poor communication, poor planning, changes in design or build, and late or misprogrammed events. Each of these, their treatment, effect, management and resolution is principally governed by the requirements under law. This underpins the need to streamline legal and financing procedures to compartmentalise the root causes and the effects of failure in projects. This is where blockchain technology is touted as a solution that can address project complexity and in doing so reduce late payments, remediations and disputes that place companies under cash flow risk.

In Chapter 2, we provide an explanation of blockchain, followed by a more detailed explanation of its features and potential limitations. Blockchain is defined as a distributed index or database holding a growing list of records, grouped in packs or 'blocks'. These blocks are sequentially linked using cryptography and each block contains a cryptographic hash of the previous block, a timestamp, and transaction data. This technology is the basis for use-cases of the following categories: Strategic Registry, Identity, Smart Contracts, Dynamic Registries, Payment Infrastructures, and Others. Blockchain drives smart contracts, which are applications that run exactly as programmed without any possibility of downtime, censorship, fraud or third-party interference. They have the potential to become fully developed computational legal contracts and dramatically improve all aspects of construction project administration and payment systems in the sector. However, there are some potential limitations which must be considered.

In Chapter 3, we draw attention to how recent technological developments (LawTech, FinTech, MagTech and Supply-Tech) have the potential to improve the way the legal and AEC sectors operate offering greater efficiency and, therefore, cost-saving. LawTech presents the opportunity for the legal sector to automate repetitive tasks, develop methods to locate, identify and access critical information faster, and improve collaborative working methods in multidisciplinary teams. FinTech can provide clear administrative oversight, with transparent cash-handling and transaction execution providing clarity and certainty to all parties, helping to avoid cash mismanagement, late or non-payments down the supply chain, project or project party insolvency and, ultimately, disputes. MagTech and Supply-Tech could address the increasing demand for quality scopes, predictable schedules, and reliable budgets through more efficient information transfer, including design decisions, as well as managing design changes as a result of requests for information, submittal adjustments, and change orders. Lastly, we consider numerous industry reports into blockchain and related technologies, which indicate that there is much progress to be made to educate about, and sustainably implement, such technologies. The reports recognise a number of potential advantages to new technologies but with varying critical analysis, which is crucial to successful implementation.

Chapter 4 examines the scope for implementing blockchain solutions in the construction industry's cash flow systems. It takes into account the legal context and challenges to this in detail. We emphasise that any solution that does not sit within this framework would not be legal and, therefore, could not be implemented. In the immediate, there are opportunities for blockchain implementation which could include automation and acceleration of payment, automation of accounting, and improved project management and administration. Otherwise, future opportunities could include automated management and administration of complex financial and contractual arrangements and mechanisms, automatic enforcement and dispute resolution of damages arrangements and payments, and improved procurement processes. Importantly, blockchain is likely to lead to redundancies of existing legal, financial, and process orthodoxies, and transformation of them. This chapter also specifies the array of potential legal and financial compliance requirements and regulatory stipulations for any new technology.

We conclude by setting out the challenges identified in the document and a roadmap for taking the technology forward. Challenges include:

- Ensuring that there is a greater understanding of the current legal regime and financial regulations across the industry;
- Providing stakeholders with appropriate training so they can be appropriately consulted and engaged throughout the process of adoption; and
- Considering the legal and financial requirements of different geographic jurisdictions.

We suggest a six-point roadmap, involving:

1. Devising of a strategy and timeline for encouraging/mandating adoption;
2. Identifying major stakeholders which will drive change;
3. Starting with the automation of simple processes before considering larger ones;
4. Ensuring that the underlying source-code of smart contracts is developed for specific applications in order to fully leverage the technology;
5. Attending to cybersecurity implications that may arise from deploying this technology; and
6. Considering a mandate for the use of smart contracts either in conjunction with the BIM mandate or in a similar fashion to it.

Whilst this roadmap requires significant coordination, it is an opportunity for all of us - academia, industry and government - to prove our commitment to improving the construction sector.

1.0 Nature of Finance in Construction

Summary

- The complexity of construction projects and implications for cash flow starts from the outset given that they are often financed from multiple sources, such as government-backed large infrastructure or public works to private funding of commercial real estate.
- Failure in projects may happen as a result of poor project execution and a number of common issues can arise, such as cost overruns as a result of poor communication, poor planning, changes in design or build, and late or misprogrammed events.
- Each of these, their treatment, effect, management and resolution is principally governed by the requirements under law. This underpins the need to streamline legal and financing procedures to compartmentalise the root causes and the effects of failure in projects.
- Blockchain technology is touted as a solution that can address project complexity and in doing so reduce late payments, remediations and disputes that place companies under cash flow risk.

1.1 Introduction

The construction industry is a high impact sector and a key driver for all national economies, be it through employment of people, development of - and return on - investment for the development of society, or as a fundamental stimulator for economic activity. Yet, the structural and processual complexity of construction, especially with regards to legal and financial aspects, is causing persistent problems that the industry is in constant need of addressing. The power of digitalization, specifically with blockchain technology, brings an opportunity to overcome these obstacles. The following sections introduce the nature of construction, its persistent challenges, and their implications. We then explore the proposed solution of streamlining financing and cash flows in construction projects through blockchain technology.

1.2 Structural and Processual Complexity

In the UK, it is forecast that construction will contribute more than £163 billion per annum and constitute 6.5% of GDP to the UK's Gross Domestic Product (GDP) between 2015 and 2020 **(ONS, 2018, 2017)**. Whilst in the US, construction contributed $590 to 650 billion per annum or 3.8 to 4.1% of GDP to the US GDP between 2015 and 2018 **(Statista, 2020)**. The importance and complexity of the construction sector can be outlined by the following characteristics:

1. At a national macro-level, construction contributed 6% to UK GDP, or approximately £113 billion, in 2017. In Q3 2018, 2.4 million people were employed by the UK construction sector **(Rhodes, 2018)** and 10.7 million by the US construction sector **(Statista, 2019)**;

2. At a sectorial micro-level, construction projects vary significantly by size and economic value. By market segment, housing accounts for 25% of the value of construction sector orders, infrastructure for 12%, repairs and maintenance for 34%, other private orders 22% and other public 7% **(Rhodes, 2018)**.

Construction is ripe for automation and disruption because it is a highly project-based sector. Through temporary and typically non-repetitive endeavours, various professionals organised in firms come together to deliver construction projects.

In a typical project-level structure of a construction project there are numerous stakeholder parties involved throughout the supply chain, such as:

a. sponsors: client, funders, etc.;
b. design: architect, engineers, etc.;
c. build: main (prime or general) contractor, sub-contractors;
d. supply chain: manufacturers and product suppliers;
e. operation: management agent, facilities management; and
f. users: tenants, residents, customers.

The complexity of construction projects starts from its onset, as these temporary endeavours are financed from multiple sources; from governmental backing of large infrastructure or public works, to private funding of commercial real estate. The driver for such financing is, generally, stimulus of economic activities including improvement of delivery of services, environmental resilience, transportation connectivity, efficient utilisation of capital, and for profit activities.

As such, all disparate stakeholders of construction projects are the main parties whose interests are impacted by adverse project events. On a similar note, the construction industry supply chain is highly fragmented into various organisations of which over 99% of businesses are Small-Medium Enterprises (SMEs) **(White, 2015)**. This is consistent with the European average construction industry structure **(White, 2015).**

The fundamental approach to the project based, multi-party nature of construction and financing generates the need to review these layers of complexity in terms of cash flow. In order to determine the opportunities for technological applications, it is important to understand the failures, and the remedies implemented to mitigate the challenges faced by the complex nature of accounting in construction.

1.3 Framing the Problem: Implications for Financing and Cash Flow

At a project-level, being inter-organisational, construction projects can range from large, multi-party, multi-year complex undertakings to small kitchen remodels in your home. No matter the size, elements for the conduct of such projects include project management, contract administration, cash flow management, planning, supply chain management and other similar project oversight requirements. Underpinning these activities, describing the overarching responsibilities on the parties, are the legal obligations arising from the governing laws, contracts and common practices. As different types of procurement delineate degrees of collaboration among project parties, decision-making on contracting approach and procurement strategies has paramount implications for project success. Because of these varied approaches to decision making and contractual obligation, there is often failure in projects that lead to dispute.

Failure in projects may happen as a result of poor project execution and a number of common, or commonly experienced, issues can arise. These include cost overruns as a result of poor communication, poor planning, changes in design or build, and late or misprogrammed events. Each of these, their treatment, effect, management and resolution is principally governed by the requirements under law. This underpins the need to streamline legal and financing procedures to compartmentalise the root causes and the effects of failure in projects.

A report on disputes in construction from Arcadis **(2018)** confirmed that disputes typically arise due to (a) failure to properly administer the contract, (b) poorly drafted or incomplete/unsubstantiated claims, and (c) parties failing to understand and/or comply with contractual obligations. When disputes remain unresolved, parties may resort to litigation, activating the legal mechanisms of their contracts. As litigation is a lengthy and expensive process, 82% of disputes are usually solved before trial **(Arcadis, 2018, 2015)** or other formal dispute resolution forum.

The Fulbright's Annual Litigation Trends Survey **(Dan McKenna, 2013)** found that engineering and construction companies led in litigation, with 80% of them filing at least one suit last year. In 2017, the global average value of disputes was US$43.4 million and the global average length of disputes has increased slightly over the past years to 14.8 months **(Arcadis, 2018)**.

According to Arcadis **(2018)**, although the number of disputes has largely remained the same, both the time needed for dispute resolution and their value has increased. Project complexity is a contributing factor to this increase. The typical time scales to resolve disputes such as adjudication (1 month), arbitration (6 months to 1 year), or litigation (2 to 3 years), indicate the scale of adverse impacts even simple actions such as non-payments can have. The average payment time for construction companies and SMEs is 82 days, which can rise as high as up to 120 days. This has repercussions that can escalate down the whole supply chain.

Due to the cost of legal dispute and the timeline associated with a disruption in cash flow, it is important for investors to be confident in their procurement framework, contractual obligations, and have access to relevant information as these elements are decisive factors for avoiding disputes. Various lenders and developers believe that automation may expedite the financing process and make them confident in decision-making and quicker in disbursement of funds **(Danielle South, 2019)**.

1.4 Prospecting the Solution

Blockchain technology is touted as a solution that can address project complexity and in doing so reduce late payments, remediations and disputes that place companies under cash flow risk **(ICE, 2018)**. Considering blockchain technology within its context of intensive digital transformation that the construction sector is going through (such as Building Information Modelling (BIM), Internet of Things (IoT) and Artificial Intelligence (AI) among others) technological advances can help streamline information flows. At the same time, collaborative procurement is a decisive enabler of digital transformation.

To address the issues identified above, enhanced project management and control, contract administration, transparency and availability of accurate information in construction project governance are needed. A sector-generic and project-bespoke blockchain-enabled solution could potentially alleviate these repercussions and optimise cash flow restrictions.

2.0 Features of Blockchain

Summary

- Blockchain is a distributed index or database holding a growing list of records, grouped in packs or 'blocks'. These blocks are sequentially linked using cryptography and each block contains a cryptographic hash of the previous block, a timestamp, and transaction data.
- In a blockchain like Bitcoin, transactions are recorded into a distributed, replicated public database. The 'distributed consensus mechanism' is achieved by a 'proof-of-work' system called 'mining'.
- There are numerous blockchain applications and use cases, and they have been structured into six categories across its two fundamental functions of record keeping and transacting: Strategic Registry, Identity, Smart Contracts, Dynamic Registries, Payment Infrastructures, and Others.
- Employing blockchain in payment systems can help to avoid double spending.
- Smart contracts are applications that run exactly as programmed without any possibility of downtime, censorship, fraud or third-party interference. They have the potential to become fully developed computational legal contracts and dramatically improve all aspects of construction project administration and payment systems in the sector.
- Potential limitations to blockchain include those related to technical issues with the underlying technology, ongoing industry thefts and scandals, public perception, government regulation, and the mainstream adoption of technology.

In this chapter, we explore fundamental underpinning characteristics of blockchain that are relevant to potential solutions for project failure and disputes. Construction projects bring together large teams to design and shape the built environment. As new collaborative technologies - in particular Building Information Modeling (BIM) - become more widespread, openness to collaboration and new ideas is increasing across the industry. This momentum could be leveraged to bring the use of Blockchain technology to the fore.

2.1 Basic Principles

As a key technology of the current industrial revolution, Blockchain is a distributed index or database holding a growing list of records, grouped in packs or *'blocks'.* These blocks are sequentially linked using cryptography and each block contains a cryptographic hash of the previous block, a timestamp, and transaction data[1] .

A cryptographic hash is generated by a function that has certain properties which make it suitable for use in cryptography of blockchains. It is a mathematical algorithm that maps data of arbitrary size to a bit string of a fixed size (a hash) and is

[1] Transaction data is generally represented as a Merkle tree in which every leaf node is labelled with the hash of a data block, and every non-leaf node is labelled with the cryptographic hash of the labels of its child nodes.

designed to be a one-way function, that is, a function which is infeasible to invert **(Halevi and Krawczyk, 2006).** The bitcoin blockchain uses the SHA-256 (Secure Hash Algorithm) standard typically looking like the following:

"hash": "0000000082b5015589a3fdf2d4baff403e6f0be035a5d9742c1cae6295464449"

Table 1: SHA-256 example

The original blockchain in Bitcoin (fig. 2) displays the basic components of what is considered a blockchained ledger today.

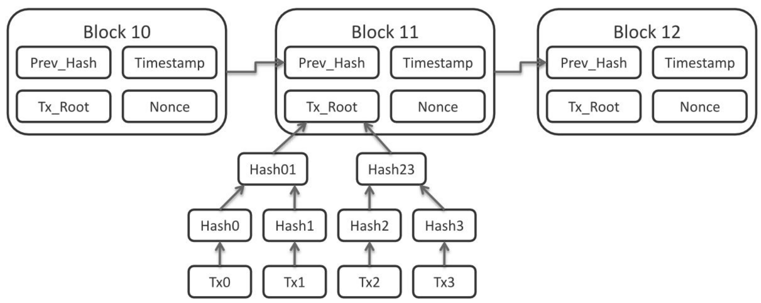

Figure 2: Bitcoin Block Data **(Wander, 2015)**

Each bitcoin block contains a '***Timestamp***'[2], a '***Prev_Hash***'[3] referencing a '***Previous***' or '***Parent***' block, a Merkle Root called ***'Tx_Root',*** which is a reduced representation of the set of transactions confirmed with the particular block.

The block's transactions themselves are provided independently, forming the body of the block. In the case of Bitcoin, there must be at least one transaction, called the '***Coinbase***'. The Coinbase is a special transaction that may create new bitcoins and collects the transaction fees. Other transactions are optional.

The '***Target***' corresponds to the difficulty of finding a new block. It is updated every 2016 blocks when the *difficulty reset* occurs.

An arbitrarily picked number labeled ***'Nonce'*** is employed to add entropy to a block header without rebuilding the Merkle tree.

All of the above header items (i.e. all except the transaction data) get hashed into the '***Block own hash***', which for one is proof that the other parts of the header have not been changed, and then is used as a reference by the succeeding block.

[2] Timestamp refers to the time when the block was found.
[3] Prev_Hash is a hash of the previous block header which ties each block to its parent, and therefore by induction to all previous blocks. This chain of references is the eponymic concept for the blockchain.

2.2 Synchronising Ledgers

In a blockchain like Bitcoin, transactions are recorded into a distributed, replicated public database. The '***distributed consensus mechanism***' is achieved by a '***proof-of-work***' system called '***mining***'[4].

When a transaction is submitted to the network, it is passed on peer-to-peer by all clients. Upon discovery, miners will put it on their list of transactions that they want to verify and update the Merkle Root (hash of all hashes). This process of mining for HashTags is a cryptographic protocol designed to keep consistency in the compilation of new blocks. In the process of synchronizing the ledgers, as many miners compete to find the next block, often there will be more than one valid next block discovered. This is resolved as soon as one of the two '***forks***' in the blockchain progresses to a greater length, at which any client that receives the newest block knows to discard the shorter fork. These discarded blocks are referred to as '***extinct blocks***'.

This mining process modulating the acceptance of a new block in the blockchain and requiring proof-of-work to accept a new block to the blockchain was Satoshi Nakamoto's key innovation in the deployment of the bitcoin system **(Nakamoto, 2008)**. The mathematical puzzle executed in this process is energy demanding, causing about 90% of miners' operational costs.

Other blockchains may or may not use a proof similar to bitcoin's PoW. For instance, the Ethereum blockchain currently uses a PoW but plans to change its consensus mechanism to a Proof of Stake (PoS) on its 2.0 release. This is a category of consensus algorithm for public blockchains that depend on a validator's economic stake in the network **(Ethereum Foundation, 2018)**.

2.3 Disruptive Aspects of Blockchain

As noted earlier, technologies and workflows like Building Information Modeling (BIM) bring openness to collaboration across the industry, which invites the use of Blockchain technology **(Hughes, 2017)**.

Blockchain represents a significant leap in the ways of digitally manipulating value, identity and automation of processes. There are numerous blockchain applications and use cases, and they have previously been structured into six categories (Strategic registry, Identity, Smart Contracts, Dynamic Registries, Payment Infrastructures, and Others) across its two fundamental functions: record keeping and transacting **(Brant Carson et al., 2018)**. In the remaining subsections of 2.4, the most relevant functions will be addressed as we review investments, financing and cash flow so that they are deemed secure, accurate, and able to support multi-party complex construction projects.

2.3.1 Digital Network of Value

One of the primary concerns of any cryptocurrency developer is the issue of double-spending. This refers to the incidence of an individual spending a balance of that cryptocurrency more than once, effectively creating a disparity between the spending record and the amount of that cryptocurrency available, as well as the way that it is distributed. The issue of

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[4] Technically, POW is not actually a consensus mechanism, though often described as one. PoW as designed for Bitcoin is the final step before committing the data to the blockchain. Technically, the full database architecture and its subparts are the consensus mechanism but the PoW is what commits the data to its immutable format in the blockchain and therefore is referred to as the consensus mechanism. So, if the PoW cannot compile a block, the consensus has not be finalised.

double-spending is a problem that cash does not have. A transaction using a digital currency like bitcoin, however, occurs entirely digitally. This means that it is not possible to copy the transaction details and rebroadcast it so that the same BTC could be spent multiple times by a single owner. Below, we'll examine how cryptocurrency developers have insured that double spending cannot happen.

2.3.2 Ownership of Digital Identity

Decentralized Identifiers (DIDs) are a type of identifier for verifiable, "self-sovereign" digital identities. DIDs are fully under the control of the DID subject, independent from any centralized registry, identity provider, or certificate authority. DIDs are URLs that relate a DID subject to a means for trustable interactions with that subject. DIDs resolve to DID Documents, which are simple documents that describe how to use that specific DID. Each DID Document may contain at least three things: proof purposes, verification methods, and service endpoints. Proof purposes are combined with verification methods to provide mechanisms for proving things. For example, a DID Document can specify that a particular verification method, such as a cryptographic public key or pseudonymous biometric protocol, can be used to verify a proof that was created for the purpose of authentication. Service endpoints enable trusted interactions with the DID controller **(W3C, 2019)**.

There are purpose-built open-source projects for decentralized identity **(Hyperledger, 2019)**. This provides tools, libraries, and reusable components for creating and using independent digital identities rooted on blockchains so that they are interoperable across administrative domains, applications, and any other “silo.”

Because blockchain cannot be altered ‘after the fact’, it is essential that use cases for ledger-based identity carefully consider foundational components, including performance, scale, trust model, and privacy. In particular, Privacy by design and privacy-preserving technologies are critically important for cybersecurity aspects of construction assets’ total lifecycle.

Identity is commonly cited as one of the most promising use-cases for distributed ledger technology. Initiatives and solutions focused on creating, transmitting and storing verifiable digital credentials will benefit from a shared, reusable, interoperable tool kit. Hyperledger Aries **(George et al., 2019)**, one of the newest Hyperledger projects, is a shared infrastructure of tools that enables the exchange of blockchain-based data, supports peer-to-peer messaging in various scenarios, and facilitates interoperable interaction between different blockchains and other distributed ledger technologies (DLTs).

Hyperledger Aries intends to provide code for peer-to-peer interactions, secrets management, verifiable information exchange, and secure messaging for different decentralized systems **(George et al., 2019)**. It also fosters practical interoperability in support of ongoing standards work and extends the applicability of technologies developed beyond its current community components from the Hyperledger stack into a single, effective business solution.

2.3.3 Smart and Computational Contracts

Computational contracts or smart contracts are currently described as applications that run exactly as programmed without any possibility of downtime, censorship, fraud or third-party interference **(Ethereum Foundation, 2018)**. Smart contracts have the potential to become fully developed computational legal contracts and improve dramatically all aspects of construction project administration and payment systems in the sector. Computational Legal contracts can become the engine for smart infrastructure and the combined circular economy.

Smart contracts have some groundbreaking properties. They are automated and proactive (vs. reactive) and the Distributed Applications (or DApps) are designed to be resilient (no down time) and an auditable source of truth. They have the potential to incorporate intelligences, from simple correlations and linear regressions to more complex Machine Learning methods.

Although complex smart contracts are currently untested, this technology promises unforeseen efficiencies in the construction sector and represents a foundation technology for intelligent environments. It can eradicate or dramatically diminish corruption and the misuse of law, promoting transparent global development.

Smart contracts can be developed to use single or multi signatures to approve its transactions. This facilitates the complex application for commercial implementations like asset management **(BitGo, 2019)**.

Programming Computational and Smart Contracts

A number of initiatives to advance the usability of smart contracts are creating domain specific programming language designed to be accessible for managers and lawyers. Initiatives like this aim to define technical specifications code such as data schemas, models, templates, a smart legal contract programming language, and a contract execution engine to enable anyone to implement smart legal contracts. The Accord Project **(Accord, 2018)** is one of these initiatives. It incubates an open-source codebase, enabling applications to be built on a common software foundation for smart legal contracts. The core execution elements are open-sourced, including the Cicero templating system **(Cicero, 2019)** and the Ergo programming language **(Ergo, 2019)**.

2.3.4 Decentralised Autonomous Organisations

Decentralised Autonomous Organisations (DAOs) aim to script and automate rules that a company would from the very inception. This could be setting aside a certain percentage of earnings for a cause or determining a process by which such a rule could be changed **(CoinDesk, 2019)**. DAOS can be formulated as an ecosystem of smart contracts coordinating large complex operations. They represent a new wave of automation in the development of the current industrial revolution.

2.3.5 Natural Language Processing Challenges

Natural language processing (NLP) is a subfield of linguistics, computer science, and artificial intelligence concerned with the interactions between computers and human language, in particular how to program computers to process and analyze large amounts of natural language data.

Various groups, including the CBC, have begun building libraries of machine readable transaction modules that correspond to natural language contracting elements. In doing so, they are creating the building blocks for ever more complex transactions that will ultimately define the entire envelope of computational legal conduct in these environments, and likely standardise the field.

However, there are numerous challenges in Natural Language processing and how to convey correct legal semantics and meaning from computer languages and scripts. There is significant progress on this domain but challenges highlight that the application of smart contracts at scale is not only untested but also, to an extenand, unpredictable. To find out more and participate in the CBC codebase, please visit constructionblockchain.org.

2.4 Technical Challenges and Limitations

There are many different kinds of potential limitations to blockchain. They are both internal and external and include those related to technical issues with the underlying technology, ongoing industry thefts and scandals, public perception, government regulation, and the mainstream adoption of technology.

The issues are in clear sight of developers, with different answers to the challenges posited through discussion and coding of potential solutions. Many are building different new and separate blockchains or technology that does not use a blockchain to circumvent limitations. One central challenge with the underlying Bitcoin technology is scaling up from the current maximum limit of 7 transactions per second, especially if there were to be mainstream adoption of Bitcoin **(Lee, 2013)**. Some of the other issues include increasing the block size, addressing blockchain bloat, countering vulnerability to 51 percent mining attacks, and implementing hard forks (changes that are not backward compatible) to the code are throughput, latency, size and bandwidth, security, resources, usability, infrastructure, and ecosystem (summarized in the Appendix) **(Spaven, 2014)**.

2.5 Further Information

Additional information about blockchain and its technical challenges are outlined in Appendix A. A list of further reading resources is listed at the end of this document.

3.0 Disruption & Applicability

Summary

- Recent technological developments have the potential to improve the way the legal and AEC sectors operate offering greater efficiency and, therefore, cost-saving.
- LawTech presents the opportunity for the legal sector to automate repetitive tasks, develop methods to locate, identify and access critical information faster, and improve collaborative working methods in multidisciplinary teams.
- FinTech can provide clear administrative oversight, with transparent cash-handling and transaction execution providing clarity and certainty to all parties, helping to avoid cash mismanagement, late or non-payments down the supply chain, project or project party insolvency and, ultimately, disputes.
- MagTech and Supply-Tech could address the increasing demand for quality scopes, predictable schedules, and reliable budgets through more efficient information transfer, including design decisions, as well as managing design changes as a result of requests for information, submittal adjustments, and change orders.
- Industry reports into blockchain and related technologies indicate that there is much progress to be made to educate about, and sustainably implement, such technologies. The reports recognise a number of potential advantages to new technologies but with varying critical analysis, which is crucial to successful implementation.

This section considers the current state of technology and technological development in key areas related to and that underpin activity in the construction industry. These areas are law, finance and project management. An understanding of these areas is essential to identify opportunities for disruptive solution development in the context. Finally the section considers the current state and maturation of blockchain technology as it may be applied to the construction industry.

3.1 Law and Technology (LawTech)

The process or execution of law has, over the last 20 to 30 years, changed both greatly and not at all. Whilst it is true lawyers have adopted personal working technologies, when it comes to 'working with the law' it remains overwhelmingly the case that lawyers revert, literally, to the printed word. However, there is significant appetite to (i) automate repetitive tasks, (ii) develop methods to locate, identify and access critical information faster, and (iii) improve collaborative working methods in multidisciplinary teams.

The administration of legal principles, processes and, ultimately, adherence to the mechanisms agreed under a contract is critical to the successful execution of a project. The failure to follow the required procedures leads to uncertainty, recrimination and disputes. A clear strategy to manage and adhere to the mechanisms agreed under the contract provides clarity and certainty to all parties.

At present many services are either single or point solutions for simple contracts with few variations, or else require complex logic paths and so are bespoke solutions, or are platforms that digitise the work of lawyers, transferring pen and paper to screen and keyboard. In the first instance there is little flexibility and all eventualities must be catered for, in the second instance there is also little flexibility as processes are commoditised such that they may be translated into a software platform.

There are a number of lawtech providers purporting to deliver a variety of solutions for the legal industry. These solutions are typically around the automation of contract creation and execution, the idea being that a great deal of lawyerly time is unnecessarily expended delivering low value standard contracts that clients could either self-serve or could be created faster through a standardised series of choices.

With blockchain, there are multiple opportunities to develop an integrated platform of smart contracts that can modularise, as opposed to commoditise, common legal processes. This would allow for greater flexibility and governance of legal processes that could support contract administration in construction projects.

3.2 Finance and Technology (FinTech)

The process or execution of finance has, over the last 5 to 10 years, seen seismic shifts in access to services. The credit crisis of 2008, in part, served as a catalyst for this change when it was felt that financial institutions could no longer be trusted to manage global markets and were taking too much risk with investors' money. The advent of blockchain, Open Banking, and the rise of fintech solutions pushed back against these centralised, monolithic, financial centres in an effort to return power and control back into the hands of investors and individuals.

Ease of access to finance, coordination of administration of financial services and/or products, as well as oversight of cash flow and financial accounting, are critical to the successful execution of a project. The failure of financial governance and accounting procedures can lead to (i) cash mismanagement, (ii) late or non-payments down the supply chain, (iii) project or project party insolvency and, ultimately, (iv) disputes. Clear administrative oversight, with transparent cash-handling and transaction execution provides clarity and certainty to all parties.

There are a number of fintech providers purporting to deliver a variety of solutions for the financial industry. These solutions are typically (i) banking integration and access: the idea being that a simplification of financial administrative oversight will (a) support improved cash management behaviours, (b) easier access through technology validation will reduce overhead costs, and (c) simplify data management, or (ii) trading platforms: accelerating personal trading activity and reducing or eliminating intermediary costs. At present these services appear fragmented as between the specific solutions provided, with integration between those services an afterthought if at all. There are few, if any, holistic fintech solutions that provide a single point of access and use for all parties to any financial media.

With blockchain, there are multiple opportunities to develop an integrated platform of smart contracts that can modularise common financial processes. This allows for greater flexibility and governance of financial processes that could support and improve project financial management in construction projects.

3.3 Management and Technology (MagTech and SupplyTech)

Utilizing project and supply chain management software is still not the standard operating practice for construction projects globally. However, due to the increasing demand for quality scopes, predictable schedules, and reliable budgets, there is a rising demand for technology to support the transfer of information, including design decisions, as well as managing design changes as a result of requests for information, submittal adjustments, and change orders.

These changes, updates, adjustments and other necessary nuisances come from many different sources, and can stem from any party at any time in the project. When these changes take place after the general contractor has materials already ordered, it provides another level of complexity that needs to be managed seamlessly to ensure the owner's/operator's needs are met.

3.3.1 Project Management

Communicating accurate project data, be it Requests for Information (RFIs), submittals, approvals, accounting and so on, within each party contracted on a project is very important. Each piece of information - correct, inaccurate, or lack thereof - could impact whether the budget is adhered to, the schedule is met, if the quality standard is met or when mechanical equipment (for example) will need to be replaced in 20 years versus 70 years.

In February 2013, in response to the need for clarity on how to manage information during projects, the PAS 1192 Standards suite was established by the British Standards Institute. The standard is becoming well known internationally as the approach to Information Management for the capital/delivery phase of construction projects. Recently, PAS 1192 internationalized in the form of an ISO standard and CEN (the European standards body) has confirmed that another standard, ISO 19650, will be adopted as a European standard where it focuses on managing information over the whole life cycle of a built asset using BIM.

ISO 19650 contains all of the same principles and expectations of Level 2 BIM as set out within the PAS 1192 standards. There is still much to do to standardize an approach to managing information globally. The need for information management at all stages of the asset lifecycle is becoming more prevalent for project teams to execute in a more efficient way and for owners to make better decisions about asset management.

Today, there are many cloud based technology solutions available for tracking the aforementioned information. These advancements allow for better collaboration and have improved from Building Information Management especially if there is a governance structure. Even with these provisions to manage project information, it can take days or sometimes weeks to collect information from a multiparty project team. Much of the project data is typically held in spreadsheets, word processing software and PDF file types. Most of the efforts for standardization are focused on converting this data into a form that a computer can process. However, there is also a concern about the validity of the data because typically there is no validation of the data confirming its accuracy in many instances.

With blockchain, each transaction of information between contracted parties can confirm the sincerity of data by including a validation step via a consensus model. This allows for trusted information that is time stamped and transparent to be located in one single source of truth database. A governance structure can be defined in such a way to support the functionality of a construction based project team.

Standard utilization, project level approvals, and record documentation for the lifecycle of a building asset in a trusted data set allows for new opportunities to gain lessons learned. As BIM Level 2 utilization increases, there is a new opportunity to track how the data management meets the specifications provided by PAS 1192 and ISO 19650.

3.3.2 Supply Chain (Goods and Materials Tracking)

Historically, the tracking of goods and materials through supply chains has leveraged RFID/barcode tagging of many different types of materials allowing for the receipt and shipment of materials to be documented at the point of receipt/transfer. Because there are different types of tracking mechanisms, there has been a need for either multiple databases respective to geolocation and the need for manual tracking in the supply chain to track the validity of the shipping node. A reliance on communication via phone, email and disparate databases is how verticals communicate about material tracking.

It is not uncommon for a project owner to request a status of a shipped unit from overseas, and for the response to take days to learn that it has only been shipped a number of days beforehand. Unfortunately, an update of that same item may not be available until it arrives at the next node for transfer.

3.3.3 IoT

Geolocation is the primary data set communicated via the supply chain, indicating whether an item has arrived or left a particular port. However, IoT sensors also have the capability to collect additional criteria about materials including temperature, humidity, proximity to other objects, pressure, collision, vibration, weight, and more. IoT has provided the ability for the condition of any particular item to be tracked and recorded to a server.

Blockchain allows for the quality of materials to be known, or verified, at any standpoint and thus more reliably trusted in order to meet the expectations upon delivery. The information is supplied to a cloud based platform on a digital ledger that can be accessed by anyone who has access to the network. The sensor-collected data is time stamped and has the ability to be verified by personnel if desired. With blockchain, there is the ability to transform the supply chain dataset to one that is more reliable using a cohesive and congruent transactional system. This is where blockchain can and has supported many industries in their supply chain/materials management.

With the ability to combine IoT and Blockchain, all parties including Subcontractors, General Contractors, and Owners can have a higher probability to rely and trust the traceability and quality of conditions for materials that are being transferred to the project site. It can verify that the material is stored properly on site, and that it has been installed correctly if reviewed against an augmented design model.

3.4 Blockchain Maturity in the Industry

Numerous reports have been published since the peak of the popularisation of blockchain technology in 2016 (see appendix A). They provide a useful understanding of the state of the industry's attitude and adoption (if at all) of blockchain technology. They indicate that there is much progress to be made with education about and implementation of blockchain technology and point to a number of prospects and opportunities posed by using the technology, including: efficiency (payments and transactions); cost savings; transparency; and augmentation of IoT, AI and BIM.

The main points of analysis made in the reports are as follows.

1. Full-scale adoption could take years because the majority of use cases are in test phases.
2. Concerns about profits and the vested interests underpinning these may hinder adoption.
3. There is a lack of understanding and trust in the technology which is slowing investment in and adoption of the technology.

4. The assumption that blockchain technology is inherently secure is wrong. Security vulnerabilities have been uncovered, with potentially more arising in future, and need to be addressed rapidly on an ongoing basis.
5. Failure of firms to ensure that blockchain is appropriately integrated into their processes and business model - and with necessary interoperability - could result in any potential cost savings being nulled or reversed.
6. A system of globally compatible governance needs to be created in order for blockchain adoption to effectively address global challenges and work seamlessly across regions and borders.

The reports assessed here come from a range of backgrounds: academic, governmental, industrial and commercial. In the period that the reports featured in this paper have been published (2016 to 2020), a trend is apparent in their content that suggests the technology has matured slightly, enough for reports published from 2018 onwards to provide more critical analysis of the technology's progression and industry attitudes towards it. Critical analysis of blockchain and its related technologies as a means of informing industry and policymakers is crucial if they are to be implemented successfully in the long term.

Indeed, the majority of reports begin with sections explaining the technology at least in basic terms and its potential advantages (several pages in the case of longer reports). That this was still the case in 2019 suggests that industry audience's knowledge of the technology is still not assumed.

However, a recent report by Deloitte **(Pawczuk et al., 2020)** based on a survey of 1,500 senior executives and practitioners in 14 countries suggests that a range of blockchain use cases are being developed including payments and transactions, data access/sharing, identity and asset protection, certification, revenue sharing, and access to IP. Over half of the respondents said that they perceived blockchain as a priority and a larger proportion said they have been increasing their investments in relevant staffing and related technologies. Respondents who agreed that their business would lose competitive advantage if they did not adopt blockchain increased to 83% from 77% in 2019 and 68% in 2018. These recent findings suggest that the adoption of blockchain is a serious consideration for industry. This is, therefore, a ripe time for legislators to consider stages of mandated adoption akin to the BIM adoption framework. This should involve staged increases in the sophistication of the technology's application within this statutory framework.

This intention of this paper is to present one of a few realistic avenues for blockchain implementation in the AEC sectors. The following chapter will examine the scope for such implementation in cash flow systems and, crucially, take into account the legal context and challenges to this in detail.

4.0 Application Analysis

Summary

- Examining the scope for implementing blockchain solutions in the construction industry's cash flow systems must take into account the legal context and challenges to this in detail. Any solution that does not sit within this framework would not be legal and, therefore, could not be implemented.
- Immediate opportunities for blockchain implementation could include automation and acceleration of payment, automation of accounting, and improved project management and administration.
- Future opportunities could include automated management and administration of complex financial and contractual arrangements and mechanisms, automatic enforcement and dispute resolution of damages arrangements and payments, and improved procurement processes.
- Blockchain is likely to lead to redundancies of existing legal, financial, and process orthodoxies, and transformation of them.
- There are a significant number of potential legal and financial compliance requirements and regulatory stipulations for any new technology, specified in this chapter.

In this section the Whitepaper explores the considerations and ramifications for any potential cash flow solution for the construction industry and the paths to its evolution. The evolution of solutions in the legal and finance space and the key considerations that cash flow and cash management solutions must address are discussed. Appendix C considers several projects with an assessment of their functionality and applicability to comparative problems in a construction context.

In general terms the construction industry faces three core challenges: financial (money), programme (time) and quality (negligence/workmanship) management. Various laws and regulations have been introduced to address the financial element and assuage this greatest source of construction project pain. It is critical that the development of project cash management solutions for the construction industry must first understand the legal frameworks with which they are obligated to comply. Any solution that fails to do so would not be legal and would have no effect.

4.1 Evolution of Law on Cash Flow Management in Construction

4.1.1 United Kingdom (Broad View)

A fundamental change introduced by the Housing Grants, Construction and Regeneration Act 1996 was to outlaw "pay-when-paid" arrangements in construction projects[5] **(HGCRA, 1996 Ch.53, s.113)**. The parties had to agree to a "pay-on-invoice" arrangement under which, on submission of a valid and payable invoice by the sub-contracted party, the

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[5] *Historically, prior to 1996 and the assent into law of the Housing Grants Construction and Regeneration Act 1996 (the "HGCRA" or "1996 Act") enacted in 1998* ***(HGCRA, 1996 Ch. 53)****, the wider construction industry, and particularly construction on a project by project basis, suffered from considerable cash flow and inter party payment problems. This, notably, led to considerable litigation on the basis of challenges to non- or under-payment with or without sufficient grounds to do so. The payment position was typically described as "pay-when-paid" meaning that a sub-contracted party would only receive payment against their invoices once the contracted party had also received payment.*

contracted party could not withhold payment pending payment of their invoice to the upstream supply chain. However, that is not to say payment could never be withheld as the HGCRA also formalised the process by which payment could be withheld.

Furthermore, on failure of agreement between the parties to specify the payment mechanism, the Scheme for Construction Contracts 1998 (the “Scheme”) provided a default payment mechanism **(HGCRA, 1996 Ch. 53, ss. 3-10)**. This default mechanism required issuance by the invoice receiving party of:

1. A payment notice not later than 5 days after the due date for payment (payment usually being due on receipt of the sub-contracted party’s invoice); and
2. A withholding notice not later than 7 days prior to the final date for payment, stating the amount and reason for which payment, or part thereof, was to be withheld **(HGCRA, 1996 Ch.53, ss. 109-113; SCCR, 1998 Part 2, s.2)**.

The Local Democracy, Economic Development and Construction Act 2009 (the “LDEDCA” or “2009 Act”), enacted in 2011, introduced several significant amendments to the 1996 Act, e.g., (i) amendments were made to the payment regime, in particular the enhancement of payment notice provisions, obligation to pay the notified sum, and the creation of pay less notices, although the overall principles remained unchanged, and (ii) several adjudication principles were formalised that had not been adequately addressed under the 1996 Act and had seen a significant number of legal challenges **(LDEDCA, 2009)**.

Specifically on payment, the 2009 Act amended the 1996 Act by incorporating detailed notice requirements **(LDEDCA, 2009, Part 8)**. The parties to a construction contract were no longer free to agree payment notice periods not otherwise in accordance with those specified in the legislation or, on failure to agree such payment notice periods under the contract, those prescribed by the Scheme (as amended), i.e., payment notice periods became fixed or are prescribed by legislation.

The payment mechanism changes, either in legislation or required by default under the Scheme, included:

1. A right to the party applying for payment to issue a notice, titled an “application for payment”, to be made 7 days in advance of the due date for such payment **(LDEDCA, 2009 s.143; SCCR, 1998 Part 2, s.2)**. This differs as it is not necessarily an invoice that is issued at this point, but a calculation of and the reason for the amount intended to be included in an invoice and requested for payment. It is a pre-emptive mechanism designed to avoid payment and withholding disputes;
2. Contractual provision to be made for the issue of payment notices, by either payer or payee, not later than 5 days after the payment due date, i.e., usually the date of issue of the invoice. This differs as now the payee is able to issue this notice on failure of the payer so to do, although a delay in issuance of this notice by the payee may extend the final date for payment by a concomitant amount; and
3. The “notice of intention to withhold” was retitled “requirement to pay notified sum” with parties to agree the time period within which the “pay less” notice must be issued in advance of the final date for payment, otherwise the Scheme default mechanism applies. This differs as withholding may only apply to the payment request in hand and payment cannot be arbitrarily delayed for failure to issue this notice within the required period ahead of payment.

The resulting payment cycle mechanism may be seen in the image below.

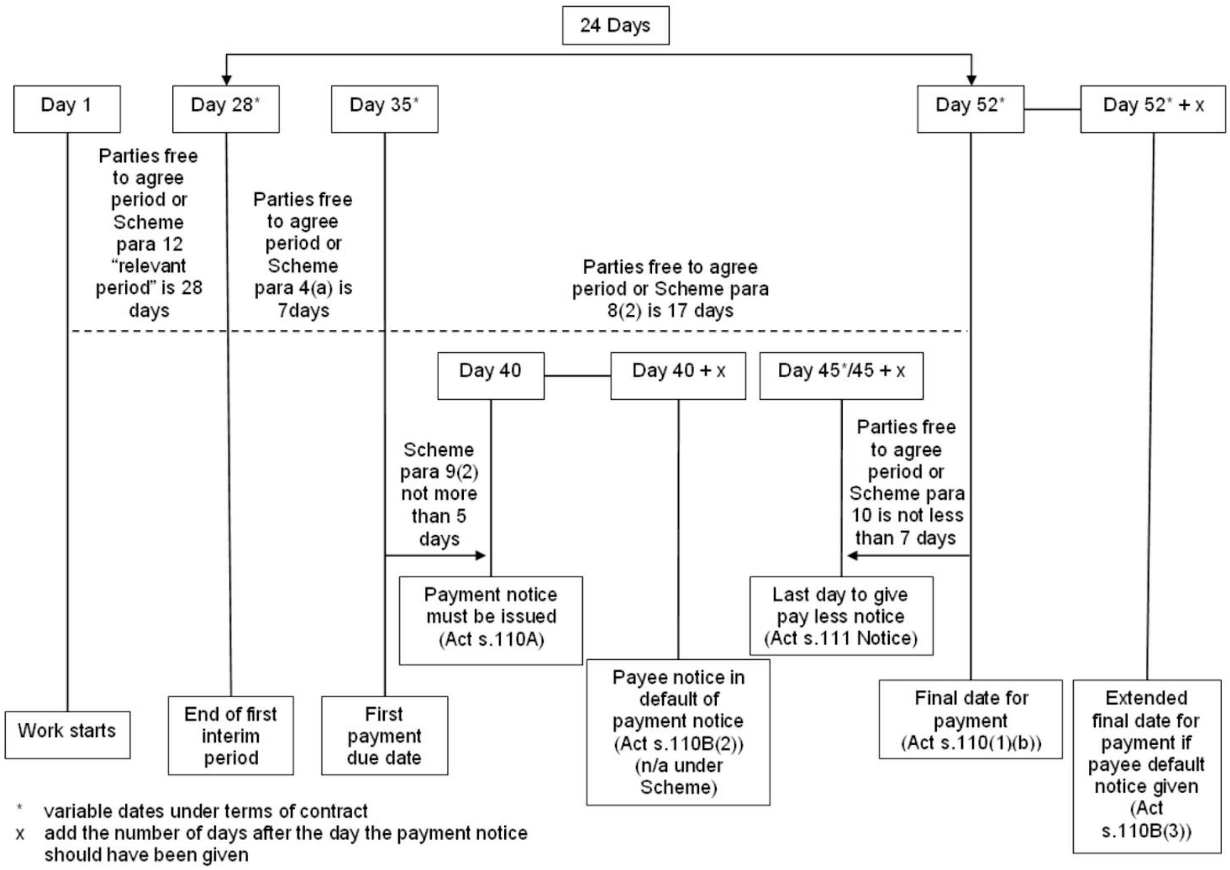

Fig. **(CRIPPS, 2011)**

4.1.2 United States of America (Overview)

In the United States, an over $1.27 trillion industry in construction alone, the governance for "pay-when-paid" (and "pay-if-paid") provisions have federal and state level jurisdictions with varied expectations when it comes to cash flow and payment for construction projects. On a project by project basis, it is common to see such payment practices vary, which causes owner organizations (public or private) to put precautions in place to ensure subcontractors and suppliers receive payment from the general contractor. A risk management process has been put in place to ensure payments are made because as of 2017, 39% are in the moderate late payment class for payments up to 30 days late on average. The other payment classes are more or less stable compared with 2015 levels: 3.8% of US companies pay between 30 and 90 days late on average, whereas 3.4% of the total demonstrates critical management of payments, paying suppliers more than 90 days late on average **(Dun & Bradstreet, 2017)**.

The terms of a contract can be varied, but net 30 day payments are generally expected, i.e., 30 days for the owner to pay the general contractor and then 30 days to the subcontractor or supplier from the date the general contractor is paid. If, for some reason, a subcontractor is not paid there are provisions in place to protect the project. Often, third party organizations like title companies or project management consultants ensure that sworn statements, lien waivers, Payment Applications and Continuation sheets are populated correctly and reconciled throughout the duration of the project **(AIA-G702, 1992)**.

There is no legal requirement to include exact language issued via federal or state law, i.e., that precludes “pay-when-paid” or “pay-if-paid” clauses, and it can often be unclear what arrangement is intended. There is precedent requiring parties to include express payment clauses, however there are often conflicting interpretations of the meaning of such clauses. Furthermore, these clauses are typically litigated in state court with varying interpretations, although more consistently the interpretation determined is as a “pay-when-paid” clause. A major restriction to the use of such clauses is that a general contractor may not enforce another valid payment clause if the reason for the owner’s non-payment is attributed to the failure of the general contractor to comply with contractual requirements **(Ledet et al., 2019)**.

4.2 Areas of Intervention

4.2.1 Short-term Interventions

The are several immediate impacts that a technological solution using distributed ledger and blockchain elements could achieve for project cash management:

1. Interparty Payments I - Automation of Payment:

   In-project as between each level, e.g., Employer to Main Contractor, Main Contractor to Subcontractors, Sub-contractors to Suppliers and so on down the supply chain, and under any procurement arrangement. Payments may be automated, as executed on satisfaction of predetermined criteria or conditions within smart contracts, and improve project-wide liquidity. This, by necessity, would evolve to include the automation of the management of withholding and subsequent release of payment monies;

2. Interparty Payments II - Acceleration of Payment:

   In-project elimination of long and/or delayed invoice payment terms. A long stop for payment may be the “standard” 30 days, however payment could be effected within this period immediately on satisfaction of predetermined criteria or conditions within smart contracts. This acceleration in cash flow allows faster downstream payments, reduces or eliminates payment processing delays, reduces credit risk and reduces contract, subcontract and supply party insolvency risk;

3. Interparty Payments III - Automation of Accounting:

   In-project automatic issue of invoices, and other payment notices, in accordance with the contractual payment mechanism, as against predetermined criteria or conditions within smart contracts. Requests and/or applications for payment may be automated once goods or services are confirmed as performed, delivered, installed, operational and so on, i.e., once the contractually predetermined criteria are confirmed satisfied. Payments may be made on immediate or scheduled bases, or as may otherwise agreed to be made such as on advance (mobilisation or deposit), interim, or periodic bases. Accounting processes may no longer need to be fixed to monthly, quarterly, or annual cycles. Similarly, post-project completion, releases of retentions could be automatically triggered on satisfaction of pre-agreed criteria. This payment fluidity, or flexibility, improves project liquidity and reduces potential cash mismanagement, as well as inappropriate or unreasonable withholding. Automation of event feeds to accounting software would provide greater insight and accuracy to accounts balances and projections, create more robust and timely accounting and reduce reliance on intensive human driven accounting processes;

4. Project Management:

   In-project oversight of interparty cash flows and supply chain cash management, at all levels or strata of project stakeholders, will identify payment bottlenecks and allow project management to resolve payment issues before dispute risks arise. This improves project liquidity with timely completion of payments, payment mechanism efficacy through targeted process analyses and issue resolution and, ultimately, reduces dispute risk and the consequential adverse project impacts.

   A secondary benefit, derived through greater visibility of payment data, may be party and project performance monitoring. It may be possible to execute comparative analyses of payments between parties, i.e., how much has been paid and for what works as recorded in the smart contracts, against actual project progress. Individual parties, and the project as a whole, may be assessed against the project plan. Collective analyses may then be executed to determine whether parties are ahead or behind of planned progress, whether they are therefore over- or under-claiming payment, and whether corrective actions, such as acceleration or mitigation, are required by project management; and

5. Project Administration:

   In-project oversight of project finances for auditability, account reporting, overall progress of spend on and to completion, i.e., burn rates, and fund level analytics. Beyond individual or overall project performance, it may be possible to determine the overall project's financial performance. Through aggregation of payment data across all project parties determination of project capital burn rates, i.e., how much is being spent, when and on what, for reporting analytics. Through this improved data visibility comparative analyses of costs, both individual and project-wide, along with under- and over-estimations, may be identified.

4.2.2 Long-term Interventions

The are several long term impacts that a technological solution using distributed ledger and blockchain elements could achieve for project cash management beyond immediate payment cycle management:

1. Complex Financials:

   Management and administration of complex financial arrangements will be automated, e.g., automated in-system performance and guarantee bonds, automated retention and release of retention on completion (practical and final);

2. Variations, Delay and Extensions of Time:

   Payment for (i) variations, against (presumably) validly raised invoices, and (ii) withholding and/or adjustments following assessments of delay and/or EOT costs are addressed in the short term process improvements described above. However, certain contractual mechanisms, such as variations, delays and extensions of time that require the issue of requests or notices, valuations and consents or approvals, are more complex project management processes with specific or bespoke contractual, commercial and practical requirements to be observed and conditions to be satisfied;

3. Liquidated Damages:

   Contractually agreed liquidated damages arrangements may be automatically enforced by reference to, or integration with, current approved project programmes.

   An interim measure, ahead of formal dispute resolution processes, may be to automate disputed sums retention (c.f. security for costs and/or sums on account) with deposit or escrow account holding pending formal resolution;

4. Dispute Resolution:

   Disputes, typically those subject to dispute boards or that are adjudicable, and that specifically arise from matters of payment, may be managed and resolved in-system with automated settlements. It is noted that escalated, complex, or post-project disputes would require much more sophisticated cashflow solutions that may not be suitable for solution development at this time.

5. Procurement:

   As a result of the project administration, data visibility, and collection over multiple projects over time, could begin to feed into procurement activities indicating likely or appropriate costs levels for specific activities and types of construction project.

4.3 Redundancies

4.3.1 Legal

Although legal principles remain the foundation for payment mechanisms, processes that overlay these to create fully integrated workflows may result in some standard legal devices becoming redundant or deprecated. One such example may be the generation and execution of bonds. As, effectively, all cash or claimable equivalents (in-system 'cash flow' may be a tokenised analogy as a representation of value) will be held in-system, with automated processes to account for performance measurement and withholding, parties may no longer be required to provide bonded funds.

4.3.2 Financial

If there were no requirement to provide bonded funds, such instruments and their costs, administration, management and release would no longer be necessary to be provided by third parties (banks or insurers). An alternative scenario may be for a solution to incorporate such bonded funds functionality and potentially disintermediate the function performed by banks or insurers. Consideration of such InsureTech solutions is beyond the scope of this paper.

4.3.3 Process

As a result of the adoption of technological solutions for cash flow and cash management human administrative functions and interaction with repetitive processes will be redundant. Similarly, financial instrument initiation and administration would either be automated in execution or managed in-system.

4.4 Transformation

4.4.1 Legal

All solutions must be legally compliant as there will be no (immediate) transformation in legal or regulatory requirements. However, the solution may facilitate accelerated legal and regulatory compliance and simplify execution of financial instruments and mechanisms[6, 7]. An example may be retentions under JCT contracts, which may become less relevant (due to the direct relationship between payment claims, assessed works completion and satisfaction of conditions within the smart contracts), but also would reduce the administrative burden and time required to monitor, manage and maintain them. The same is true whether payment milestones are time-event based, e.g., monthly or other periodic scheduled payments, or performance-event based, e.g., completion of work elements. In both cases satisfaction of criteria within a smart contract is the determining element to trigger payment processes.

Strict application of legal concepts will prevent, or at least reduce, improper implementation and inadequate execution of those concepts and process failures, e.g., failure to issue pay less notices on time will prevent inappropriate withholding or deduction at the time payment is due.

4.4.2 Financial

Improvements to cash flow and cash management will significantly impact downstream supply chain participants, in particular individual, small or medium enterprise sub-contracted parties that are less able to bridge operating cash flow between client payments and/or have less access to credit.

4.4.3 Process

Improvements in cash flow and cash management will significantly reduce management oversight and financial administration. As solutions develop and integration with project management systems advances, interconnections between, e.g., (i) works progress reviews through QS, architect and site engineer activities, (ii) the automation of inspection sign-off against progressed or completed works in accordance with overall project works schedule and/or, more simply, (iii) on-time subcontract party supplier deliveries, will all be possible. Over time performance data and metrics will be extractable to determine delay impacts, withholding, pain-share/gain-share claim rights and for similar contractual incentive mechanisms.

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[6] *It should be noted that the case under consideration is, broadly, assumed to be a common law system with comparable payment mechanisms and/or requirements. However, different legal systems will have differing statutory and regulatory requirements, legal principles and standard form contracts. When developing solutions for specific jurisdictions developers should seek local legal advice accordingly.*

[7] *A point for consideration is whether the use of such software needs to be contractually incorporated into the project. On one view the use of general software tools is not usually a point for incorporation, other than perhaps a broad performance specification. On another view it would be desirable for all parties involved in a given project to adopt a single coordinated payment solution to ensure adherence to payment requirements, simplification of administration, financial and accounting oversight, and benefit from the advantages described in this paper.*

4.5 Current Blockchain Technology Solutions

The blockchain solution space is presently dominated by finance solutions, many targeted at the tokenisation of securities to, assumptively, improve market liquidities and generally improve value transfers (in the monetary or monetised sense) between parties. Secondary effects of this are to reduce the costs of such activities through disintermediation of third parties, improve market accountability, and secure record keeping. However, many such projects struggle due to the high level of regulation imposed on financial activities, in particular when dealing with securities or securitised assets **(Al-Naji, 2018)**.

There are a number of solutions at various stages of development that seek to address in-project exchanges of value, several of which are discussed in Appendix C. However, there are as yet no blockchain projects in development that aim to deliver a solution that, holistically, addresses the particular needs of the construction industry.

4.6 Solution Requirements

Any immediate cash flow and cash management solution for the construction industry must comply with the following requirements as a matter of law, commercial practicality and common practice. That is not to say better, or best, practices should not be integrated into the solution only that, as a case for immediate adoption and execution within the industry, the solution must reflect current working practices, understandings and, in any event without exception, comply with law.

4.6.1 Solution Legal and Financial Compliance Requirements

The 10 core requirements for any proposed solution are:

1. any UK solution, compliance with the 1996 Act, as amended by the 2009 Act, payment requirements **(HGCRA, 1996, Part 1; LDEDCA, 2009)**;
2. any US solution, compliance with the standard 30 day net payment standard with pay-when-paid clause, determined by State or Federal jurisdictions **(Ledet et al., 2019)**;
3. any solution, ultimately, should be jurisdiction agnostic so that the solution may be universally adopted and tailored to the specific project on hand;
4. as a general principle, any solution must be procurement arrangement agnostic as to invoice settlements between parties, must reflect standard contractual settlement terms and periods, but must also reflect the overall project procurement structure for cash flow and cash management;
5. any solution must ensure transaction transparency within the project supply chain and consistently execute an unknown number of transactions at predetermined times against predetermined criteria;
6. if there is to be a single, be it a decentralised or distributed, network then any solution must be project and party separable from other projects to insulate liability and ensure clear separation (anti-commingling) of funding. This tends to be an issue determined contractually, but is not consistently addressed contractually. At a party level multiple project funds would ultimately become commingled within, e.g., their solution wallet. It may be necessary to appropriately mark received tokens prior to and pending cash-out to a party’s bank account. Source of funds information would also need to be passed to the end bank;
7. any solution must ensure Know-Your-Client (“KYC”) and Anti-Money Laundering (“AML”), at least at point of first access to the solution, regulations and requirements are complied with, as applicable. On a private or public permissioned platform, once “wallets” are set up and validated for the issue and acceptance of tokenised/escrowed cash claims, the digital signature may be sufficient for future KYC and AML requirements on the assumption that the

"once proven, always proven" principle applies. It is noted that KYC, as generally regulated (i) in the UK under the purview of the Solicitors Regulatory Authority ("SRA") (legal) and Financial Conduct Authority ("FCA") (financial) and (ii) in the USA under the purview of the state bar associations (legal), Securities and Exchange Commission ("SEC") (financial) and Commodities and Futures Trading Commission ("CFTC") (financial), applies (i) in the legal instance in all cases and to all clients **(Frisby, 2019; SRA, 2019, 2018)** and (ii) in the financial instance when conducting designated investment business. It is not known at this time whether the activities described to be part of a cash flow solution would fall within this description **(FCA, 2019a; Frisby, 2019)** and KYC principles need be considered **(FINRA 2090, 2017; FINRA 3280, 2019)**;

8. any solution must be able to interact with a party's accounting software for the exchange and reconciliation of financial and accounting information. In the UK, the requirements of "making tax digital" **(GOV.UK, 2019a)** and other HMRC reporting requirements may also need to be considered. In the US, the reporting requirements of the IRS may also need to be considered;
9. any solution must be able to interact with a party's banking arrangements for the final settlement of funds both paid in and out, subject to their position within the project structure or supply chain. Single party payment netting-off may or may not be appropriate depending on cash flow movements, but should be considered to simplify settlements to off-platform accounts and reduce settlement and/or transaction costs, particularly in cross-border, foreign currency and/or multi-currency arrangements. Additional consideration is required to address issues such as forex and sanctions scenarios; and
10. any solution must be open to financial, accounting, data integrity and performance analytics audits **(GOV.UK, 2019b)**.

4.6.2 Solution Legal and Financial Investigation and Advisory Requirements

There are a number of problems to be overcome in delivering a cashflow or cash management solution that, as yet, are not fully settled as a matter of law in the UK, EU or the USA. The 10 core investigation and advisory requirements that any proposed solution development will need to consider and resolve are:

1. UK, EU and US regulators, i.e., the FCA **(2019b)**, EBA **(2019)**, SEC **(2019a)** and CFTC **(2019)**, do not treat tokens as cash. In broad terms, tokens are treated as an asset. As the solution centres on project cashflow, a legal and financially viable method of the value transfer needs to be identified **(FCA, 2019c; HC910, 2018; SEC, 2019b)**;
2. the exchange of tokens is treated as an exchange of assets. Crypto-currencies are not cash currencies nor equivalent in treatment, under current regulations, to fiat currencies **(FCA, 2019c; HC910, 2018; SEC, 2019b)**;
3. although any solution is likely to be closed to non-authorised parties, at least at a project level, consideration should be given to outward token tradability. The representative token is likely to have, or it will represent, cash value. It may or may not be desirable for parties, at least within the scope of a cash flow solution, to be able to speculatively trade such tokens given current crypto-currency trading volatilities. However, future development, in particular project funding, may wish to undertake this type of activity with or by funder parties using resale or trading of tokens to, e.g., aggregate lending or financing risks, purchase insurance or deal in other complex financial instruments;
4. the tax treatment of token exchanges are, with rare exceptions, based on capital gains tax principles and not income or corporation tax principles. This presents a potential problem for accounting purposes **(HMRC, 2019)**. The application of Value Added Tax (VAT), sometimes at variable rates, on supplies of goods and services is a further complicating factor;
5. the legal and accounting requirements on the treatment of funds, if securities or cash equivalents, received through the platform are yet to be determined beyond the initial tax treatment described above;

6. the impact of AML5 **(Jourová, 2018)** (that specifically includes virtual currencies within the AML criteria), Markets in Financial Instruments Directive ("MiFID") II **(FCA, 2019d; MiFID II, 2018)**, Payment Services Directive ("PSD") **(EC 2366, 2015; EUR-LEX, 2015)** and/or regulatory authorisation, i.e., licensing, requirements will need to be considered in the context of any provision of financial credit, escrow or other third party funds holding account;
7. the legal requirements for KYC/AML and the ongoing duties, if any, under relevant financial regulations will need to be fully determined. It may be that the technological solution is in effect a permanent and/or ongoing confirmation of KYC, whereas AML may not be appropriate in all circumstances depending on the sums, parties, sources and location involved in the project on hand;
8. the requirements of financial accounting and audit schemes, e.g., Generally Accepted Accounting Principles ("GAAP"), Sarbanes Oxley ("SOX") **(SOXLAW, 2008)**, Foreign Corrupt Practices Act ("FCPA") **(USDOJ, 2015)** and others, may add additional legal and regulatory requirements to the issue of requests for and receipts of payment;
9. the impact of cross-project and/or cross-contract liability claims. Although this may be a long term intervention in view of the complexity of dispute resolution processes, there may be cross-project and/or cross-contract rights of set-off, net-off, abatement and/or other principles that require implementation of automated net settlement;[8] and
10. as the movement of cash, or its equivalent, is transitory throughout a supply chain, it is critical that the functionality of any token holding wallet operates on clear principles of originator request, payment party source, reference project identifiers, and work element or task payment status. Transparency, auditability and efficiency are critical industry improvements achievable with the application of blockchain technology.

4.6.3 Regulatory Approval and Development

It is suggested that any proposed UK solution should consider entry into the FCA sandbox regime and any proposed US solution should consider engagement with the SEC FinHub. In either case to trial any digital asset, financial or securitised element of their solution, such that may act as a "cash equivalent token" or a "token that is a claim on cash in some form of exchange, or otherwise escrowed, account", and/or any other potentially regulated financial activities.

4.6.4 Business Transformation and Adoption

Change and transformation projects in any enterprise or industry can be difficult to deliver, whilst Start-ups face their own challenges of credibility. Often people fear change and resist it even to their own detriment. Any proposed solution should be intuitive and, at least initially, reflective of what people already do and how they work. Over time better and best practices will be introduced and maintained through "enforcement" in-system.

[8] *Such arrangements are usually contract specific and would need to be addressed on a contract by contract basis. Further complications may arise as, e.g., rights of set-off may be caveated with rights to object or specific obligations under dispute resolution clauses.*

5.0 Recommendations

A core challenge in construction is the coordination and management of multiple involved parties. Historically, construction has had a reputation for poor performance as to meeting time and cost targets. It is thought that by mediating payment and cash flow, and enforcing contract mechanisms for the governance of such, it will in fact alleviate uncertainty and de-stress project cash flows. Furthermore, by providing an ecosystem or environment that demands transparency, improving project wide visibility, and collaboration will ultimately reduce time and costs risks, waste as well as corruption and financial mismanagement.

5.1 Challenges

In order to formulate adequate solutions to procurement challenges in the built environment, the question of what problem the technology is addressing should be foremost in stakeholders' minds. In addition to this, there are the following considerations.

A	Greater understanding of the current **legal regime and financial regulations** is needed across the industry. Legal and financial advice is needed to gauge feasibility of new technologies.
B	Stakeholders across the supply chain must be educated about the technology to a level at which they can be **consulted and engaged** throughout the process of adoption.
C	Consideration should be paid to tailoring technologies to different **geographic jurisdictions**. Eventually all jurisdictions could be accommodated for, but earlier cases may need implementation solely within one in order to ensure proper testing.

5.2 Roadmap

For successful implementation, a master plan should be devised, taking into account education, testing (including thought experiments), pilots, allocation of funding and then roll-out. In addition to this, the following points should be taken into account.

1	A strategy and timeline for **encouraging/mandating adoption** should be devised. For smaller firms lacking technical expertise, it should be marketed as a system to help stakeholders be paid correctly and according to standardised payment timelines. For larger firms, it should be marketed as a way of providing certainty and streamlining their processes.
2	**Major stakeholders which will drive change** should be identified. This will be the government in partnership with larger firms, as well as SMEs and Micro businesses leveraging the new technology. Government leadership should accompany the establishment of a framework for the technology's use.
3	Solutions should **start with automation of simple processes** before considering automation of complex operations. This will facilitate easy integration with existing legal and financial systems. Smart contract code can be fairly easily integrated within existing practises. Interactivity between APIs needs to be identified. One option would be to execute the blockchain process and have the payment process behind it, meaning verification would apply first, which would then trigger the payment process.
4	There is an obvious conflict in the implementation of blockchain-based computational legal contracts when discussing **code integrity vs execution flexibility**. This should be carefully analysed and developed so that the key features of computational smart legal contracts are not obscured by technological work-arounds.
5	The advent of smart legal contracts on the blockchain brings a new set of **cybersecurity implications**. With the promise of greater automation in the construction sector, cybersecurity protocols and frameworks will have to be adjusted and extended. This will ensure that they are resilient, traceable and respect privacy and other statutory rights.
6	Smart contracts technologies, when associated with the construction sector, are complementary and **could be fully integrated with the already established BIM mandate** and integrated with established BIM processes such as BIM Execution Plans (BEPs) and early-stage Employer's Information Requirements (EIRs).

To conclude, the adoption of blockchain remains a serious and growing consideration for the industry. However, much of the initial hype regarding blockchain's applicability is fading away, and the technology is changing and maturing rapidly. This represents a strategic moment for legislators and the industry to join forces and shape the technology's adoption.

Blockchain is a digital network of value and a key financial technology, promising greater collaboration between project parties, spurring greater financial openness and accountability and, over time, reducing costs and preventing losses to opaque business processes. It is up to us - government, industry and academia - to decide how serious we are about achieving this crucial transformation of the construction sector.

Glossary

B

Blockchain: Please refer to chapter 2.

Building Information Modelling (BIM): A set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space.

C

Cash Flow: The net amount of cash and cash-equivalents being transferred into and out of a business.

CDM: see 'Common Data Environment'.

Cryptocurrency: A digital currency in which encryption techniques are used to regulate the generation of units of currency and verify the transfer of funds, operating independently of a central bank.

Common Data Environment: The common data environment (CDE) is a central repository where construction project information is housed. The contents of the CDE are not limited to assets created in a 'BIM environment' and it will therefore include documentation, graphical models and non-graphical assets.

D

Distributed Ledger Technology (DLT): A data architecture using peer-to-peer data distribution to synchronise a ledge of transaction.

E

Ethereum: Ethereum is an open-source, blockchain-based, decentralized software platform used for its own cryptocurrency, ether. It enables SmartContracts and Distributed Applications (DApps) to be built and run without any downtime, fraud, control, or interference from a third party.

Hash: A mathematical algorithm that maps data of arbitrary size to a bit string of a fixed size.

I

Industry 4.0: The Fourth Industrial Revolution (or Industry 4.0) is the ongoing automation of traditional manufacturing and industrial practices, using modern smart technology.

Intellectual Property (IP): Intangible property that is the result of creativity, such as patents, copyrights, etc.

P

Procurement: The function that describes the activities and processes to acquire goods and services. Importantly, and distinct from "purchasing", procurement involves the activities involved in establishing fundamental requirements, sourcing activities such as market research and vendor evaluation and negotiation of contracts. It can also include the purchasing activities required to order and receive goods

Proof of Work: a consensus algorithm mechanism by which a blockchain implementation can confirm transactions and produce new blocks in the chain.

Proof of Stake: a type of consensus algorithm by which a blockchain network aims to achieve distributed consensus.

R

Retentions: An amount of money that is owed to someone for doing work but that is not paid until the work has been completed in a satisfactory way.

S

Smart Contracts: A smart contract is a self-executing contract with the terms of the agreement between buyer and seller being directly written into lines of code. The code and the agreements contained therein exist across a distributed, decentralized blockchain network.

Supply Chain: In the UK, supply chain refers to tier 2 contractors and manufacturers. In the USA supply chain often refers to subcontractors and/or suppliers handling materials.

SME: A Small-Medium Enterprise is an entity comprising either less than 250 employees (Medium) or less than 50 employees (Small). Additional parameters in some jurisdictions may also include turnover limits.

T

Token: a digital representation of a tangible (i.e., real or financial) or intangible (i.e., non-physical) asset, or part thereof..

Tokenisation: the process of identifying the key features and attributes of an asset to be digitally represented as a token.

About the Authors

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Brittanie Campbell-Turner is a Construction Management Professional who works with Corporate Real Estate owners and operators to reduce uncertainty as they make decisions on their construction projects. She is passionate about servicing the engineering and construction management industry and has been working for 10+ years in Project Management.

Brittanie is also currently the Workplace Innovation and Construction Manager and Owner's Representative at American Family Insurance and Managing Director of Constructrr where she hosts the Constructrr Podcast. Brittanie serves on the USA Alliance of the Construction Blockchain Consortium Steering Committee. She has presented at multiple AEC Technology Conferences including CoreNet Global Tech Day Conference Carolinas Keynote Speaker, Mechanical Contractors Association (MCA) Tech Day Seminar Speaker and panelist, International Facilities Management Association (IFMA) Facility Fusion Panelist, International Facilities Management Association (IFMA) Chicago World FM Day Featured Speaker, Computational Law + Blockchain Festival 2018, Chicago Node guest speaker, Congress on the Future of Engineering Software (COFES) round table host, Builtworlds Summit Guest Speaker, among others.

Leo Garbutt

Leo Garbutt is the Coordinator of the Construction Blockchain Consortium at The Bartlett Faculty of the Built Environment at UCL. He studied BA (Hons) Politics and Social Policy at the University of Leeds, graduating in 2014, followed by an MSc in Globalisation and Latin American Development at UCL, graduating in 2015. Since then, he has held a number of roles at UCL, including at The Bartlett School of Construction and Project Management.

Leo is interested in how blockchain and DLTs can change practices and behaviours in the construction sectors, which face a variety of challenges. He is intrigued by the potential of blockchain to alleviate issues with payments, safety, transparency, and environmental sustainability.

Gavin Johnson

Dr. Gavin Johnson is a solicitor and a member of the Policy Project Committee for the Construction Blockchain Consortium (CBC) advising on a range of issues including legal, regulatory, whitepaper development and general policy. Gavin is the Founder and CEO of aGenium, an xTech Consultancy, providing services for the legal, professional services and technology sectors. His professional work lies at the intersection of law, technology and process efficiency. He is also involved in several start-ups developing blockchain solutions for a range of financial, asset and self-sovereign identity applications.

Gavin has extensive experience in construction law and a passion for technology. He has worked in senior positions in several leading law firms, as a consultant to LPOs and technology start-ups. He trained at the global engineering firm Arup and has worked in both the transactional and litigation sectors of construction law for over 10 years. He is a Lean Six Sigma practitioner and an advocate for technological development and the implementation of efficient systems.

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Dr. Abel Maciel is an Architect and Senior Research Associate at the University College London. His research interests include Computational Design, Artificial Intelligence (AI) and Distributed Ledger Technology (Blockchain). He is Director of Design Computation, a specialist consultancy based in London. There, he focuses on the development and delivery of complex Building Information Modelling, Programmatic Design, and Digital Fabrication. Abel brings extensive experience in architecture and research on a wide range of design typologies and scales, working with some of the world's leading design practices, such as Arup, Foster and Partners, Heatherwick Studio and Zaha Hadid Architects. He is a Founding Director of the Construction Blockchain Consortium (CBC) and Faculty Member of the UCL Centre of Blockchain Technologies.

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Richard Saxon

Richard Saxon is one of the “foremost thinkers in the construction industry” according to Don Ward, lately Chief Executive of Constructing Excellence in the Built Environment. In 2001, Richard was awarded the CBE for services to architecture and construction, recognising his work for the modernisation of the industry and the greater satisfaction of customers. Richard is the former chairman of BDP, one of the UK's largest firms of international architects, designers and engineers. He now acts as a client and business adviser and is chairman of the Joint Contracts Tribunal (JCT).

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Appendices

Appendix A) Additional Features of Blockchain

A.1. Blockchain Data Features

This is a sample of a simple solidity smart contract for storing data. This basic example describes how to set the value of a variable and expose it for other contracts to access **(Solidity, 2019)**.

The first line simply tells that the source code is written for Solidity version 0.4.0 or anything newer that does not break functionality (up to, but not including, version 0.7.0)	`pragma solidity >=0.4.0 <0.7.0;`
The line uint storedData; declares a state variable called storedData of type uint (unsigned integer of 256 bits).	`contract SimpleStorage {` `    uint storedData;`

A contract in the sense of Solidity is a collection of code (its functions) and data (its state) that resides at a specific address on the Ethereum blockchain. The line uint storedData; declares a state variable called storedData of type uint (unsigned integer of 256 bits).	`function set(uint x) public {`
	`        storedData = x;`
	`    }`

In this case, the functions set and get can be used to modify or retrieve the value of the variable.	`function get() public view returns (uint) {`
	`        return storedData;`
	`    }`

This closes the script for the smart contract.	`}`

This contract does not do much yet apart from (due to the infrastructure built by Ethereum) allow anyone to store a single number that is accessible by anyone in the world without a (feasible) way to prevent you from publishing this number. Of course, anyone could just call "set" again with a different value and overwrite your number, but the number will still be stored in the history of the blockchain.

A.2. Blockchain Technical Challenges

Throughput

The Bitcoin network has a potential issue with throughput in that it is processing only one transaction per second (tps), with a theoretical current maximum of 7 tps. The Ethereum blockchain supports 15 tps **(Etherscan, 2019; Hertig, 2018)**.

For reference, metrics in other transaction processing networks are VISA (2,000 tps typical; 10,000 tps peak), Twitter (5,000 tps typical; 15,000 tps peak), and advertising networks (>100,000 tps typical). A higher performance would be necessary and core Bitcoin and Ethereum developers are working to raise limits for when it becomes necessary. One way that Bitcoin could handle higher throughput is if each block were bigger, though right now that leads to other issues with regard to size and blockchain bloat **(Swan, 2015)**.

Latency

Average confirmation time of Bitcoin transactions in 2019 was about 10 minutes **(Statista, 2019)**. For sufficient security, you should wait more time—about an hour—and for larger transfer amounts it needs to be even longer, because it must outweigh the cost of a *double spend* attack. Again, as the comparison metric, VISA takes seconds at most.

Size and bandwidth

The Bitcoin blockchain already takes a long time to download (about one day over a fast internet connection). If throughput were to increase by a factor of 2,000 to VISA standards, for example, that would be 1.42 PB/year or 3.9 GB/day. At 150,000 tps, the blockchain would grow by 214 PB/year. The Bitcoin community calls the size problem “bloat,” but that assumes that we want a small blockchain. However, to really scale to mainstream use, the blockchain would need to be big, but more efficiently accessed too. This motivates centralization, because it takes resources to run the full node, and only about 7,000 servers worldwide do in fact run full Bitcoin nodes, meaning the Bitcoin daemon (the full Bitcoin node running in the background).

It is being discussed whether locations running full nodes should be compensated with rewards. Although 25 GB of data is trivial in many areas of the modern “big data” era and data-intensive science with terabytes of data being the standard, this data can be compressed, whereas the blockchain cannot for security and accessibility reasons.

However, perhaps this is an opportunity to innovate new kinds of compression algorithms that would make the blockchain (at much larger future scales) still usable, and storable, while retaining its integrity and accessibility. One innovation to address blockchain bloat and make the data more accessible is APIs, like those from Chain and other vendors, that facilitate automated calls to the full Bitcoin blockchain. Some of the operations are to obtain address balances, record balances changes, and notify user applications when new transactions or blocks are created on the network. In addition, there are web-based block explorers **(Blockchain, 2019)** - middleware applications - allowing partial queries of blockchain data, and frontend customer-facing mobile e-wallets with greatly streamlined blockchain data.

Security

There are some potential security issues with blockchain. The most worrisome is the possibility of a 51% attack, in which one mining entity could grab control of the blockchain and double-spend previously transacted coins into his own account **(Valkenburgh, 2018)**. The issue arises from the centralization tendency in mining where the competition to record new transaction blocks in the blockchain has meant that only a few large mining pools control the majority of the transaction recording. At present, the incentive is for them to be good players, and some have stated that they would not take over the network in a 51% attack, but the network is insecure **(Rizzo, 2014)**. Double-spending might also still be possible in other ways—for example, spoofing users to resend transactions, allowing malicious coders to double-spend coins.

Another security issue is that the current cryptography standard that Bitcoin uses - Elliptic Curve Cryptography - might be crackable. However, financial cryptography experts have proposed potential upgrades to address this weakness **(Wang et al., 2019)**

Resources

Mining draws an enormous amount of energy. The earlier estimate cited was $15 million per day, and other estimates are higher **(O’Dwyer and Malone, 2014)**. Bitcoin's annual electricity consumption adds up to 45.8 TWh. The corresponding annual carbon emissions range from 22.0 to 22.9 $MtCO_2$. This level sits between the levels produced by the nations of Jordan and Sri Lanka **(Stoll et al., 2019)**. The wastefulness of PoW and mining is what makes that particular blockchain trustable but such a huge waste indicates the consensus mechanism needs to be improved and become sustainable.

Usability

APIs for working with blockchains like Bitcoin, Ethereum and Hyperledger projects are far less user-friendly than the current standards of other easy-to-use modern APIs, such as widely used REST APIs **(RestfulAPI, 2019; W3C, 2019)**, although there interoperability and common standards exist between them.

Infrastructure

Many technical issues in blockchain have to do with the infrastructure. One issue is the proliferation of blockchains and, with so many different blockchains in existence, it is becoming easier to deploy the resources to launch a 51% attack on smaller chains as happened with the Ethereum Classic (ETC) in January 2019 **(Nesbitt, 2019)**.

Another issue is that when chains are split for administrative or versioning purposes, there is no easy way to merge or cross-transact on forked chains.

Ecosystem

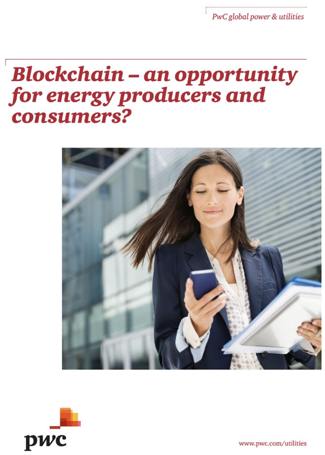
Another significant technical challenge is that a complete ecosystem of solutions has to be developed to fulfill the value of the blockchain promises, particularly in services delivery. There is a need to have secure decentralized storage (MaidSafe, 2019; Storj, 2019), messaging, transport, communications protocols, namespace and address management, network administration, and archival to name a few.

The blockchain industry may develop similarly to the cloud-computing industry, for which standard infrastructure components were defined and implemented at the beginning to allow for the development of value-added services instead of the core infrastructure. This is important in the blockchain economy due to the cryptographic engineering aspects of decentralized networks. The industry is learning how much computer network security, cryptography, and mathematics expertise the average blockchain startup should have. It should rely on a secure infrastructure stack where this functionality already exists and provide agility in the delivery of new applications.

Appendix B) Reports

Title	Organisation	Year	Resource
Blockchain – an opportunity for energy producers and consumers?	PwC	2016	Link to report
Blockchain Technology: How the Inventions Behind Bitcoin are Enabling a Network of Trust for the Built Environment.	Arup	2017	Link to report
Blockchain in commercial real estate: The future is here	Deloitte	2017	Link to report
Blockchain and Smart Contracts: What the AEC sector needs to know	CDBB	2018	Link to report
Blockchain in Action: State of the UK Market	Digital Catapult	2018	Link to report
Can Blockchain Fix The Construction Industry Productivity Problem?	ENSTOA	2018	Link to report
Blockchain: The next innovation to make our cities smarter	FICCI-PwC	2018	Link to report
Blockchain Technology in the Construction Industry	ICE	2018	Link to report
Blockchain for Construction/Real Estate	Thomson Reuters	2018	Link to report
Building Block(chain)s for a Better Planet	WEF	2018	Link to report
Blockchain and the Built Environment	Arup	2019	Link to report
BIM and JCT Contracts	JCT	2019	Link to report
Deloitte's 2020 Global Blockchain Survey	Deloitte	2020	Link to report

2016



PwC | Blockchain – an opportunity for energy producers and consumers?

Description

PwC's study **(PwC, 2016)** into blockchain has a particular emphasis on its potential impact on energy and consumers. It notes its potential to serve as an efficient peer-to-peer transaction platform and to lower costs, speed up processes and allow greater flexibility. It asserts that blockchain could streamline metering, billing and clearing processes in the energy market and potentially transform it. The study also explores the current barriers hindering the implementation of blockchain applications and the varying extent of maturity across industry. It notes that energy is only at a conceptual stage in energy and some other sectors, whilst it is more developed in financial services. The study argues that there may be potential benefits for "prosumers" who both consume and produce energy as there is a clear legal and regulatory framework for this, albeit one that will have to be adjusted to accommodate for decentralised transaction models.

Conclusions

The study concludes that whilst financial blockchain applications have reached a high level of maturity, it remains to be seen whether the technology will succeed in revolutionising the entire sector. It describes the state of blockchain's penetration in the energy market as "early days". However, initial test projects have given some indication that the technology could deliver significant benefits in terms of cost savings, speed and flexibility.

2017

Arup | Blockchain Technology: How the Inventions Behind Bitcoin are Enabling a Network of Trust for the Built Environment

Description

This report **(Arup, 2017)** was produced by Foresight, Arup's internal think-tank that examines and reports on new trends in the Built Environment and broader society to inform AEC decision-making and practise. It is the first of their reports on blockchain. The authors explain the technology and explore its potential interaction with contracts, supply chains, cities, IOT and BIM. There is some discussion of the potential legal implications of blockchain technology, followed by a thought experiment on a potential use-case for blockchain in transportation, followed by a report on a new distributed ledger platform for engineers. There is a brief description of Arup's first blockchain technology workshop in February 2017 which was attended by representatives from Deloitte, PwC, Skanska and HM Government, among others, who were receptive to the potential applications of blockchain. A one-page non-exhaustive list of some blockchain use cases outside AEC is provided (Financial, Corporate, Governments, and Cross-Industry), followed by a one-page summary of its limits in which a trade-off between speed, openness and security depending on the type of blockchain application is described.

Conclusions

The report concludes by suggesting that, although there are some risks associated, the industry should seriously consider the adoption of blockchain technology. It draws comparisons with the adoption of the internet and the benefits it brought, such as the improvement of interactions. It argues that blockchain will provide a trust network that will enhance operations and mitigate corruption or disputes. The conclusion also describes output improvements made possible through better contract management, increased supply chain transparency and operability between the Circular Economy, BIM, IoT and smart sensors.

Deloitte | Blockchain in commercial real estate: The future is here

Description

Deloitte's Centre for Financial Services published its report on blockchain **(Deloitte, 2017)** with a particular emphasis on commercial real estate (CRE). The report opens with a summary of the "new technology", and assesses how blockchain can assist with CRE leasing and purchase and sale transactions via six listed "opportunities": improving property search processes; expediting pre-lease due diligence; easing the leasing and subsequent property and cash flow management; enabling smarter decision-making; enabling transparent and relatively cheaper property title management; and enabling more efficient processing of financing and payments. It concludes with an assessment of the next steps for the adoption of blockchain technology and how the industry should approach it.

Conclusions

The report describes blockchain technology as being at a "nascent" stage, especially in the CRE sector. It notes that the feasibility of its applications is likely to be ascertained through continuous testing of use-cases. There is a warning that blockchain is not the solution to all of the CRE sector's inefficiencies and, even with an automated system, "trusted intermediaries" will still be needed. Failure to implement blockchain correctly could increase costs, it argues. Thus, the paper suggests that companies should "educate" to increase their knowledge of blockchain, consider whether to "collaborate" or "create" opportunities, and "facilitate" the implementation of blockchain. The report concludes with the assertion that blockchain will require companies to reevaluate their practises thoroughly and that the technology could bring much value to the industry so should be considered and revisited by companies on an ongoing basis.

2018

CDBB | Blockchain and Smart Contracts: What the AEC sector needs to know

Description

This working paper **(Lamb, 2018)** was produced by the Centre for Digital Built Britain at the University of Cambridge. Its purpose is to inform AEC about the basic components of blockchain technology, with a particular emphasis on Smart Contracts and related project management processes. It examines potential benefits, including: faster and less costly transactions; improved information sharing and transparency; greater quality assurance; and the democratisation of transactions without repercussions for workers. Barriers to adoption are also identified, such as: over-estimation of cost reductions; the energy cost of operating blockchain; skills gaps in a workforce that is unaware of blockchain; lack of interoperability between various blockchain platforms; and lack of guarantees over data quality. The legal status of smart contracts is also questioned, as is the maturity of blockchain technology across different sectors. The paper draws attention to an estimate that “90% of pilots will fail over the next 18 to 24 months” **(Omale, 2019)**. It notes that there are some areas of AEC that are more suited to adoption of blockchain than others, such as applying blockchain via BIM and smart contracts. The author states that this has potential but there is little academic literature on the intersection of these technologies. Finally, it asserts that there are pressing technical questions that need addressing, an assessment of supporting infrastructure should be carried out, and policies and standards need to be put in place before full-scale adoption.

Conclusions

The paper concludes that blockchain technology is not yet mature enough to be adopted at a large scale, especially as it has not been proven in any sectors similar to AEC. Nonetheless, there are some interesting smaller-scale trials that could add weight to the technology. There is also some further research needed in specific technical areas that, once known, could make blockchain’s integration with certain areas of AEC more inviting.

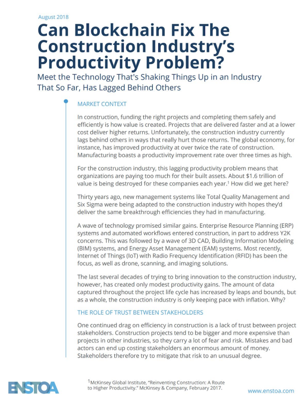
Digital Catapult | Blockchain in Action: State of the UK Market

Description

Digital Catapult is an advanced digital technology innovation centre funded by the UK Government to drive early adoption of technologies and, in turn, make UK businesses more competitive and productive. Their report **(Digital Catapult, 2018)** into the state of the UK market begins with a brief introduction to blockchain technology and key terms. It explores some potential applications of DLT, including supply chain traceability, smart contracts, and govtech (confidential information sharing). There is a description of the global blockchain landscape explores efforts by other nations to develop blockchain technology, followed by an overview of the UK’s situation which, it notes, draws strength from its “higher education and research institutions, historic environment for innovation and the presence of global corporations”. It lists some blockchain initiatives in creative industries and manufacturing. The report proceeds to present its market research findings into the state of blockchain in the UK. It explores the various types of blockchain platforms in operation (distributed ledger developers, dApp developers, service providers, and centralised systems), their share of the market, and qualitative findings. It explores their funding and growth, and notes the market's concerns over legal, regulation and banking issues, such as the inaccessibility of DLT specialist lawyers (due to costs, lack of quality/understanding) and confusion over regulations. The document finishes by advertising Digital Catapult's DLT Field Labs which explores the full implications of DLT across multiple economic sectors.

Conclusions

The report concludes by asserting that there are many opportunities presented by DLTs in the UK, including the streamlining of processes, enhancing supply chain traceability, and the transforming of citizen and corporate relationships with centralised or traditional authorities. It advises that policy makers should provide more guidance around GDPR and the use of tokens (including ICOs) and there should be more cooperation between banks and DLT companies. Corporations, the report argues, should increase the visibility of DLT's potential beyond cryptocurrencies and for industries outside of the financial sector and increase collaboration. It ends by suggesting that DLT companies should create safe spaces for reduced-risk experimentation with technology and pursue avenues that can help to explore DLT's potential.



August 2018

Can Blockchain Fix The Construction Industry's Productivity Problem?

Meet the Technology That's Shaking Things Up in an Industry That So Far, Has Lagged Behind Others

MARKET CONTEXT

In construction, funding the right projects and completing them safely and efficiently is how value is created. Projects that are delivered faster and at a lower cost deliver higher returns. Unfortunately, the construction industry currently lags behind others in ways that really hurt those returns. The global economy, for instance, has improved productivity at over twice the rate of construction. Manufacturing boasts a productivity improvement rate over three times as high.

For the construction industry, this lagging productivity problem means that organizations are paying too much for their built assets. About $1.6 trillion of value is being destroyed for these companies each year.[1] How did we get here?

Thirty years ago, new management systems like Total Quality Management and Six Sigma were being adapted to the construction industry with hopes they'd deliver the same breakthrough efficiencies they had in manufacturing.

A wave of technology promised similar gains. Enterprise Resource Planning (ERP) systems and automated workflows entered construction, in part to address Y2K concerns. This was followed by a wave of 3D CAD, Building Information Modeling (BIM) systems, and Energy Asset Management (EAM) systems. Most recently, Internet of Things (IoT) with Radio Frequency Identification (RFID) has been the focus, as well as drone, scanning, and imaging solutions.

The last several decades of trying to bring innovation to the construction industry, however, has created only modest productivity gains. The amount of data captured throughout the project life cycle has increased by leaps and bounds, but as a whole, the construction industry is only keeping pace with inflation. Why?

THE ROLE OF TRUST BETWEEN STAKEHOLDERS

One continued drag on efficiency in construction is a lack of trust between project stakeholders. Construction projects tend to be bigger and more expensive than projects in other industries, so they carry a lot of fear and risk. Mistakes and bad actors can end up costing stakeholders an enormous amount of money. Stakeholders therefore try to mitigate that risk to an unusual degree.

ENSTOA

[1] McKinsey Global Institute, "Reinventing Construction: A Route to Higher Productivity." McKinsey & Company, February 2017.

www.enstoa.com

ENSTOA | Can Blockchain Fix The Construction Industry Productivity Problem?

Description

ENSTOA is a technology consultancy that assists organisations with improving the efficiency of their operations through ledger technology. Their summary of blockchain **(ENSTOA, 2018)** begins by outlining the construction industry context and examining the role of trust between stakeholders and factors hindering productivity in construction. It then explores how blockchain and smart contracts could disrupt the industry as a departure from the "document driven model" which could give stakeholders a more complete picture of the supply chain and allow for more effective change management and forecasting.

Conclusions

The report suggests that organisations that are interested in adopting blockchain should explore whether blockchain/smart contracts would add significant value to their operation, whether their existing vendors are - or would be interested in - using the technology, whether blockchain would increase their productivity at a structural level, and if there are any problems they are trying to solve that could be a good candidate to test blockchain/smart contracts.

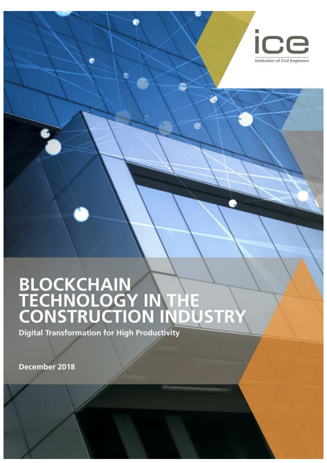
FICCI/PwC | Blockchain: The next innovation to make our cities smarter

Description

Multinational consultancy firm PwC and the Federation of Indian Chambers of Commerce and Industry (FICCI) in India have published a report into blockchain and, specifically, its role in creating smart cities **(PwC, 2018)**. It begins by outlining the attraction of blockchain technology in terms of solving current issues, and then describes what blockchain is, its benefits, its types and the conditions needed for blockchain to be implemented. It explores how blockchain can be implemented in the “smart city landscape”, including: citizen participation; economy and employment; health; identity and culture; education; land use; housing and inclusiveness; transportation; intelligent government services; energy; water; air quality; waste and sanitation; and safety. It describes a means of prioritising use cases by assessing the impact, complexity and governance need of each one in turn. The report then describes some detailed use cases in areas including social benefits, land registration management, and agriculture.

Conclusions

In describing a way forward, the report cautions that large scale implementation of blockchain – or indeed any new technology – will take time. This is especially as blockchain is still being tested at a small scale. For adoption by the government and public sector, the report argues that the technology will need to be “validated, regulated and adopted”, it asserts. The report suggests that a structured approach is needed, and details what this would entail in phases.



Institute of Civil Engineers | Blockchain Technology in the Construction Industry

Description

This late 2018 Institute of Civil Engineers report into blockchain technology in the construction industry **(ICE, 2018)** serves to introduce readers to the technology and outline some potential applications. It begins by describing what the technology is and why it is relevant for the construction industry. It explores blockchain in the context of smart contracts and how this might benefit the construction industry. This is further elucidated in chapters on payment and project management, procurement and supply chain management, and BIM and smart asset management. The report outlines some barriers to adoption as identified by industry leaders. These are divided into early challenges (regulatory uncertainty and lack of trust among users) and obstacles in 3 to 5 years (cost, how to start, and lack of governance). The author also identifies some construction industry-specific challenges: regulation; vested interests; culture; narrow margins; knowledge sharing; and fragmentation. The stages within which to move towards the implementation of blockchain are then described.

Conclusions

The report concludes by highlighting that blockchain has the potential to influence the digital and business practise “revolution” that the construction industry is currently undergoing. It states that, whilst there are challenges to its implementation, “the potential of reshaping the industry for the better is simply too great to miss”.

Thomson Reuters | Blockchain for Construction/Real Estate

Description

Thomson Reuters’ brief report **(Reuters, 2018)** into blockchain for construction with an emphasis on real estate was written following their webinar on the subject in April 2018. The report notes industry challenges and introduces blockchain as a potential solution to them. Blockchain applications to support privacy and transparency, supply chain tracking, easing data complexity and transforming contractual arrangements are explored. It then explores the impact of blockchain on industry litigation via smart contracts, and how legal disputes can be resolved more efficiently. The report also mentions the potential for blockchain to facilitate a master ledger for property listings. It briefly touches upon blockchain’s application in banking, construction, and cryptocurrencies with references to real-world uses in the case of banking, with a short case study of a Maersk/IBM blockchain application.

Conclusions

The report ends by asserting that blockchain will provide companies with a “completely different business model” and change how firms operate contracts with each other. It suggests that, whilst blockchain will bring cost savings, faster transactions and workflow, and transparency, “new legislation is needed to guide the use of blockchain”. It argues that more time will be needed for the construction industry to accept the new technology and that more business use will encourage others to adopt it and spur regulators to engage more fully.

World Economic Forum | Building Block(chain)s for a Better Planet

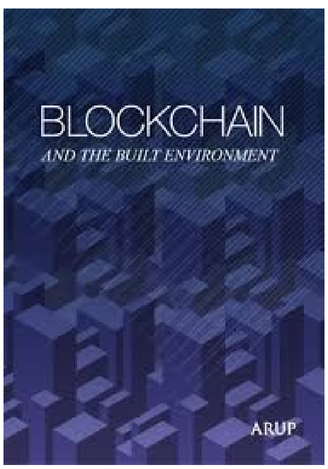
Description

The World Economic Forum’s report **(WEF, 2018)** into blockchain assesses its impact in a non-construction specific context. It sets out the challenges facing the world and potential opportunities. It then provides a summary of what blockchain is, its maturity, and its associated technologies since the 1990s. It notes potential applications of it in areas such as global heating, biodiversity and conservation, healthy oceans, water security, clean air, and weather and disaster resilience. It describes a number of advantages, particularly cross-industry benefits such as transparent supply chains, resource management, sustainable financing. The report then outlines the risks of blockchain and the challenges facing widespread deployment: adoption challenges; technology barriers; security risks; legal and regulatory challenges; interoperability risks; and energy consumption challenges.

Conclusions

The report concludes with some recommendations under the umbrellas of (1) developing effective blockchain solutions; (2) ensuring blockchain technology is sustainable; and (3) formulating the necessary governance arrangements. Under the first heading, it recommends that blockchain is harnessed for environmental value in addition to financial, that it is integrated with other “Fourth Industrial Revolution” technologies such as AI and IoT, and that collaboration is undertaken to enhance blockchain’s capability. For sustainability, it recommends that wider political economy challenges and unintended consequences are anticipated and that blockchain is delivered responsibly (such as compliance with privacy rights and accountability). Finally, it recommends that an agile approach to governance and regulation is developed and that a more global remedy to governance, or at least a globally coordinated solution, is built. For this latter point, it critiques the relative merits of employing industry self-regulation, country-specific regulation and the formation of government policies, and globally coherent regulation, but does not recommend a specific route.

2019



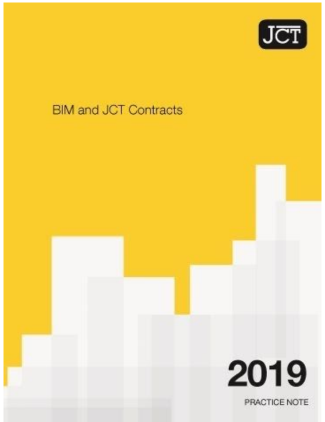
Arup | Blockchain and the Built Environment

Description

Arup’s second report into blockchain **(Arup, 2019)** recognises the state of the industry’s adoption and experimentation with the technology, its applicability, and its implication for markets – including built environment markets. The report sets out a possible timeline from 2018 to 2050 among what it identifies as five key markets of the built environment, being: cities, energy, property, transport, and water. It notes that there are no significant case studies approaching early adoption outside the financial sector, but that in the cities, energy and transport markets adoption from 2025 is likely. An in-depth exploration of blockchain and the aforementioned key markets is set out.

Conclusions

The authors conclude that blockchain has the capacity to transform the built environment by facilitating the interaction and transaction between machines and humans. Whilst blockchain technologies have not yet been transformational, it argues, early use cases are showing significant potential – first with automated payments and transactions, with the expectation for more complex ones in transaction efficiency and fidelity, governance and data management. Integration with the circular economy, BIM, IoT and smart sensors will have a positive mutual impact. The authors assert that the capability of blockchain to facilitate interactions between millions of people will particularly benefit cities, especially when linked with AI in the future. The report also draws attention to risks and challenges, mainly security vulnerabilities that are relatively untested and have been exposed before. There is also a comparison of what firms and technologists perceive as challenges, which appear to be relatively unaligned.



JCT | BIM and JCT Contracts

Description

BIM and JCT Contracts is a new practice note **(Winfield et al., 2019)** which provides guidance on using JCT contracts on projects where BIM is to be used. The aim of BIM and JCT Contracts is to further the understanding of BIM-related legal and contractual issues and suggest ways of approaching such issues in a collaborative and constructive way. It also aims to provide practical and clear guidance to project participants and their professional advisers.

Conclusions

This document provides a starting point for framing how smart contracts can be developed within the BIM framework.

2020

Deloitte | Deloitte's 2020 Global Blockchain Survey

Description

This Deloitte report **(Pawczuk et al., 2020)** relays data from its 2020 survey, conducted between 6th February and 3rd March 2020. They surveyed 1,488 senior executives and practitioners in 14 countries. The document begins with data demonstrating more permanent implementations and a growth of attitudes seeing the technology as a permanent fixture. The report notes the anticipated growth of digital assets under consideration for organisations' business models, and then moves to present findings relating to cybersecurity. Whilst a majority of respondents had concerns about cybersecurity challenges presented by new technologies, they said that this was not necessarily a roadblock to progressing with their adoption of blockchain. After a brief consideration of global identity, the report considers responses regarding regulatory considerations. Respondents were confident that these could be met, but the authors moot that this confidence may be misplaced due to potential complacency to engage in these areas. The report considers how commercial blockchain consortia are driving adoption globally, but that there have been issues with governance. Finally, it summarises attitudes to blockchain across different continents, but excludes Africa and Latin America.

Conclusions

The key findings from this survey are that initial doubts about the technology are fading, and that the potential use of blockchain is very apparent in the minds of strategic thinkers of organisations across industries and applications. There are a growing number of substantive marketplace examples where both startups and mature businesses are deploying blockchain. Crucially, organisations are demonstrating their commitment to blockchain by implementing it as part of their normal course of business. Given the survey was conducted before the COVID-19 lockdown commencing on 23rd March 2020, it remains to be seen whether positive responses about blockchain will have strengthened or weakened.

Appendix C) Blockchain Projects

This appendix discusses several specific blockchain projects in other, non-specific construction, sectors that may be relevant to the consideration of the development of blockchain solutions for the construction industry. Three key areas were considered, (i) “LawTech” (law technology), (ii) “FinTech” (finance technology) and (iii) “MagTech” (management technology).

C.1 Law and LawTech

There are several lawtech blockchain projects identified as delivering (or at least attempting to) functionality potentially relevant to any construction solution. Three noted projects are discussed below.

OpenLaw

OpenLaw **(OpenLaw, 2019)** is a blockchain-based protocol for the creation and execution of legal agreements. The project’s stated aim is to connect the execution of legal agreements with blockchain-based smart contracts in a user-friendly and legally compliant manner. The objective is to enable lawyers to more efficiently engage in transactional work, digitally sign and securely store agreements.

The solution is aimed at lawyers, although additional training in use of the proprietary markup language is necessary to create programmable legal agreements capable of executing, e.g., basic logic actions and calculations. The solution utilises the Ethereum platform to manage the contract execution actions. On execution, the agreement is hashed and recorded on the Ethereum blockchain.

The solution, at present, only provides limited contract management support. Information concerning the author, signatories and signature status, date and time stamps of creation. Although more features are planned to be added, e.g., party notifications for renewal periods or “terms of enforceability”. From a legal perspective there is a concern that a public solution for what are inherently private, confidential and/or privileged agreements runs contrary to legal principles. Although reference is made to private instances in the project’s FAQs, it is unclear if this means a public vs. private instance of the blockchain solution.

The limitations of the proprietary markup language are not discussed and may cause difficulty in complex multi-party agreements, framework agreements with unspecified numbers of call-offs and so on.

Although an interesting solution, it seems at present that OpenLaw.io does not provide true contract management functionality and, insofar as execution of contracts is concerned, other online software solutions, e.g., Docusign and/or Adobe Sign, offer equivalent if less technical options.

Mattereum

Mattereum **(Gupta et al., 2018; Mattereum, 2019)** purports to be a “smart property register”, essentially focussing on the tokenization of generalised real world property, i.e., tangible assets, by providing the legal, technical and commercial infrastructure layer for blockchain based transfers and control. This allows trading activities, such as fractional trading, and other exotic financialisation arrangements to take place. However, there are management and governance structures off-chain that control asset acquisition and disposal.

Accord Project

The Accord Project **(Accord, 2018)** is described as a non-profit collaborative initiative that is developing an ecosystem and open source tools for the creation and development of smart legal contracts. The project's view is that smart agreements hold the promise to reduce friction and transaction costs in the creation and management of commercial relationships. The Accord Project establishes and maintains a universal legal and technical foundation for smart legal contracts in a technology neutral manner.

It is unknown how effective such a tool is in the development of non-simple contracts (as construction arrangements tend to be). However, it may be a useful reference tool for the creation of point solutions in and around highly definable contract mechanisms, such as payment, for a construction relevant solution.

C.2 Finance and FinTech

There are several fintech blockchain projects identified as delivering, or at least attempting to, functionality potentially relevant to any construction solution. Two noted projects are discussed below.

QPQ

QPQ **(QPQ, 2019)** are developing an enterprise grade trade settlement and digital governance network that is designed to be efficient and scalable. The solution is described to eliminate all transactional administration and efficiencies from operations. The solution is similarly intended to reduce operational costs to a fraction of their current level. The solution claims to make it possible to encode contracts in their entirety, even complex contracts with multiple regulatory requirements, to allow governance of trade between counterparties and other stakeholders.

WePower

WePower **(WePower, 2019)** is a sustainable energy start-up to support smarter energy purchasing decisions. A platform has been developed to facilitate renewable energy procurement on a blockchain based trading platform. WePower aims to democratise the energy procurement process by connecting renewable energy buyers directly with renewable energy sellers, providing standardised tools and contracts to enable the transaction.

The project aims to reduce electricity costs to below market rates at any given time with full transparency and ease. Sellers may access a wider range of buyers, hence a wider/larger market. In doing so, ease of access to project financing is achieved. The project enables faster, less expensive and more convenient renewable energy contracting and trading, above that of current intermediated methods. The desired outcome is a faster global transition to renewable energy. Although there are questions as to how, physically, energy is transferred, if at all, between buyers and sellers, and whether this is truly disintermediating or is simply an alternative marketplace.

C.3 Project and Supply Chain Management and MagTech

There are several magtech blockchain projects identified as delivering, or at least attempting to, functionality potentially relevant to any construction solution. Three noted projects are discussed below.

BIMCHAIN

BIMCHAIN **(BIMCHAIN, 2019)** is a construction market blockchain based solution to deliver a higher standard of BIM, reinforce BIM processes and enhance data quality. Accelerated through a blockchain solution, it seeks to deliver and/or improve the trustability of BIM. The project's goal is to deliver BIM models to a "one-source-of-truth" standard. The integrated solution provides traceability, eliminates paper records and places BIM data on a contractual basis. Ensuring collaboration in a trusted environment and unlocking efficiencies, empowering stakeholders with trusted data, improving project/building controls.

The project's vision is that by leveraging decentralised technologies in an open collaboration and data connected environment, improvements to building lifecycle management will be achieved.

Provenance

Provenance **(Provenance, 2019)** is a blockchain solution for supply chain management. The project seeks to overcome opaque supply chains that are damaging the environment and the wellbeing of those exposed to them. The project seeks to deliver improved and verified information and data, and therefore transparency, to businesses and consumers to enable/facilitate informed purchase decision making. Visibility of product origin, journey and impact is all accessible to consumers.

Konfid.io Contract Solutions

Konfid.io Contract Solutions **(Konfidio, 2019)** is a sub-project to the wider Konfid.io blockchain development venture and focuses on utilising blockchain to deliver project procurement and contract management services.

The project seeks to address key business challenges in procurement contract management, e.g., (i) multiple versions of the truth from contradicting and siloed databases, (ii) manual reconciliation processes, (iii) duplication, tampering and data corruption, (iv) lack of real-time management information and (v) non-compliance and dispute resolution. The project aims to reduce the time and expenditure on maintaining synchronisation between disparate databases, reduce processing delays to accelerate value settlements, obviate data mismanagement, accelerate decision-making with improved information visibility and minimise the likelihood of legal costs and the consequences of failure.

The project claims: (i) to be a single source of truth, by the use of a distributed ledger, the project estimates a cost reduction of up to 85% on reconciliation, (ii) financial obligations are instantly accessible, with project estimates of up to 12 months in time beings saved compared to manual reconciliation and value settlement, (iii) audit trails are verifiable, tamper-proof and immutable as recorded on a blockchain, the project estimates audit costs reduction of up to 80%, (iv) analytics dashboards are available in real-time, the project anticipates management can confidently and accurately manage all procurement processes, and (v) a disputes mechanism is integrated with smart legal language to enable seamless dispute resolution, the project estimates legal costs reduction of up to 50%.

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