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Exploring the potential of Blockchain technology for the UK Construction industry

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Abstract

This report explores the potential that Blockchain, a currently fast-developing area of technology, may have for the Construction industry. Blockchain, the technology upon which Bitcoin is based, is a database that:

- is append-only (provides immutability)
- can be readable by all parties involved (provides transparency)
- is decentralised and not controlled by any one party (provides trust)

Blockchain discussions are gathering momentum as a potential key catalyst for harnessing sustainable growth, productivity improvements and cost reductions, but there is little clarity within Construction regarding how to achieve this. It is important for the industry to understand the potential opportunities for improved business Sustainability that may be unlocked in time with this emerging technology.

This subject has been chosen as a highly topical area of research, drawing upon the researcher's interest and previous experience as a Digital Engineer and active contributor to the Institution of Civil Engineers' Digital Transformation campaign. It is intended that this research will serve to raise awareness and understanding of this area of technology and how it may relate to Construction, and be a useful tool for those within the industry who are perhaps considering, or are about to, a Blockchain-based business case.

Acknowledgements

I would like to take this opportunity to thank my mentors over the duration of this scholarship; Bob Heathfield and Jonathan Hubert for selecting me as a scholar and for their enthusiasm, time and encouragement, Alistair O'Reilly and the Laing O'Rourke Blockchain working group for their guidance on this topic and Lyndsey Montgomery for her administrative support.

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Glossary

BIM Level 2	Managed 3D environment with data attached, but created in separate discipline-based models.
BIM Level 3	A single collaborative, online project model with Construction sequencing, cost and project life cycle information.
Blockchain	A form of distributed, shared ledger where transactions are permanently and immutably recorded by appending blocks. The chronological time-stamped block serves as a historical record of all transactions ever occurred.
Block	Cryptographically secured packages of data, which carry transaction information on a Blockchain network.
Building Information Management	The process of designing or operating a building or infrastructure asset using digital object-oriented information.
Centralised database	A database that is maintained and stored in a single location, usually a central location.
Common Data Environment	The single source of information for the project, used to collect, manage and disseminate documentation, the graphical model and non-graphical data for the whole project team.
Consensus mechanism	The process when all nodes of a distributed ledger network agree on the validity of a transaction and ensure that the stored individual ledgers are exact copies of each other.
Cryptocurrency	A form of digital cash which exist as an encrypted, unique, digital information registered on a Blockchain.

Database	An organised collection of data in an electronic system that allows data to be easily accessed, manipulated and updated. Databases are used by organisations as a method of storing, managing and retrieving information.
Decentralisation	No single entity has exclusive control over data or processes.
Distributed (ledger)	A digital transparent record of transactions where the information is stored across a network of decentralised nodes, which may also help to validate these records. A distributed ledger can be permissioned or private.
Industry 4.0	The current trend of automation and data exchange within industries, particularly Manufacturing.
Ethereum	An open software platform based on Blockchain technology that enables developers to build and deploy decentralised applications. Like Bitcoin, Ethereum is a distributed public Blockchain network.
Hyperledger	An umbrella project of open source Blockchains and related tools started in December 2015 by the Linux Foundation and supported by big industry players like IBM, Intel and SAP to support the collaborative development of Blockchain-based distributed ledgers.
Immutability	An inability to be altered or changed over time. Blockchains are designed to be immutable; once a block is written to a Blockchain, it cannot be altered.
Internet of Things	A network of physical devices, vehicles, home appliances, and other items embedded with electronics, software and sensors that can capture data automatically and distribute across the network to support decision processes in various public, commercial and scientific systems.
Mining	The process of adding transactions to the Blockchain.

Node	A computer in the Blockchain network. Each node has a copy of the digital ledger and checks the validity of each transaction. If a majority of nodes agree, based on rules, that a transaction is valid then it is written into the block.
Open source	Any program whose source code is made available for use or modification. Open source software is usually developed as a public collaboration and made freely available.
Peer to peer	Computer systems that are connected to each other via the Internet. Files can be shared directly between systems on the network without the need of a central server so each computer in the network becomes a file server as well as a client.
Proof of Work consensus	Part of the mining process when the miner node is required to demonstrate its contributed computational effort to approve a transaction. The proof of that the computational work has been done is included in the block.
Public key cryptography	A method for securing communication using code.
Satoshi Nakamoto	The name used by the unknown person or people who developed Bitcoin, authored the Bitcoin white paper, and created Bitcoin's original implementation, devising the first Blockchain database in the process.
Smart Contracts	A programmed contract which can execute itself automatically when predefined conditions are met.

1.0 Introduction

As the Construction industry embraces the fourth industrial revolution and moves towards what is being called ***Industry 4.0***, Construction companies are exploring and experimenting with new disruptive technology and innovation. The industry is moving fast into 'a world of connectivity, automation and data abundance', claims the Institution of Civil Engineers (ICE) in its 2018 Shaping a Digital World report, which presents an opportunity to improve the productivity, efficiency and Sustainability of the industry. Perhaps the most 'exciting' technological advancement, the report continues, is ***Blockchain***.

IBM, one of the largest technology companies in the world and responsible for some of the most ground-breaking inventions in the technology industry (Gordon. 2018), is investing $160 million per year and devoting 1,600 people to work on projects related to Blockchain (Georgiev, 2018) and it is estimated that $2.9 billion will be spent globally on Blockchain technology in 2019 (Battrick, 2019). Companies, in and out of the Construction sector, are in the process of trying to understand the implications of Blockchain. Numerous sources, including The Guardian, are touting it as the business buzzword of the year (Busby, 2018), prompting many companies to believe Blockchain should be implemented without fully being able to explain what it is or how to do so (Popper, 2018).

This report seeks to explain what Blockchain is, explore the relevance and potential applications of this technology for the Construction industry and make recommendations for how it might be initially implemented to help the industry become more effective, collaborative and transparent. It does not purport to hold all the answers to Blockchain but aims to prompt better informed conversations between Blockchain experts and Construction leaders as the industry moves into the digital age.

1.1 Background

Productivity in the UK Construction industry has stagnated for the past twenty years, limiting growth and representing a productivity gap of more than £100 billion a year of economic benefit (Mace, 2018). Speaking after the publishing of the 2018 Mace report into Construction productivity (Walker, 2018) Mark Reynolds, Mace Chief Executive, explained that 'improved productivity is the key to more sustainable growth and stability across the industry. Unless we take swift action, narrow margins and below average productivity will prevent the UK's Construction sector reaching its potential.'

The Construction sector is moving, slowly, towards achieving tangible improvements. As the UK Government Construction Sector Deal of 2018 illustrates, a lot of investment is being channelled into building right first time and more efficiently, to improve industry productivity and create assets that give customers and society added value, more Sustainability and better value for money. This drive has been supported significantly by a push over the past few years towards embedding ***Building Information Management***, BIM, into the way work is done, with the UK Government mandating ***BIM Level 2*** across all centrally-funded projects in 2016. As highlighted by the Mace productivity report (Walker, 2018) productivity is crucial in determining the UK's long-term prosperity and economic Sustainability.

1.1.1 Blockchain and Sustainability

Sustainability has been defined in many ways but the most frequently quoted definition is from the World Commission on Environment and Development's 1987 Brundtland Report: 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' To put this in the context of our industry, 'Sustainability is about maximising our environmental, economic and socio-economic performance in the interests of the business, our stakeholders and our planet' explains Ray O'Rourke, Laing O'Rourke Chief Executive.

For the industry to be sustainable, efficiency and productivity improvements are required. Recognising the importance of this, the UK Government published in 2013 the Construction 2025 joint strategy from Government and industry for the future of the UK Construction industry, setting out ambitions by 2025 of 50% faster delivery, 50% lower greenhouse gas emissions, 50% improvements in exports and 33% lower costs. Blockchain, frequently hailed as having potentially greater impact than the invention of the internet (Jenkins, 2017), might have the potential to improve productivity, improve efficiencies and reduce costs. Accenture reported in 2017 in their value analysis of Blockchain for the finance industry that Blockchain technology could save the world's largest investment banks, the industry where Blockchain was first exploited, up to $12 billion a year- that's more than the annual GDP of half the world's countries (Anon, 2018, a).

Technological development can have positive outcomes for economic, social and environmental Sustainability (Purt, 2011). Blockchain discussions are gathering momentum as a potential key catalyst for unlocking sustainable growth and productivity improvements, and is 'real game-changer for Construction' (Gueguen, 2018) but there is little clarity within the industry regarding how to achieve this. It is important for the industry to understand the potential opportunities for improved business Sustainability that may be unlocked in time with this emerging technology, even if the conclusion is not to actively develop Blockchain solutions at this time.

1.2 Aim and objectives

The aim of this report is to function as a useful tool for those within the industry seeking introductory understanding of Blockchain and preliminary guidance on whether it could be a valid area for development in Construction.

The key objectives of this report are to provide:

- An understanding of the Blockchain technology, including the advantages and disadvantages of using a Blockchain solution and examples of current Blockchain developments

- Potential use cases for the technology in the Construction industry

- Considerations for initial implementation of Blockchain technology within the industry

This report has been written for readers within the Construction industry without much, or any, prior understanding of Blockchain and its uses. However, a basic understanding of technology advances, terminology and applications within the industry has been assumed. It is worth noting that a definition of words or phrases emboldened and in italics within this report has been provided, in alphabetical order, in the glossary section. Glossary definitions have been taken from Blockchain Technologies, an online education resource for entrepreneurs, investors, and consumers, and Designing Buildings Wiki, an online knowledge sharing platform supported by industry leaders such as the Institution of Civil Engineers (ICE) and the Chartered Institute of Building (CIOB).

1.3 Report layout

This section briefly outlines each chapter of the report to provide an expectation of the its contents.

- Understanding Blockchain

  This chapter reviews existing literature and relevant research findings to provide an understanding of what Blockchain technology is, how it works and why it is being developed and invested in across many industries.

- Benefits of a Blockchain system

  This chapter presents examples of Blockchain use cases developed or being developed across a variety of industries, to provide an idea of the problems which Blockchain can address and the benefits of doing so.

- Blockchain in Construction

  This chapter combines an understanding of Blockchain and research into developing Blockchain use cases to provide an insight into the potential areas for Blockchain development within the Construction industry and the associated benefits of doing so.

- Conclusions

  The focus of this chapter is to provide a summary of the conducted research with areas for further research highlighted, which could perhaps form the basis of a future Sustainability Scholarship research proposal.

1.4 Research methodology

Given the highly complex nature of the topic and resource constraints, research has been limited to the following selection of methods:

- Desk study research

  Review of numerous articles, reports and educational online guides from appropriate and credible sources

- Blockchain experts

  Attendance at several prolific UK Blockchain events including the second annual Blockchain Live conference in September 2018 and the Construction Blockchain Consortium Business Network workshop in October 2018

- Industry professionals

  Formation of a Laing O'Rourke Blockchain working group to assimilate ideas

A general understanding of Blockchain and how it works has been gained from the key literature, referenced in the Bibliography in Section 7.0.

2.0 Understanding Blockchain

Blockchain is the underlying technology that enables ***cryptocurrencies*** such as Bitcoin. Many confuse Blockchain with Bitcoin but as Leibson (2018) makes clear 'Bitcoin is not Blockchain and Blockchain is not Bitcoin' in his article with the same title. Sally Davies, a technology reporter for The Financial Times, draws the analogy that 'Blockchain is to Bitcoin what the internet is to email; a big electronic system on top of which you can build applications-currency is just one.'

Although cryptocurrencies have tended to dominate Blockchain conversations, Blockchain has far wider potential applications as an enabler of a ***decentralised*** and digital economy. At the start of 2018, Forbes published a prediction that Blockchain would be one of the top technology trends to watch; the discussion around Blockchain in Construction specifically has also been building momentum over the past year, which is discussed in greater detail in Section 4.0.

2.1 A brief history of Blockchain

In 2008 ***Satoshi Nakamoto*** (whose identity still remains unknown) released the whitepaper, Bitcoin: A ***Peer to Peer*** Electronic Cash System, which described a truly electronic version of cash and payments called Bitcoin. This was also the first time that Blockchain, the technology that runs Bitcoin, was introduced. Shortly after the release of Nakamoto's whitepaper, Bitcoin was offered to the ***open source*** community. Within the following few years, programmers

began to recognise that Blockchain could be used for more than cryptocurrency and started to explore its wider potential, leading to a rise in entrepreneurial investment (Marr, 2018).

In 2013, Vitalik Buterin, an initial contributor to Bitcoin, became frustrated with its programming limitations and so developed a more flexible (but still public) Blockchain, which he called ***Ethereum*** (Marr, 2018). The largest difference between Bitcoin and Ethereum is that Ethereum can record other assets such as loans or contracts, not just currency. Ethereum launched in 2015 and can be used to build ***Smart Contracts***- those that can automatically process based on a set of criteria established in the Blockchain. This technology attracted the attention of multinational corporations, such as IBM, Microsoft and UBS (Irrera, 2017) with its potential to save time and money.

William Mougayar, author of The Business Blockchain (2016), describes Blockchain in his book as more than just a revolution; 'it is a tsunami-like phenomenon, slowly advancing and gradually enveloping everything along its way by the force of its progression'. There is little sign of the interest in Blockchain development abating; one interesting indication of the speed at which this area is growing is the number of Blockchain jobs, as reported by multinational recruitment website Indeed.com, increasing by 631% in two years since November 2015 (Castillo, 2017).

Speaking at the 2018 Blockchain Live conference in London, MP for digital and creative industries Margot James expressed the UK Government's interest in Blockchain exploration. £10 million is to be invested through Innovate UK and UK research councils to support Blockchain projects in diverse areas like energy, voting systems and charitable giving. In his 2018 'Unlocking Blockchain' report Eddie Hughes, MP for Walsall North, urged fellow MPs to gain a better understanding of Blockchain after the US state of Ohio launched a scheme to allow businesses to pay taxes with Bitcoin and called for the Government to create the new position of 'Chief Blockchain Officer' who would be responsible for coordinating efforts to help the public sector embrace the new technology.

2.2 How Blockchain works

Blockchain can be complicated and difficult to understand, especially as it is still very much a developing technology.

To start, it is worth explaining how Blockchain gets its name. Blockchain technology is a way of recording information and transactions onto lots of different devices all at once through the internet. The data that is recorded on a Blockchain is copied onto many different devices that are connected to each other to form a network. Whenever any new information is added, all of the devices are updated simultaneously.

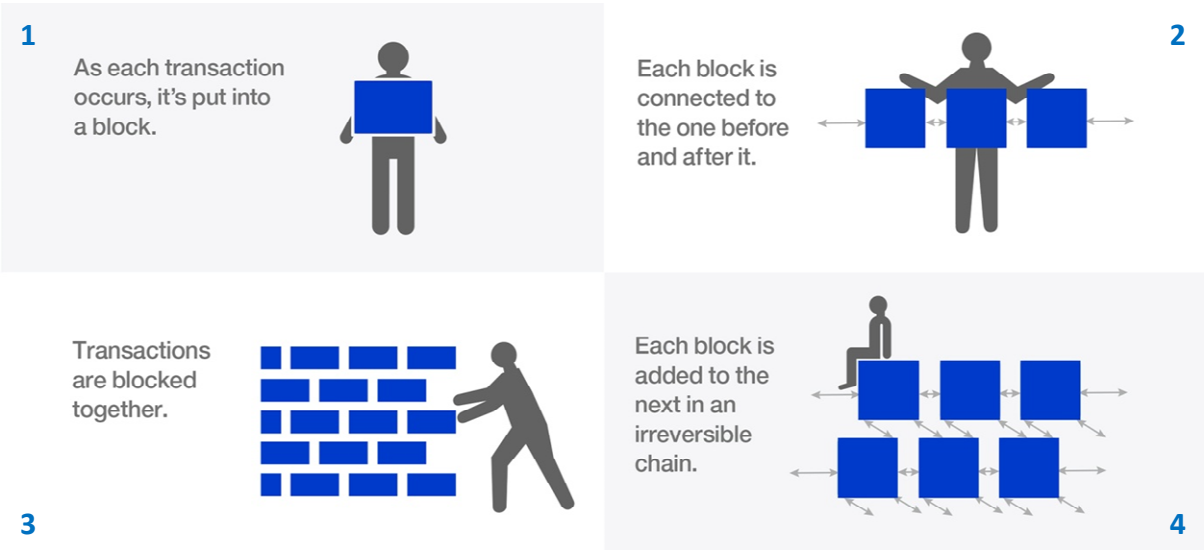

Fig. 1 Simple illustration of the basic Blockchain structure
Source: IBM (2018)

Blockchain is a particular type of ***database***, an organised collection of data, in which the data is set out and built up in successive ***blocks***. Any information that is added to a Blockchain is packed into these blocks, which connect together to form a chain. Each of the blocks includes a small piece of data that verifies the content of the previous block, creating a code. Every time more information is added to the chain, the code changes. As a result, if an attempt is made to modify an earlier block in the chain, all of the later blocks, built upon the previous, cease to match. This sequence-based structure means that it is possible for the system that

maintains the Blockchain to identify and reject attempted modifications to blocks, making the Blockchain data ***immutable***.

Fig. 2 builds upon the Blockchain fundamentals shown in Fig. 1 to illustrate the example of a payment transaction, for example using Bitcoin, since this is how Blockchain was first used. Traditionally consumers make purchases with bank cards, which are processed through a trusted intermediary- a middleman, like the bank- that charges a transaction fee for its time and effort. In a Bitcoin transaction however, the consumer sends the cryptocurrency funds directly using a digital wallet where each transaction is processed, verified and publicly recorded by a network of advanced Bitcoin users, known as ***miners***, who instead of charging a transaction fee offer their computing power in return for the chance to gain Bitcoins. In the case of Bitcoin, Blockchain stores the details of every transaction of the digital currency and the technology stops the same Bitcoin being spent more than once.

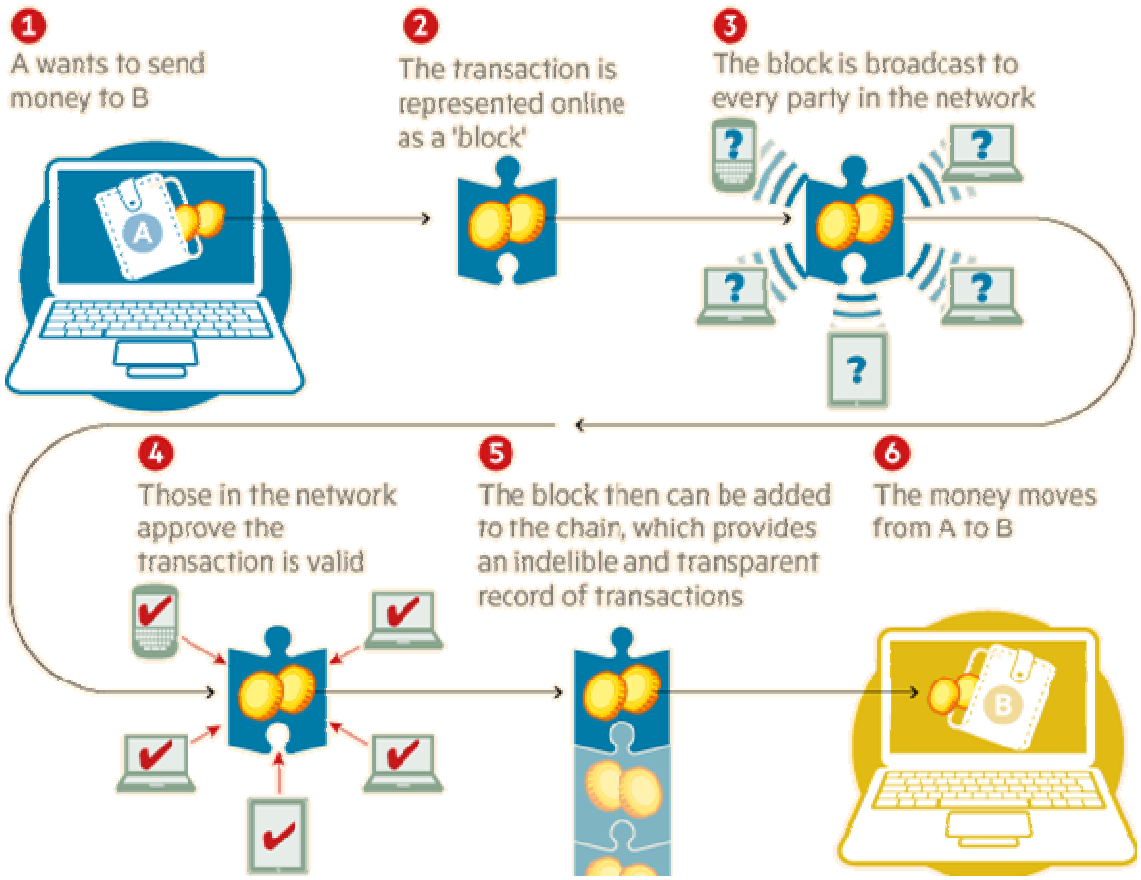

Fig. 2 Simple illustration of the Blockchain transaction process
Source: Financial Times (2015)

Clifford Chance LLP, one of the world's pre-eminent law firms, produced a brief report into the basics of Blockchain in 2017 and referred to Blockchain as being the combination of the following distinctive elements, which will be explained in turn in this section:

- ***Distributed ledgers***
- ***Public key cryptography***
- ***Consensus mechanisms***
- Miners

2.2.1 Distributed ledgers

Blockchain is a type of distributed ledger technology. A distributed ledger is a database that is copied around multiple locations as a ledger, a record of a transaction, each synchronised across the system network. Frankenfield (2016) explains in an article for Investopedia, one of the world's largest educational finance news and services websites, that this allows transactions to have public witnesses, therefore making malicious action more difficult since any changes made to the ledger are reflected and copied instantly to all participants.

2.2.2 Public key cryptography

Lord (2018), from data security software company Digital Guardian, explains that public key cryptography uses two pairs of digital keys, a public and a private one, to encrypt and decrypt data to protect it against unauthorised access. Network users receive a public and private key pair from certification authorities. If other users want to encrypt data, they get the intended recipient's public key from a public directory. This key is used to encrypt the message and to send it to the recipient. When the message arrives, the recipient decrypts it using a private

key, which only they have access to. The use of public key cryptography ensures that each participant in the system is uniquely identified and can validate any change to the Blockchain using a cryptographically secure private key. This encryption method is not unique to Blockchain but does ensure that the data is secure and can only be accessed by those with the key to decrypt it or changed by those with the required system authorities.

2.2.3 Consensus mechanisms

A change to the ledger can only be made when a sufficient number of ***nodes*** (computers) in the system verify the transaction. This validation is performed automatically by the nodes using pre-set rules to reach a consensus as to whether the new data entry is permitted. For example, two transactions could be in conflict, such as in the case of double spending in which the same spending information is sent to two different recipients. In a Blockchain, by requiring transactions to be confirmed with rules, all nodes converge on the same decision. Once the transaction has been approved ,the updated version of the Blockchain with the new entry will rapidly spread throughout the system so that that all of the nodes end up with an identical version of the ledger. This is a rigorous method of ensuring only valid data can be added to the Blockchain (Clifford Chance, 2017).

This removes the need for intermediaries (disintermediation) to authorise and validate the transaction, which can lower costs, improve transaction speed and provide automatic reconciliation (Hjønnevåg, 2018).

2.2.4 Miners

Consensus mechanisms raise the question of who is responsible for choosing the transactions that go into each block. In private Blockchains (which will be explained in further detail in Section 2.4), a closed group of validators- or miners- digitally sign the blocks they create.

These validators have much less power than the owner of traditional ***centralised databases***; they cannot fake transactions or violate the Blockchain rules to modify the database. However, it is worth noting that there are still two ways in which validators can unduly influence the contents of the database (Greenspan, 2015):

- Transaction censorship

  If enough of the validators collude, they can prevent a particular transaction from being confirmed in the Blockchain.

- Biased conflict resolution

  If two transactions conflict, the validator creating the next block decides which transaction is confirmed on the Blockchain, causing the other to be rejected. The fair choice would be the transaction that was seen first, but validators can choose based on other factors without revealing this.

For these reasons, it is vital that trusted validators are selected when considering a Blockchain solution. Depending on the use case, the validators could be:

- one or more nodes controlled by a single organisation
- a core group of organisations that maintain the chain
- every node in the network

2.3 Key characteristics of Blockchain

There are three key characteristics of Blockchain which make it a more attractive technology than traditional databases; trust, transparency and immutability.

2.3.1 Trust

For a transaction to be validated and recorded on the Blockchain, all the nodes must follow the same rules. This creates trust because each participant knows every transaction will follow rules agreed upon when the network launched. Holding data on the Blockchain in a decentralised way makes it nearly impossible for one person to modify a record whereas a traditional computer-hosted database can be easily edited and distributed, rendering it less trustworthy.

2.3.2 Transparency

Participants know where the Blockchain data has come and how it has changed over time, making all data traceable. Having the same set of data distributed across the network provides companies with data resilience in instances of data loss or corruption suffered in traditional systems.

2.3.3 Immutability

No participant can modify a transaction once recorded on the ledger. If an error occurs, a new transaction must be used to reverse the error but all transactions remain visible. Traditional databases are usually held centrally, on a server for example, making it a possible target for an effective malicious attack. Furthermore, the more nodes in a network, the more copies of the data there are so a hacker would need to attack every single node in the network and alter all of their data simultaneously, which is implausible.

2.4 Main types of Blockchain

There are three main types of Blockchain to have emerged since Bitcoin was first introduced; private, public and consortium, as illustrated in Fig. 3.

Fig. 3 Illustration of the three different types of Blockchain
Source: Innovation Insight for Blockchain Security (2017)

- Private Blockchain

  A private Blockchain is owned by an individual or organisation, which is responsible for permitting Blockchain access to others. The Blockchain owner is represented in Fig. 3 as the orange node in the network. Only nodes within the network, represented by the outside circle, can access the Blockchain, as permitted by the Blockchain owner.

- Public Blockchain

  In a public Blockchain, which is open and transparent, anyone can participate in viewing, modifying or auditing the Blockchain, without one single person in charge. Since no one is in charge, decision-making happens by decentralised consensus mechanisms. Participants would need to be incentivised in order to run a public Blockchain network and validate transactions. For example, in the case of the Bitcoin Blockchain, every miner competes to validate new transactions and add them to the Blockchain, because the miner that implemented the new block is rewarded with Bitcoins. In Fig. 3, there is no owner in the public Blockchain, nor is there a circle to represent the privacy of the Blockchain; anyone can become part of the Blockchain network in a public system.

- Consortium Blockchain

  A consortium Blockchain seeks to remove the sole autonomy of a private Blockchain by having multiple users or organisations in charge, responsible for making decisions for the benefit of the whole Blockchain network. For example, the consortium could consist of twenty organisations but the code dictates that only if a transaction is verified by more than fifteen, say, of the companies then it should get added to the Blockchain. Fig. 3 visually represents the consortium Blockchain as mix of the other two types; the network has no single owner and only those approved by the consortium will be allowed to participate in the Blockchain.

	Type of Blockchain		
	Public	**Private**	**Consortium**
Access	Anyone	Single individual/organisation	Multiple selected individuals/organisations
Participants	Permissionless, anonymous	Permissioned, known identities	
Security	Consensus mechanism	Pre-approved participants, voting consensus	
Transaction speed	Slow	Faster	

Table 1 Summary of the key characteristics of the types of Blockchain

Table 1 summarises the types of Blockchain and their differences. It is debateable whether private, even consortium, Blockchains fundamentally defeat the purpose of this open, transparent technology but it can be advantageous to have multiple types of Blockchain to suit the requirements of the solution. However for applications that require privacy and control, private and consortium Blockchains are preferable and where openness and censorship-resistance is desired, public Blockchains could be used (Khatwani, 2018).

To summarise, a Blockchain is a database that:

- is decentralised and not controlled by any one party (trust)
- is readable by all parties involved (transparency)
- is append-only (immutability)

3.0 Benefits of a Blockchain system

Research identifies a great deal of investment, effort and excitement behind Blockchain across a wide range of industries (Hutt, 2016). The characteristics discussed previously already exist in alternative technologies that can provide append-only, transparent, decentralised efficient data storage for a known set of participants. The primary differentiator is that Blockchain can offer a fully decentralised solution, with an undefined number of participants.

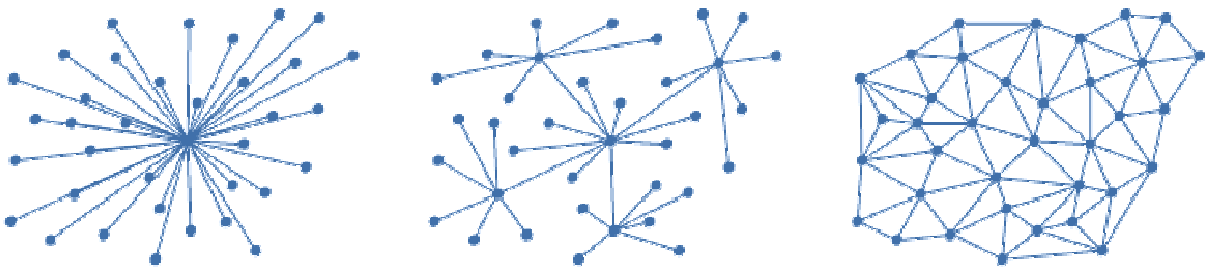

Fig. 4 Illustration of the different levels of control of a database
Source: Tech Crunch (2015)

The meaning of centralised, decentralised and distributed databases, as illustrated in Fig.4, must be understood in order to appreciate the merits of each; a description of each is included in the glossary section.

There are known risks to centralised systems, which Blockchains mitigate by removing the single central authority and decentralising the network. The larger the numbers of participants, the lower these risks are. However, decentralisation is not the only mitigation; more independent and diverse parties in a transaction chain could ensure better security and better detection and recovery from system compromise.

Many of the potential benefits of Blockchain may be realised in time, but there are limitations that must be understood before considering a Blockchain development. For comparison, the traditional method of managing data and the primary alternative to Blockchain is the centralised database. Databases have been in use since the 1980s and are based on a structure where the information held on the database is stored, and managed, on a central server system in one location. They are capable, robust, and scalable, and are likely to remain in frequent use in the short to medium term, regardless of any potential benefits Blockchain may have over them.

As previously described, Blockchain is also a type of database but it is a distributed, decentralised system, where each transaction needs to be written to every node in the network and they must agree a consensus on the content of the Blockchain.

3.0.1 Performance

With a traditional centralised database, performance should be fast since data only needs to be written once to the central location. The system can also be scaled up, for instance with additional memory or resources to improve performance.

Blockchains take longer to transmit a block of data to all involved nodes. Additional nodes joining the network add resilience, but not performance. In a public Blockchain there is no control of the performance of the nodes joining the network and in a private Blockchain the cost of performance would be higher than a traditional database since rather than just having one powerful central system you would need many nodes.

Many public Blockchains running ***Proof of Work consensus*** schemes, such as Bitcoin or Ethereum, support far fewer transactions per second than traditional systems. Private Blockchains may be faster than public options, but are often slower than traditional alternatives.

Centralised databases can scale almost limitlessly but with Blockchain it is more challenging. Concerns regarding the energy requirement of server farms needed to maintain Blockchains have already been raised (RICS, 2018) and as Blockchains grow larger with every subsequent transaction this would potentially worsen. Storage, networking, and computing limitations would be increased as block sizes and transaction volumes increase. The ***Hyperledger*** Performance and Scalability working group confirmed recently that the scalability challenge has yet to be solved (Wagner, 2017).

3.0.2 Efficiency and automation

Information only needs to be stored once to a traditional centralised database, increasing the efficiency of the transaction-creation time and minimising storage capacity requirements. A full set of the data needs to be stored by all nodes in the network of a Blockchain leading to many duplicate sets of data and increased storage and computing requirements. Blockchains can improve efficiency by automating many transactional processes using Smart Contracts, reducing complexity and improving accuracy. For example, bank transfers that typically take multiple business days and can cost, can be free and instant with Blockchain.

3.0.3 Security

Access to a traditional database is granted with permissions set by the owner of the system, to control who can access and modify information. Users should be granted the minimum level of access required to complete their job. System administrators must be entirely trusted since they have complete control over the system and information within; anyone with sufficient access to a centralised database can destroy or corrupt the data within it.

Furthermore, since the database is held in one location, there is a single point of attack so must be adequately protected by hosting on resilient hardware with duplicate copies of the data securely stored elsewhere.

In a traditional database, a user can perform four functions on the data: Create (Write), Read, Update, and Delete (these are often referred to as the CRUD commands). Conversely, Blockchain is an append-only structure; users can only read and add data (as additional blocks). All previous data is permanently stored and cannot be altered. So, unlike a traditional database where records can be updated or deleted, entries on the Blockchain are immutable- this means once they have been written they cannot be changed or tampered with.

Although Blockchain has structural security advantages, it is important to note that it may not improve overall security, as pointed out by Haley and Whitaker in their 2017 Forbes article 'To Blockchain or not to Blockchain'. The key challenge is to make the whole system as tamper-proof as the Blockchain itself, which will be assisted in time with the adoption of the ***Internet of Things***, because if the data inputted is corrupt or incorrect, inaccurate decisions can be made.

3.0.4 Cost

The cost of Blockchains relative to centralised databases is unclear. Many believe Blockchain can lower costs when compared with the support fees charged by database giants such as Oracle (Haley and Whitaker, 2017). A good example to support this, cited in Haley and Whitaker's article, is the $960 million American post-trade financial services company, Depository Trust and Clearing Corporation, moving its credit default swap platform to a private Blockchain, which is now expected to save 20-30% compared with the original system.

However, there are potential significant costs associated with Blockchain that must be considered, beside the short term development costs:

- Hiring or outsourcing of resources to maintain the system

- Energy costs may rise tremendously as the transaction volume increases

- A contingency buffer for unknown-unknowns is recommended

Small-scale proof of concepts should be conducted wherever possible to validate expected cost savings relative to existing systems.

3.1 Current Blockchain applications to improve Sustainability

Blockgeeks, a growing Blockchain technology company that provides a platform for online Blockchain education, list the main potential business applications likely to result from Blockchain developments in a guide for beginners on 'What is Blockchain Technology?' (Fig. 5).

This section presents a selection of applications being developed at the moment to improve efficiencies across the three broad areas of Sustainability below where trusted intermediaries are currently required to record, validate and reconcile transactions without adding value to the original transaction.

- Environmental Sustainability

- Economic Sustainability

- Social Sustainability

Smart contracts

Distributed ledgers enable the coding of simple contracts that will execute when specified conditions are met.

The sharing economy

By enabling peer-to-peer payments, the blockchain opens the door to direct interaction between parties — a truly decentralized sharing economy results.

Crowd funding

Blockchains take this interest to the next level, potentially creating crowd-sourced venture capital funds.

Governance

By making the results fully transparent and publically accessible, distributed database technology could bring full transparency to elections or any other kind of poll taking.

Supply chain auditing

Distributed ledgers provide an easy way to certify that the backstories of the things we buy are genuine. Transparency comes with blockchain-based timestamping of a date and location — on ethical diamonds, for instance — that corresponds to a product number.

File storage

Decentralizing file storage on the internet brings clear benefits. Distributing data throughout the network protects files from getting hacked or lost.

Prediction markets

Prediction markets that pay out according to event outcomes are already active. Blockchains are a "wisdom of the crowd" technology that will no doubt find other applications in the years to come.

Protection of intellectual property

Smart contracts can protect copyright and automate the sale of creative works online, eliminating the risk of file copying and redistribution.

Internet of Things (IoT)

Smart contracts make the automation of remote systems management possible. A combination of software, sensors, and the network facilitates an exchange of data between objects and mechanisms.

NeighbourhoodMicrogrids

Blockchain technology enables the buying and selling of the renewable energy generated by neighbourhoodmicrogrids.

Identity management

Distributed ledgers offer enhanced methods for proving who you are, along with the possibility to digitize personal documents. Having a secure identity will also be important for online interactions — for instance, in the sharing economy.

AML and KYC

Anti-money laundering (AML) and know your customer (KYC) practices have a strong potential for being adapted to the blockchain. Currently, financial institutions must perform a labour intensive multi-step process for each new customer. KYC costs could be reduced through cross-institution client verification, and at the same time increase monitoring and analysis effectiveness.

Data management

In the future, users will have the ability to manage and sell the data their online activity generates. Because it can be easily distributed in small fractional amounts, Bitcoin — or something like it.

Land title registration

AsPublicly-accessible ledgers, blockchains can make all kinds of record-keeping more efficient. Property titles are a case in point. They tend to be susceptible to fraud, as well as costly and labour intensive to administer.

Stock trading

When executed peer-to-peer, trade confirmations become almost instantaneous. This means intermediaries — such as the clearing house, auditors and custodians — get removed from the process.

Fig. 5 List of emerging Blockchain applications
Source: What is Blockchain Technology? (2018)

3.1.1 Environmental Sustainability

An example for Blockchain technology with a direct link to improving environmental Sustainability is in decentralising energy markets, which typically operate as oligopolies. Blockchain technology enables the smart metering of electricity generated through solar panels to be recorded, traded and settled on a ledger. If electricity can be traded like any other commodity, energy prices respond to the forces of supply and demand rather than being fixed, regulated prices. This allows individuals and organisations to be both producers and consumers of energy, which can reduce energy wastage and costs, and improve efficiency by not having to rely on a centralised grid.

In 2017, London-based energy technology company Electron was awarded considerable funding from the UK Government to prove how Blockchain can transform the market for balancing the electricity grid. EDF Energy, Shell, National Grid and Siemens are part of the energy Blockchain consortium, organised by Electron, pioneering this development (Allison, 2018).

3.1.2 Economic Sustainability

A 2018 white paper co-published by the World Economic Forum and global consulting firm Bain & Company, estimates that Blockchain technology, by addressing efficiency issues with supply chain finance, could boost global trade revenue by $1 trillion over the next decade, which equates to 1.5% GDP growth based on 2017 levels. The report claims that two major obstacles to global trade are ‘archaic’ paper-based processes and a lack of transparency in the supply chain.

Blockchain allows a product to be documented in real time as it moves from its origin to its destination. For instance Maersk, the world’s largest shipping company completed its first test of Blockchain technology in 2017 to improve cargo management and reported in August 2018 that ninety four other companies so far have joined its Blockchain platform developed with IBM (Gronholt-Pedersen, 2018). Border security were able to remotely access data about

the cargo which has potential applications for making international shipping more efficient and secure.

3.1.3 Social Sustainability

Not to be overlooked is the potential positive impact that improved provenance from Blockchain solutions could have on social Sustainability. For example, in early 2018 De Beers announced that it had successfully tracked one hundred high value diamonds from the mine to the retailer using Blockchain technology (Wood, 2018). Tracr, the platform developed by De Beers will be open to the entire diamond industry in an effort to improve consumer confidence and public trust that De Beers diamonds are non-conflict (i.e. not mined in a war zone and traded to illicitly fund fighting), in addition to increasing efficiency in the supply chain. Similarly, The New York Times reported in 2018 that Walmart, the world's largest company by revenue, has also started tracking imported products such as fruit using Blockchain to be able to identify information such as Sustainability standards and Fairtrade provenance (Corkery and Popper, 2018).

4.0 Blockchain in Construction

Although research highlights that there is much activity and investment in the field of Blockchain, it is fair to say that the Construction industry is only at the start of its journey towards understanding, let alone implementing, Blockchain. This is unsurprising given how notoriously resistant Construction is to change, particularly technological change (Prior, 2017). Even the McKinsey study (2018), Fig. 6, fails to include Construction in its analysis of Blockchain opportunities and Deloitte conducted a similar, global, survey in 2018- again the Construction industry did not feature. There was no recorded mention of any activity in the industry at the Blockchain Live conference and when delegates were asked by IBM at the Construction Blockchain Consortium Business Network event in October 2018 whether they

were involved in Blockchain development, only two out of approximately sixty attendees raised their hand.

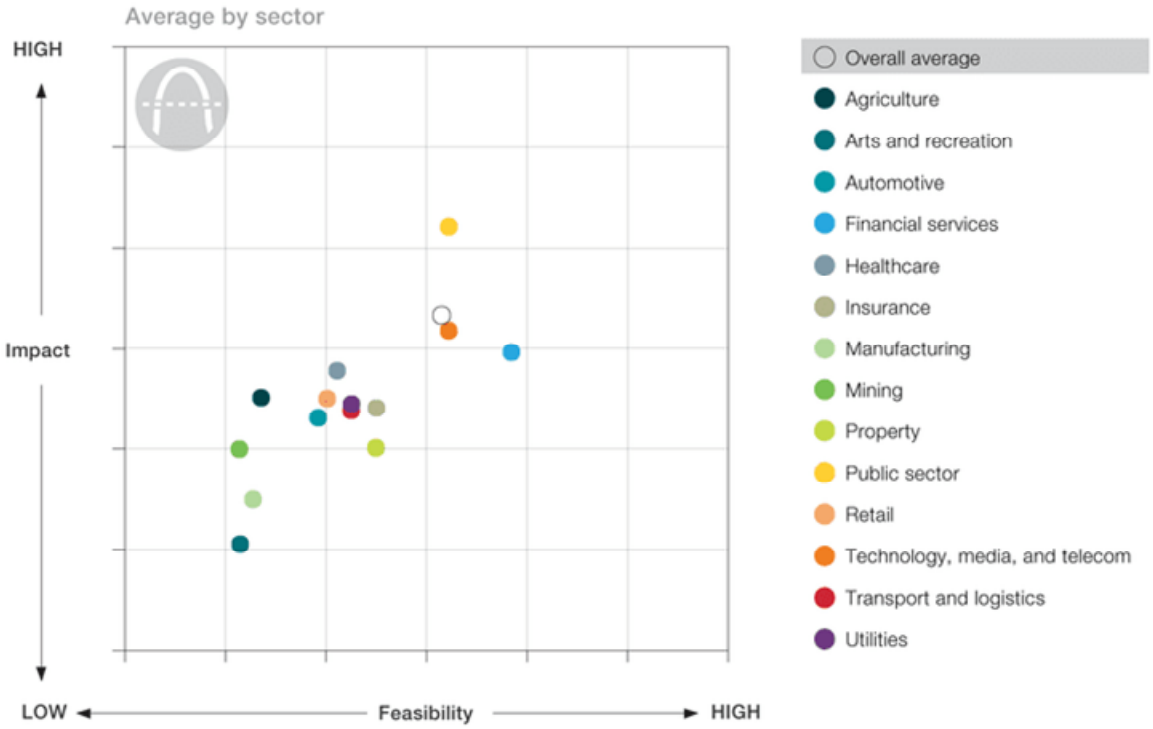

Fig. 6 Overview of Blockchain opportunities by sector
Source: McKinsey & Company (2018)

To realise Industry 4.0's potential, according to the ICE's Digital Transformation campaign, the 'sector must collaborate to tackle barriers and drive progress'. It is surprising therefore that research from the end of 2018 shows that only one fifth of the UK's largest Construction companies by turnover, as ranked by The Construction Index (2018) seem to be actively and openly researching Blockchain. This was determined by searching for the keyword 'Blockchain' on the websites of the UK's fifteen largest companies and also using a search engine to return results of a Boolean search for 'Blockchain' and the company name. Only three companies (Amey, Mace and Costain) have published articles regarding Blockchain and one company, Balfour Beatty, has published a report into 'Collaborative Construction' that mentioned it briefly (Hudson, 2018, p.6). It is worth noting that this does not conclude that further research into Blockchain within the industry is not happening, but more gives an indication of the level of open, collaborative research.

Richard Saxon, Joint Contracts Tribunal (JCT) Chairman, wonders in one of his 2017 blog posts on the JCT website whether Blockchain might enable the adversarial Construction industry to collaborate properly, in the way that BIM should but is often prevented from doing so by contract forms often driving transactional behaviour rather than long term relationships. Writing as part of the ICE's Civil Engineering blog in 2018 Brendan Morahan, Director at Invennt, expresses that digitalisation should be done intelligently and in a collaborative way that can unite the industry: 'let's work together more constructively via digital tools across an ecosystem that transcends established hierarchies or cultural practices' (Morahan, 2018).

There are already two particular Blockchain exploration initiatives that are attempting to actively promote open innovation and collaboration across the industry:

- BuiltEnvironment has been formed by a group of Construction professionals previously part of the Construction Industry Council BIM2050 Group, as a network that promotes digital adoption across the built environment.

- University College London has established the Construction Blockchain Consortium, bringing together the university's fintech experts with digital Construction experts, whose aim is to become 'the leading Construction industry knowledge transfer consortium' and a 'vehicle for tracking and testing these emerging technologies and build proof-of-concept systems' (Construction Blockchain Consortium, 2018).

Over the past year during this research project online literature pertaining to Blockchain in Construction has increased, as illustrated in Fig. 7. This graph depicts the results of a search for the keyword 'Blockchain' on the websites of the fifteen most popular Construction news sites in the world as ranked by GenieBelt, Construction innovation company, based on quality of content, social media presence and content generation rate. BIM+, the CIOB's digital Construction resource, reported that a piece on Blockchain in Construction was the most read on its website in 2018, with another Blockchain article also making the shortlist.

Further progress is demonstrated by the industry's first three publicly available reports on the topic being published in 2018 (see Section 1.4). In particular, the ICE published a fifty-two page 'Blockchain technology in the Construction industry' report in December 2018 to help clarify the opportunity for the industry presented by Blockchain technology. This includes payments and project management, procurement and supply chain management, BIM and smart asset management, and the challenges ahead for implementation.

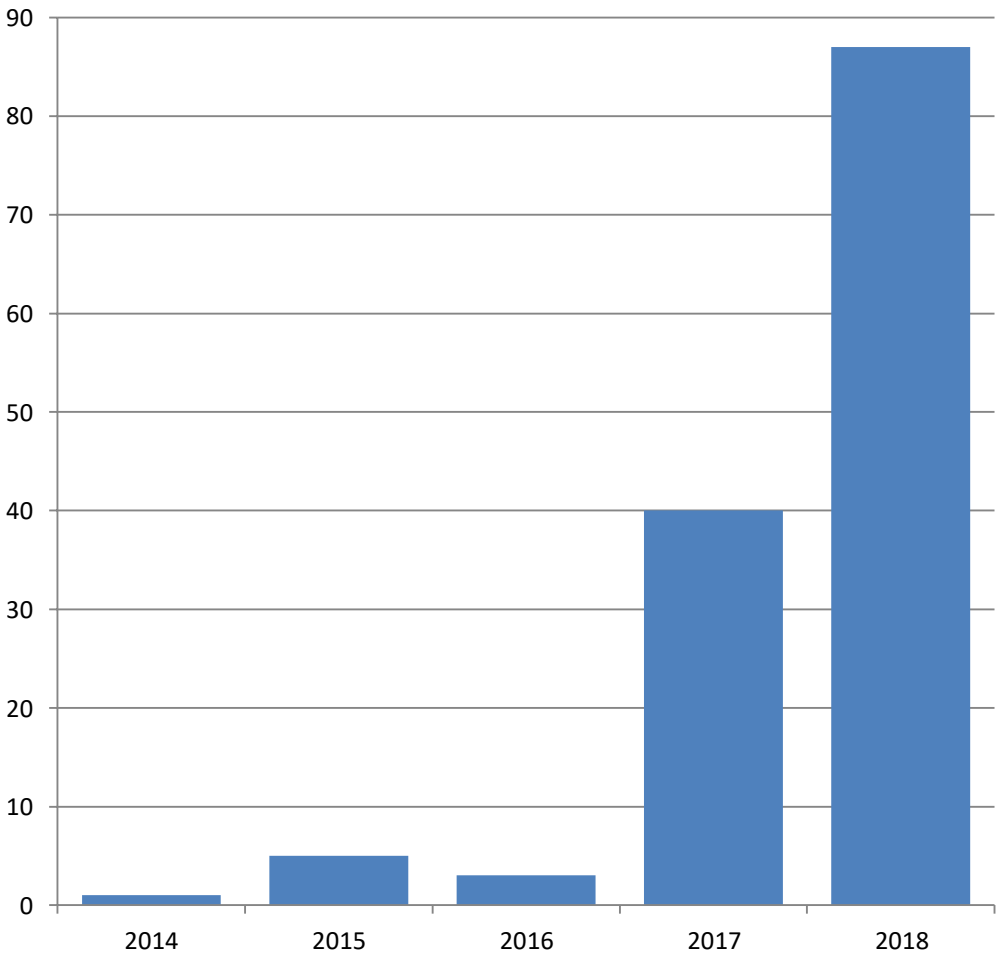

Fig. 7 Blockchain articles published by the most popular Construction news sites

4.1 Blockchain value for Construction

Neil Thompson, former head of Digital Research and Innovation at Balfour Beatty, believes Blockchain will open up 'information bottlenecks' within our industry. The Laing O'Rourke Blockchain working group, formed of a small number of employees with an Engineering and Construction background, has been informally researching potential industry applications for Blockchain to improve information flows, summarised in Table 2.

Area	Potential applications
Economic development & finance	• Project finance alternative whereby projects of significant social or economic value could be 'crowd funded' with a distributed ledger and token used to reward them for their investment • Improvements in business insurance • The Internet of Things enables Smart Assets to earn an income for their owner such as digital displays earning passive advertising income or private Wi-Fi networks charging access fees • Passive advertising could be an area of opportunity to develop digital hoardings or for TVs in welfare facilities to generate an income
Supply chain & logistics	• Value added to the proof of ownership, provenance/traceability of goods and management of shipping documentation • Creation of a logistics network to improve the percentage of return trips after delivering products from manufacturing facilities • Removal of intermediaries from the manufacturer-to-customer value chain to support direct sales from manufacturing facilities or the out-sourcing of work during production peaks to manufacturers with similar capabilities • Improved financing and hire of Construction plant and equipment
Design	• Improved collaboration in the real-time BIM environment • Protection of intellectual property held in digital assets created to represent product sets

Table 2 Summary of where Blockchain could potentially be applied to improve information flows in Construction

The potential applications highlighted by the Laing O'Rourke Blockchain working group can be split, as done in Table 3, into three key areas, which have clear parallels with the three main areas for potential industry applications set out in the ICE Blockchain in Construction report and also those highlighted as focus areas by the Construction Blockchain Consortium at the Business Network workshop in October 2018.

The remainder of this section will discuss the potential value to be added by Blockchain, with examples, in these focus areas, in more detail:

- Payments and project management
- Procurement and supply chain management
- BIM and Smart Asset management

4.1.1 Payments and project management

Late payments and associated cash flow issues are a recurring problem within the Construction industry. According to the Euler Hermes Quarterly Overdue Payments Report, late payments rose by a 27% during 2015. The average payment time for Construction companies and Small and Medium-sized Enterprises was in some cases one hundred and twenty days, which puts the supply chain at risk. Although steps have been taken to improve this (Construction Leadership Council, 2016), the impact of Carillion's collapse in January 2018- which resulted in more than thirty thousand small businesses at risk of not being paid (Kollewe, 2018)- highlighted the ongoing need for better transparency and traceability of payments in the industry.

Ramage (2018) states in an article for Constructible, an online Construction knowledge-sharing resource, that Blockchain has the potential to streamline operations, saving time and money in this area by initiating automatic payments based on digitally approved work, contractual terms and Smart Contracts.

To demonstrate this idea, the ICE (Penzes, 2018) gives an example of a Smart Contract registering operatives' working hours and triggering automatic payments (Fig. 8).

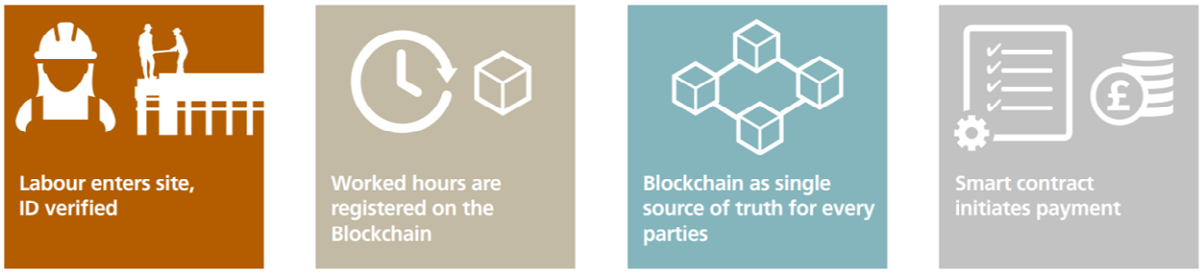

Fig. 8 Smart Contract governed site working hours register and payment system
Source: The Institution of Civil Engineers (2018)

In the above example, the information about who entered and how much time they have spent on site working is captured and registered on a Blockchain ledger between the client, the consultant and the contractor, removing unnecessary administration. When the Smart Contract initiates the payment based on the agreed number of hours worked, there should be no queries since the Blockchain provides a single source of truth.

Blockchain can also track project progress and spending in real time. Each time a milestone or task is completed, a Smart Contract is fulfilled. This removes many administrative processes and paperwork, and payments can be made in smaller amounts so cash flow is improved. Each Smart Contract's progress can be shown visually on the model, enabling better tracking of progress and spending.

4.1.2 Procurement and supply chain management

There is much discussion of Blockchain having the ability to make fundamental changes to how global procurement and supply chain management is undertaken, across all industries (Hansom, 2017). One only needs to look at the number of suppliers on London's Crossrail project- over seven hundred- to gain an appreciation that Construction in particular is a sector with a highly-fragmented supply chain (Penzes, 2018). Managing such large supply chains, coupled with tight margins and a lack of accountability in the industry, can put projects at risk of potential failures. Blockchain can help make processes more efficient, transparent and accountable between all participants involved in the project.

As alluded to in Section 3.3.3, the provenance of materials used in Construction projects is vitally important for reasons such as quality assurance, health and safety, material standards and Sustainability. The Grenfell Tower tragedy in 2017 is an example of where Blockchain could have provided the better traceability of the origin of the cladding and improved transparency of the fire specification needed to potentially avoid the disaster (Penzes 2018). The Construction industry has been under pressure since the disaster to demonstrate that project facades are fire-safety compliant, but demonstrating existing buildings' compliance has often proved difficult or impossible due to the lack of original documentation or good record keeping (Pop, 2018). The advantages of a Blockchain solution in this example are significant; all information on the materials (from procurement to maintenance) for a project could be visible and recorded securely so that stakeholders can have confidence in the quality, safety specifications and standards of materials.

Tata Steel found as part of their 2016 'Sourcing Responsibly' report that supply chain provenance is crucial for procurement Sustainability as material recycling often depends on the certified material specifications. However, impactful Sustainability is often driven by considering the whole lifecycle of a structure. If all the material certificates and quality checks during Construction are stored and shared through a Blockchain system, it will be much easier to quantify Sustainability measures like total carbon footprint. Tata Steel has initiated a Blockchain pilot project together with SAP, IBM and Arup as members of the Construction Smart Contract Committee, which aims to create a transparent chain of custody to drive the development of sustainable Construction procurement.

4.1.3 BIM and Smart Asset management

Arup claim in a recent report into 'how the inventions behind Bitcoin are enabling a network of trust for the built environment' that Blockchain technology could dramatically improve the transparency and security of collaboration in BIM. BIM projects currently share models via a centralised ***Common Data Environment*** (CDE), which raises security concerns and vulnerability to hacking. However, as discussed in Section 2.3.3, Blockchains can permanently record changes to BIM models, effectively time-stamping data so it cannot be changed or tampered with. This is relevant for ***BIM Level 3***, which proposes that all parties work together

on a truly collaborative single, shared model. Blockchain might enable the retention of intellectual property, improve change control for documents and ensure compliance and consistency throughout the project lifecycle.

Often the as-built state is not accurately captured in the 3D model, which is a current challenge to BIM adoption that could be improved using Blockchain and Smart Contracts. For example, a precast concrete beam arriving and being installed on site would not be marked as completed in the BIM model, thus triggering the next step of the Smart Contract, until the installation is verified, perhaps with a Smart Asset connected to the network like a GPS machine or laser scanner. In discussions, the Laing O'Rourke Blockchain working group hypothetically applied this to the example of Laing O'Rourke's Design for Manufacture and Assembly (DfMA) approach. Laing O'Rourke produces pre-cast concrete products in a highly automated way at Explo're Industrial Park in Worksop. Tracking systems are already in place which allows a 3D structural model to visually display progress, from design intent to delivery. Blockchain could be used with this highly automated system to not only add material provenance to the model, as discussed in Section 4.1.2, but also manage payments upon delivery of the element to site using Smart Contracts, with all relevant information (like specifications) recorded on the Blockchain and available on the BIM model. In this way the BIM model truly becomes a single source of truth, as it was intended, which is still yet to be achieved consistently (BC Group, 2016).

4.2 A practical example in Construction

This section provides a practical example of where Blockchain could be used to improve efficiency and thus promote sustainable growth within the Construction industry. The example links the three focus areas from the previous section; payments and project delivery, the supply chain and BIM.

For projects using BIM, the 3D model can be seen as the contract between the client, the main contractor and the subcontractors. The physical Construction needs to match the model and subcontractors are paid upon confirmation of completed work, as verified by consultants or

the main contractor, at pre-established milestones. Administrators are involved in receiving verifications from people checking that the milestone has been achieved and then informing finance and issuing the payment.

As explained by Ramage (2018), contractual paperwork and the costly and time-consuming process of payments could be removed using Blockchain- which could then be linked to the 3D model so that project progress and budget spend could be viewed in real time. The BIM model can be used to represent all the tasks and associated payments that make up the Construction, each with verifiable milestones. Every company working on the project can submit completed work and after verification see it added as string of information on the timeline, which is similar to CoBie data drops used on many BIM projects today (scheduled data update points to ensure the model is kept updated).

Each time a milestone is completed, a Smart Contract is fulfilled which triggers funds to be released. This avoids paperwork, payments are made in smaller more frequent amounts improving cash flow and potential sequencing issues are avoided due to the clearer progress tracking and verification. Each complete Smart Contract is displayed as progress on the 3D model, enabling completion status and spend to be tracked against granular results.

Combining Blockchain technology with the Internet of Things, sensors could be used to identify repairs needed as part of facility management, triggering Smart Contracts to arrange the maintenance.

In summary:

- The project schedule becomes numerous Smart Contracts in a CDE
- Each Smart Contract has a value

- Smart Assets and sensors could work together with Blockchain to track site progress and verify identification and track materials from suppliers

- Completion and verification of a Smart Contract triggers an automatic payment from one company to another, using a digital wallet

- The project receives its next block of information which updates the BIM model with completed work and project spend

People are paid for what they do, when they do it, without paperwork and or the need for an administrative team. This means less paper, fewer people involved and complete visibility of responsibility and budget, helping to shift the industry towards effectiveness, accountability and transparency and improve efficiency and productivity as required in a more sustainable industry (see Section 1.1.1).

4.3 Initial implementation considerations

Blockchain is still a very immature technology with few conclusive studies available yet as to its longer term impact. However, there are several high-level guidance notes available to assist with determining whether a Blockchain solution is necessary and if so what type of Blockchain (see Section 2.4). In Fig. 9, guidance from many sources (Carson, Romanelli, Walsh and Zhumaev, 2018; Peck, 2017; Pisa, 2018) has been consolidated into one simple flowchart to help users determine the first steps of implementing a potential Blockchain solution.

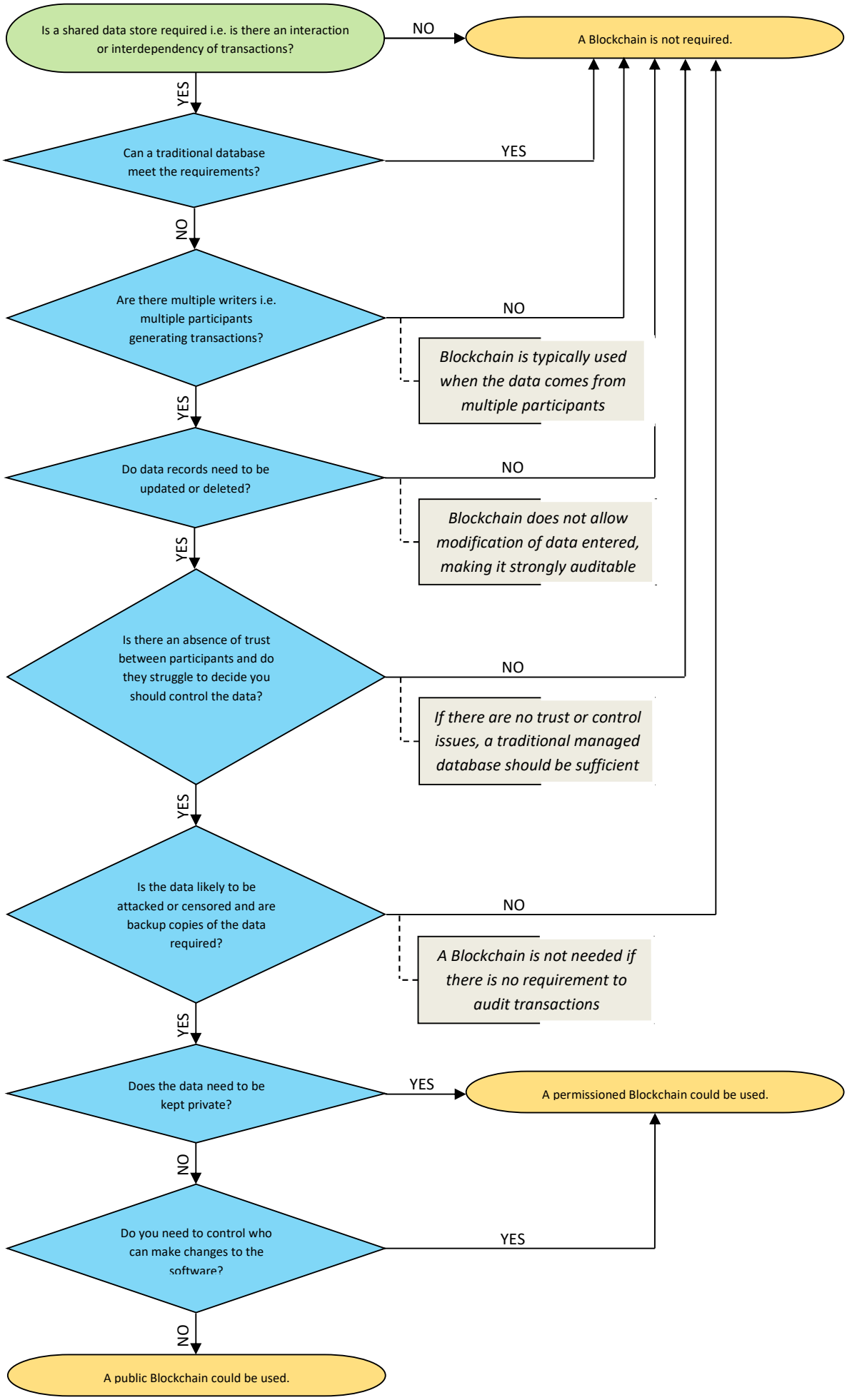

Fig. 9 Flowchart to help determine the first steps of Blockchain implementation

It is important for every organisation to understand what it wants from a data structure and assesses the relative merits, summarised in Table 3, of Blockchain compared with a traditional database, or existing alternative, before deciding on the solution.

	Blockchain	Traditional database
Disintermediation	x	
Confidentiality		x
Robustness	x	
Performance		x
Audit trail	x	

Table 3 Summary of key merits of Blockchain and traditional databases

Blockchain is still an evolving and not widely understood technology. Aside from a small number of cryptocurrencies, few Blockchains have been used and challenged in the real world for any length of time, which presents a risk and uncertainty regarding their performance. If the requirements can be satisfied by a traditional database, as the flowchart in Fig. 10 asserts, then it would be ill advised to pursue a Blockchain solution.

The ICE (Penzes, 2018) suggests the next step is to assess the applicability of a potential Blockchain solution using Return in Investment (ROI) analysis. The ROI should include intangible benefits such as reduced complexity, improved collaboration and trust and decreased risk. Research (Odell and Fadzeyeva, 2018) predicts that the economic impact of Blockchain could result in a range between 43% to 590% ROI for a sample organisation, indicating that although the potential advantages of implementing Blockchain may be significant, the ROI analysis might be difficult and each company should adjust their metrics to their own business (Penzes, 2018).

4.3.1 Limitations

Ramage (2018) makes the very valid point in his article discussing whether the Construction industry needs Blockchain that how it will be implemented in practice is important to understand before agreeing to potential Blockchain investment. Development of other new technologies such as the Internet of Things sensors and artificial intelligence technology is needed to bring in data from the built environment.

There are many articles online discussing common misunderstandings regarding what Blockchain is and can achieve in practice, not just in theory. For example, the Forbes Technology Council, comprised of technology experts and business leaders, published a piece titled 'common myths about Blockchain and cryptocurrency'. Table 4 draws together much of these discussions in a summary format, providing a brief explanation of the reality.

Misconception	In practice
Blockchain is the same as Bitcoin	Bitcoin is one cryptocurrency application of Blockchain and Blockchain can be used for many other applications.
Blockchain is better than traditional databases	Blockchain is particularly valuable in low-trust environments but Blockchain requires technological trade-offs that mean traditional databases can perform better depending on the application.
Blockchain is immutable and tamper-proof	Blockchain data is append-only so cannot be removed however the Blockchain could be tampered with if more than 50% of the network is controlled and all previous transactions are rewritten (which is practically impossible).
Blockchain is 100% secure	Blockchain uses immutable data structures such as cryptography but the overall system security depends on associated applications which may be not be as secure.

Blockchain is a single source of truth	Blockchain can verify all the data within the Blockchain but cannot assess whether the input is accurate or truthful.

Table 4 Summary of the key misconceptions about Blockchain

PwC identified in its 2018 global Blockchain survey a number of early obstacles for companies currently involved in Blockchain development, as illustrated in Fig. 10.

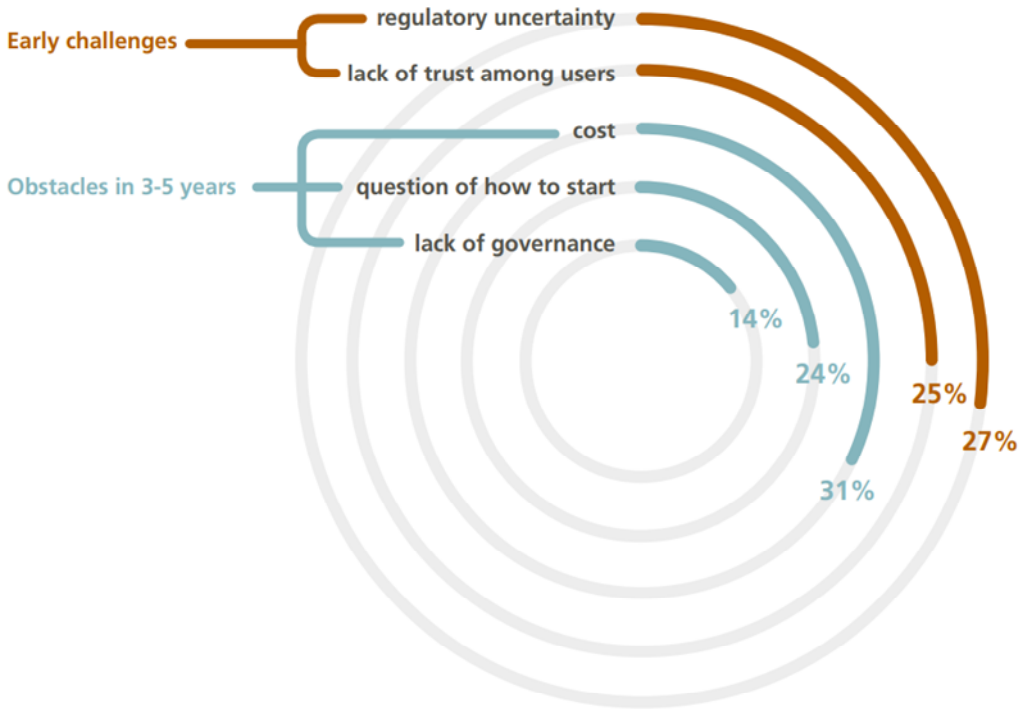

Fig. 10 Main barriers to Blockchain adoption as identified by industry leaders

Source: PwC (2018)

Although these results align with the conclusions of other Blockchain assessments, as cited by the ICE (Penzes, 2018), the Construction industry is likely to face specific challenges due to its unique business environment.

- Narrow margins

  Ernst & Young reported in 2017 that the average margin of UK Construction firms with a predominantly national focus was 1%, and only 4% for those that also worked in

international markets (Gardner, R., Driessen, M., Roland-Billecart, M. and Marson, I., 2017). This limits investment into research and development, despite the opportunity for Blockchain to potentially enhance margins in the longer term across the industry.

- Regulation

  Blockchain would need to support the existing contract structure and the current framework for distributing risk, the Construction Design and Management (CDM) Regulations. As highlighted by Clifford Chance (2017, p. 4), Smart Contracts, being self-executing electronic contracts, raise some important issues as to whether they constitute legal contracts at all.

- Fragmentation

  Given the fragmented nature of the Construction industry mentioned in Section 4.1.2, Blockchain governance is an important issue, particularly if control over the platform and its data are held by a broad set of stakeholders. The Blockchain industry too is fragmented, with many platforms and vendors, so it is important that Blockchain adopters clarify who will maintain the solution over time as there no guarantee that the provider will exist in the future, which creates an inherent risk.

'It is crucial to recognise that Blockchain is not the ideal solution to every data problem; it is a different rather than a better way to address data or transaction management. Under the right circumstances, Blockchain could be transformative, but without careful planning it could also become a costly misadventure' warn Haley and Whitaker (2017). Tom Ghelen (2018), Associate Director at Accenture Technology, emphasises that 'Blockchain is not a totem for progress and treating it as such will not bring the desired results. Rather, the focus needs to be on solving business challenges.' His advice is not to focus on the technology but finding the right solution to the problems faced in the industry; first identify the issues and analyse whether transparency, trust, traceability or multiple stakeholders requiring access to a single source of truth are critical. If so, a Blockchain solution might add value over alternative databases.

Blockchain is likely to require, and facilitate, increased collaboration within the Construction industry so it may be advantageous to share the risk and gain of Blockchain related experience through partnerships (such as the Construction Blockchain Consortium and the Construction Smart Contract Committee) with common pilot projects, Penzes continues, developing over time a common set of industry standards for the use of Blockchain. As mentioned in Section 4.0, the amount of literature being published regarding Blockchain in the industry is increasing and it can be expected that best practice and implementation experiences will be published more frequently in the near future given the establishment of these Blockchain collaborations.

5.0 Conclusion

This report has provided an understanding of Blockchain technology, an overview of use cases for the technology in the Construction industry and considerations for initial implementation of Blockchain technology within the industry. There are a number of potential advantages of Blockchain technology and an immutable, shared record together with Smart Contracts can positively impact not just payments, project management, procurement of Construction projects and the future development of BIM but also Sustainability within the industry.

Speaking on stage at the WeAreDevelopers World Congress in 2018 Apple co-founder Steve Wozniak said he believes Blockchain will have a huge impact on the technology sector, hailing it as ‘the next major IT revolution’. However, Construction is slow to adopt technology compared with other industries therefore is not a good industry to experiment with technology in, particularly when there is so much uncertainty around Blockchain. Sam Stacey, Director at the UK Research and Innovation agency warns that the industry needs ‘something that is absolutely safe’ (Wheal, 2018). Blockchain trials should be encouraged and the shadowing of Blockchain developments in other sectors to compare results.

By using Blockchain and BIM together, along with other quickly advancing technologies of Industry 4.0, there is an opportunity to create a leaner procurement method which better

engages project teams. This will result in reducing costs through disintermediation and where a client has more control and transparency of cost, time and scope on their project. Large amounts of information are constantly being exchanged within our industry and Blockchain has the potential to improve how we transfer and record data more efficiently, to improve long term business Sustainability.

Given current levels of interest and investment in Blockchain development it is believed that Blockchain will become standard technology, integrated with the Internet of Things, used across many industries within the next five years (Ismail, 2018). It is important, therefore, that the Construction industry is aware of what Blockchain is and what it can offer, regardless of whether it becomes an active developer or waits for solutions in other industries to be tried and tested before potentially adopting. The impact of sharing data using Blockchain will become clearer as participants start to pilot projects.

Construction is one of the largest industries in the UK and is a significant factor in its economic growth and productivity (BIS, 2013). As such, the industry has a responsibility to understand, explore and develop the sector to improve performance and its long term Sustainability. Although the industry is at an early stage of its potential Blockchain journey, with multiple challenges to face, there is an exciting opportunity here for all companies in the Construction industry to become more efficient, transparent, productive and sustainable.

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