

BLOCKCHAIN TECHNOLOGY IN THE CONSTRUCTION INDUSTRY

Digital Transformation for High Productivity

December 2018

Foreword from Nathan Baker, Director, ICE Engineering Knowledge

Throughout the world, the construction industry has long been challenged to improve its efficiency, productivity, and to embrace the opportunities presented by emerging technologies. This ICE insights report examines the potential of blockchain technology and asks how this disruptive technology could revolutionise the construction industry.



So, what is blockchain? Fundamentally, blockchain is a distributed ledger of information, such as transactions or agreements, that are stored across a network of computers. That information is stored chronologically, can be viewed by a community of users, but is decentralised and is not usually managed by a central authority such as a bank or a government, and once published, the information on the blockchain cannot be changed.

Make no mistake, blockchain has arrived, offering immense opportunity for industry to become more effective, transparent, productive and sustainable. But what is it, and how do businesses, engineers and built environment professionals even begin to think about how they could capitalise upon this potential?

That is where this report steps in to offer some clarity, direction and signal the opportunity presented by blockchain technology in construction. This includes smart contracts; payment and project management; procurement and supply chain management; BIM and smart asset management; and the challenges ahead for implementation.

ICE's Professional Skills (2018) report recognised the opportunities and challenges that continue to be presented by the introduction of digital technology and the profound effect that it will have on the work of civil engineers in the coming years, in both the construction and operation of infrastructure assets. In continuing this work, I would like to thank the report author, Bálint Péntzes, COWI UK Limited, and the many contributors to this Insights report for sharing their considerable knowledge and experience of the disruptive potential, application and adoption of blockchain technology.

We are at a very early stage of blockchain's inception, and we ask you to begin thinking about your systems, business and processes. What could change? And could blockchain be right for you?

Acknowledgement

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Author



Balint Penzes

Consultant Engineer - COWI UK

Contributors



Adam Kirkup

Knowledge Manager - ICE



Chris Gage

Digital Lead - IBM



Tamas Dravai

Assistant Digital Engineer
- Atkins



Mat Colmer

Digital Transformation
Lead

Special thanks

Matthew Saunders - Senior Manager - PwC

Randi Christensen - Lean, Value Management and Innovation Manager - COWI UK

Musa Chungue - Engineer - COWI UK

Alex Lubbock - Head of Digital Construction - IPA

Andrew Kidd - Commercial Director - Highways England

Tim Rook - Associate Partner - IBM

Kevin O'Grady - Associate Director - Arup

Ahmed Zghari MRICS - Director at HC BIM QS

Bellam Nguyen - Senior Consultant - Arup

Christopher Longden - CEO - Zeus ecosystem

Gary Pogson - Lead Technical Specialist - Lloyd's Register Foundation

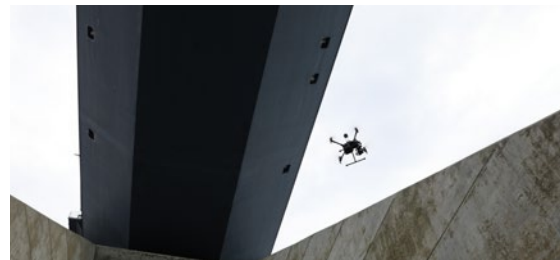
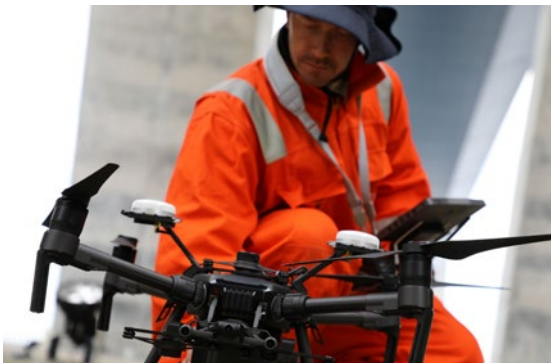
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Introduction

For all nations, the construction industry will continue to be a key driver of economic growth. It ensures and maintains key assets, fuels growth and safeguards the infrastructure framework for continuous economic and social development. Construction is one of the biggest industries in the world, making a contribution of 6.1% to the UK's Gross Domestic Product between 2010-2016 (GDP)¹.



**Maintenance survey with drones on
The Great Belt Bridge**

Credit: COWI

Yet, the productivity and effectiveness of the industry has often been called into question. According to McKinsey research, construction productivity has been flat for decades, whereas in manufacturing, productivity has nearly doubled over the same period, and continues to improve². Naturally, the construction sector is very different, but a more effective industry is needed to keep up the phase of the global economy.

Digitalisation is a part of this development. The number of different modelling tools and software make the design process more effective, and the project and document control more interactive. Perhaps the greatest change, is the use of Building Information Modelling (BIM). It is making the design process more integrated and the process is helping to build a digital description of every aspect of the built asset. It is envisioned by the industry³ that within 5 years, 61% of companies will use BIM on the majority of their project.

However, BIM is not the only major invention in the industry. Employing drones, smart sensors and

the Internet of Things (IoT) with 3D printing are all influencing the landscape of the industry. For instance, many companies have already started to discover Virtual Reality (VR) and Augmented Reality (AR) to demonstrate structures and design progress for clients. As these tools are becoming more advanced, an engineer can perform a quality check based on the BIM model and compare this with the as-built structure. Different VR tools can also be used for various training purposes⁴. All in all, the possibilities are endless and the advantages can be significant.

Furthermore, drones are now able to deliver structural and land surveys (COWI has already employed this technology to perform maintenance review on bridges and other large-scale infrastructures^{5,6}). Smart sensors are also used (and will be used more and more often) to collect data about the construction and operation of an infrastructure asset throughout its whole lifecycle. The connection of these sensors provides even more value with the Internet of Things (IoT) which can enable real time data collection and management on a high scale.

¹ Office of National statistics (2017): Construction statistics, vol. 18, 02/10/2017

² McKinsey&Company (2015): The construction productivity imperative

³ KPMG (2016): Global Construction Survey 2016

⁴ COWI (2018): New Study: Virtual Reality May Unlock Savings in Complex Infrastructure and Construction. COWI News Portal From

⁵ COWI (2017): Drones Do the Legwork for Construction of Dams in Zambia. COWI News Portal From

⁶ COWI (2018): Great Belt Bridge - Tying a Nation Together. COWI News Portal From

All of these innovations are leading the industry towards a more productive, more effectively managed digital age, where real time data and project reporting will be available for key elements of major projects and infrastructure developments. However, one can argue that the industry is not digitally matured enough to be affected by these changes. As a matter of fact, technological development has increased in recent decades, which entailed high requirements for clients, designers, contractors and overall how a project is managed in the 21st century. All in all, inevitable digitalisation is on its way – whether the industry is ready for it or not – and those who can employ the new technologies into their business model effectively will undoubtedly gain an advantage on their competitors and provide an enhanced service to their clients.

The purpose of this report is to describe how the new ‘blockchain’ technology (or distributed ledger technology) can be introduced into the construction industry. The aim is not just to show the technology and the tools which are available, but through potential use cases demonstrate its potential for the construction industry. We will overlook the hype of the new technology, break down its complexity and

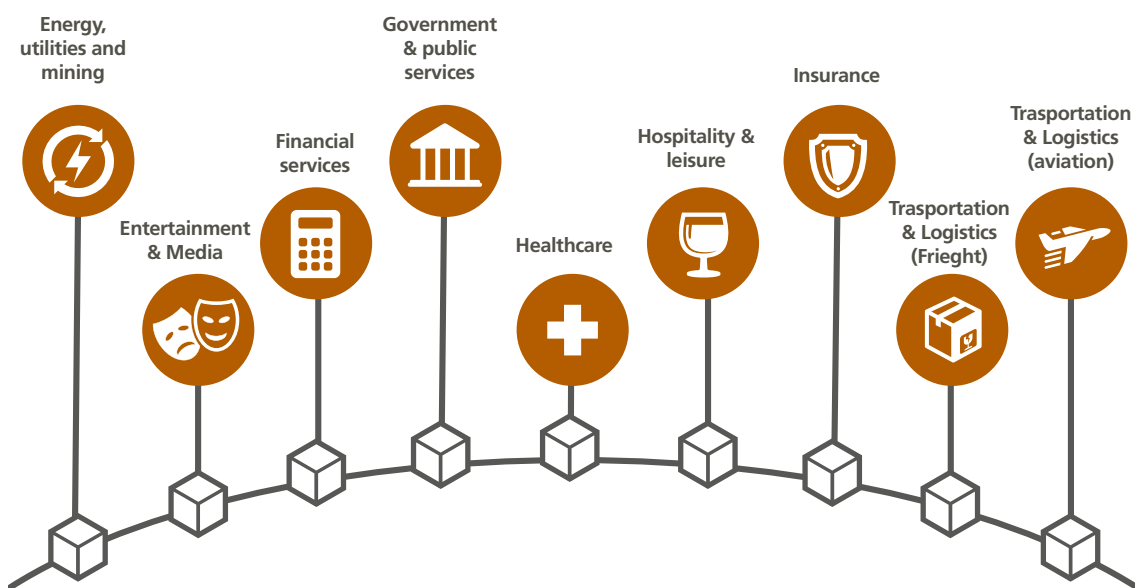
see the viable and applicable potential of blockchain technology, to help the construction industry become more effective, collaborative and transparent in the digital age.

This insight report aims to put the industry on the same page, with regards to blockchain and distributed ledger technologies, and demonstrate applicable cases where significant benefits can be achieved. Hopefully this report can encourage and facilitate a proactive conversation between experts and industry leaders.

Blockchain and trust in the global industry

Technological innovations have been established in recent years at an almost unfollowable speed. Artificial intelligence, robotics, cloud technology and the internet of things are just a few examples which are transforming our way of life and the way we work. The potential changes in the commercial and social economy are not yet fully clear, but one thing seems certain, those who can utilise these technological advances on their business model can adapt quickly

Industry use cases



and gain competitive advantages in the market and provide better service to clients and users as well.

Blockchain technology is another of these revolutionary technologies. Numerous consultants have recognised its potential to change industries, business models and operating processes; such as payment settlement, accounting, administration, supply chain, customer relations, funding, etc⁷.

The conversations have begun to find out which areas (industries, operating processes, etc.) are the most prominent candidates where blockchain technology can add value, increase transparency and effectiveness.

In every business one of the most valuable and intangible assets is trust. It has many levels within an organisation, between the management and the employees. But equally it is an integral part of any deal between the organisation and its partners or customers.

As a general approach this trust was enabled by third parties and intermediaries who ensured the contracted parties that they have the authority, transparency and legal right to do business with each other. However, this approach on a fast-paced global economy with growing complexity and volume of interaction is increasingly difficult. The trust and transparency enabled by third parties has become too complex, information is often hidden, and it can often be a time consuming and costly process. Furthermore, after the last financial crisis in 2008 it became clear that the system was highly vulnerable. Since then the so far guaranteed trust and confidence in established third parties has started to shift towards alternative solutions.

Blockchain is one these types of solutions, as it ensures a transparent distribution of information across all the participants of the network in a way where no one party holds overall control of the data. The information is shared in a pre-defined, unchangeable, almost simultaneous way. Furthermore, all of the distributed data recorded on the blockchain is immutable.

What is blockchain?

Blockchain is a type of distributed ledger technology (DLT) which was first widely introduced almost ten years ago as the underlying technology of Bitcoin⁸. To understand this, we must first familiarise ourselves with what is a distributed ledger?

A distributed ledger is a simple database, but with special properties. It is distributed, meaning that the database is scattered around multiple locations in a shared manner. It therefore shares some similarities with a typical cloud system or other shared stores on the internet. But instead of having only one source where the information is stored with multiple accesses, there are multiple stores (as ledgers) scattered which are simultaneously being updated. A distributed ledger is also a network in which each participant can interact or transact between one another in a peer-to-peer manner. This direct exchange of information between the interacting parties is enabled by the highly resilient network protocol or consensus mechanism of the DLT without the need of any intermediaries.

These interactions are then cryptographically secured and added to – and in the case of a blockchain system – an immutable chain of records.

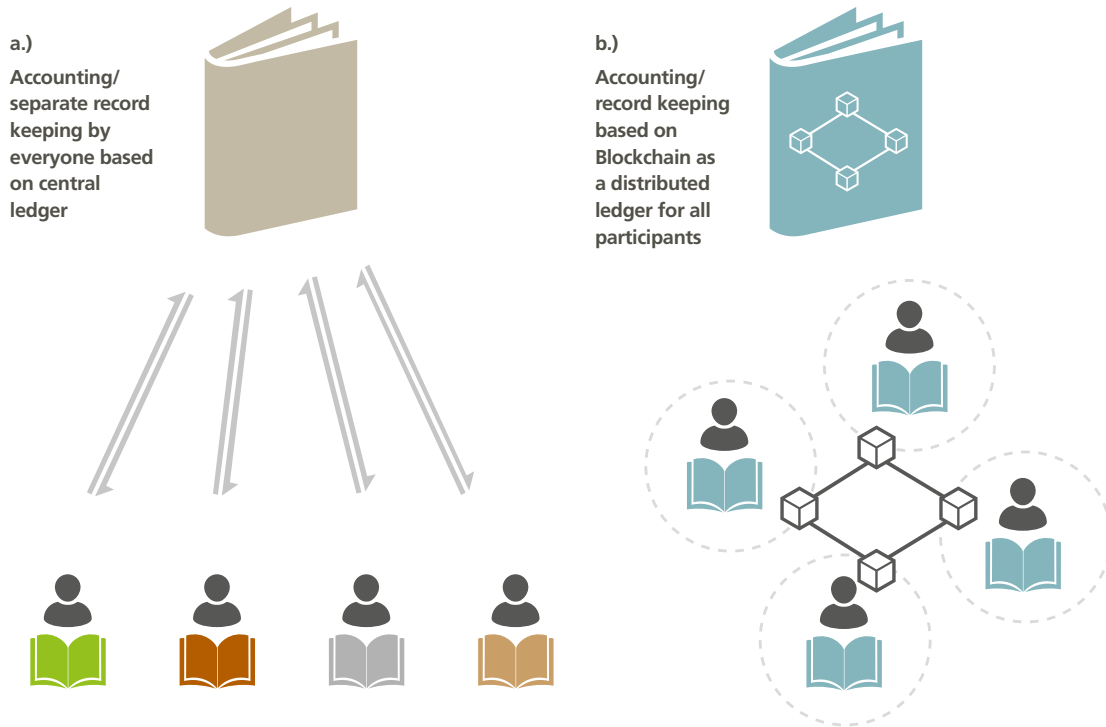
As an example, just imagine a system where instead of having one central accounting book of all transactions between contracting parties (a); there is a system maintaining multiple records simultaneously by every party (b).

There is, in its place, just one single source of information or single source of truth (immutable records of transactions, interactions) on the blockchain maintained by the network and its protocol - copied and shared with all parties who interact on the network.

7 Deloitte Digital, Tech Trends (2018): The symphonic enterprise

8 Satoshi Nakamoto (2009): A Peer to Peer Electronic Cash System

Centralised (a.) and distributed (blockchain) record keeping (b.)



By the encryption these transactions included in the blocks are incontrovertible. Moreover, as every block of the blockchain contains elements/ information of the previous blocks of the chain, an extremely resilient trusted record is created. If one would like to modify one block, the whole chain needs to be altered which cannot be done without controlling the vast majority of the network. This is the same system as the blockchain of Bitcoin, which has no central authority and its public blockchain network has been extremely resilient against attacks since its inception in 2009.

Why blockchain is important for the construction industry?

The construction industry has regularly been cited as one of the world's most fragmented, high impact sectors. The best examples for this phenomenon are all those capital infrastructure projects around the world which have a highly fragmented, scattered

and complex supply chain. For example, the Crossrail project in London, with more than 700 various suppliers just from the UK, or the Burj Khalifa, with over 12,000 workers from more than 100 countries on site at the peak of its construction. To manage such an extended supply chain, keep track of work in progress, schedule, cost and payments, enormous effort and resources are needed. On top of these challenges construction projects experience different forms of mistakes, delays and accidents at various stages and to varying degrees. The lack of accountability in the construction industry has been an ongoing issue for decades and with extremely squeezed profit margins, firms are poised to find ways to cut corners and deflect blame from the resulting failures.

These are exactly the main "pain points" and areas where blockchain can help and make the process more efficient, transparent and accountable between all participants involved in the project.

There are potential blockchain applications which

have already been introduced and had influence on the economy. Some of them can be directly applied to the construction industry and some of them can serve as a basis for a more tailored application for capital construction projects.

The report is distinguished into three main parts with regards to the potential applications:

- Payment and Project management;
- Procurement and Supply chain management;
- BIM and Smart asset management.

In the first section a more transparent way of initiating payments and managing construction projects is described. Secondly, we will explore how blockchain can bring a new level of traceability through its immutable record keeping nature and accountability to project procurement. Lastly, the connection and the possibilities of blockchain together with BIM is probed to unlock the long-awaited effective collaboration in the industry.

Blockchain enabled features for the construction industry



Along these three main features of “transparency”, “traceability” and “collaboration”, this innovative technology has already offered many competitive advantages. Now the onus is upon us to decide how it will be leveraged in our industry.

Understanding Blockchain & Smart contracts

Before we dive into the potential use cases of blockchain in the construction industry it is worth exploring the technology and how it developed from the double entry bookkeeping system invented in the Middle East in the 11th century to the distributed ledger technology.

In the early 1960s the Electronic Data Interchange (EDI) system emerged to automatically share ledger data between parties in order that transactions could be recorded by all parties without the input of a human. Whereas EDI shares transactions between independent ledgers, with the invention of distributed ledger technology, participants in a blockchain network can work from the same ledger. That ledger is then shared and validated in its entirety. In this way, blockchain has a wide-ranging potential for a new way of doing business.

In recent years, various projects have been initiated to leverage the advantages of different distributed ledger technologies with regards to the financial industry, logistic, healthcare, insurance, identity management, media services, data sharing and digital data authenticity. Some of these projects work purely on the basis of distributed ledger technology used as a shared and tamper-proof data sharing system. Whereas others function as a platform or a payment solution, which is powered by blockchain with a cryptocurrency used as an exchange of value within the platform.

The mainstream attention and hype has largely been associated with these cryptocurrencies. To date there are over two thousand various related cryptocurrencies invented and currently listed⁹. However, this is just the tip of the iceberg, and as promised, this report aims to distinguish the extremely volatile cryptocurrency market to the technology of distributed ledgers and blockchain which underpins most of these digital currencies. Cryptocurrencies are just one way of using blockchain technology. This innovative digital system itself is an emerging market with a potential to grow somewhere between \$8.7-12.5 billion business by

2025^{10,11}. Just in the UK itself there are more than 260 related companies headquartered based on a recent study by Digital Catapult¹².

"The technology behind Bitcoin could transform how the economy works."

The Economist (31/11/2015)

Blockchain in operation

But let's see then how blockchain works through a simple example of a transaction. First a transaction is initiated between two parties (1). This transaction then is created as unique data and broadcasted to the whole network waiting for validation (2). During the validation, among other things, it is checked whether the sender/ receiver are appropriate and that the same transaction was not initiated twice. After the consensus of the network, the validation is done, and the hashed transaction information is included in a "block" creating a tamper-proof record (3). Then the blockchain is updated with the new block and in this way the whole network has their own up-to-date copy of the blockchain as well (4). Finally, the transaction is concluded, the transferred digital asset, data, or order, etc. is received with the immutable record of its origin and the fact of the transfer (5).

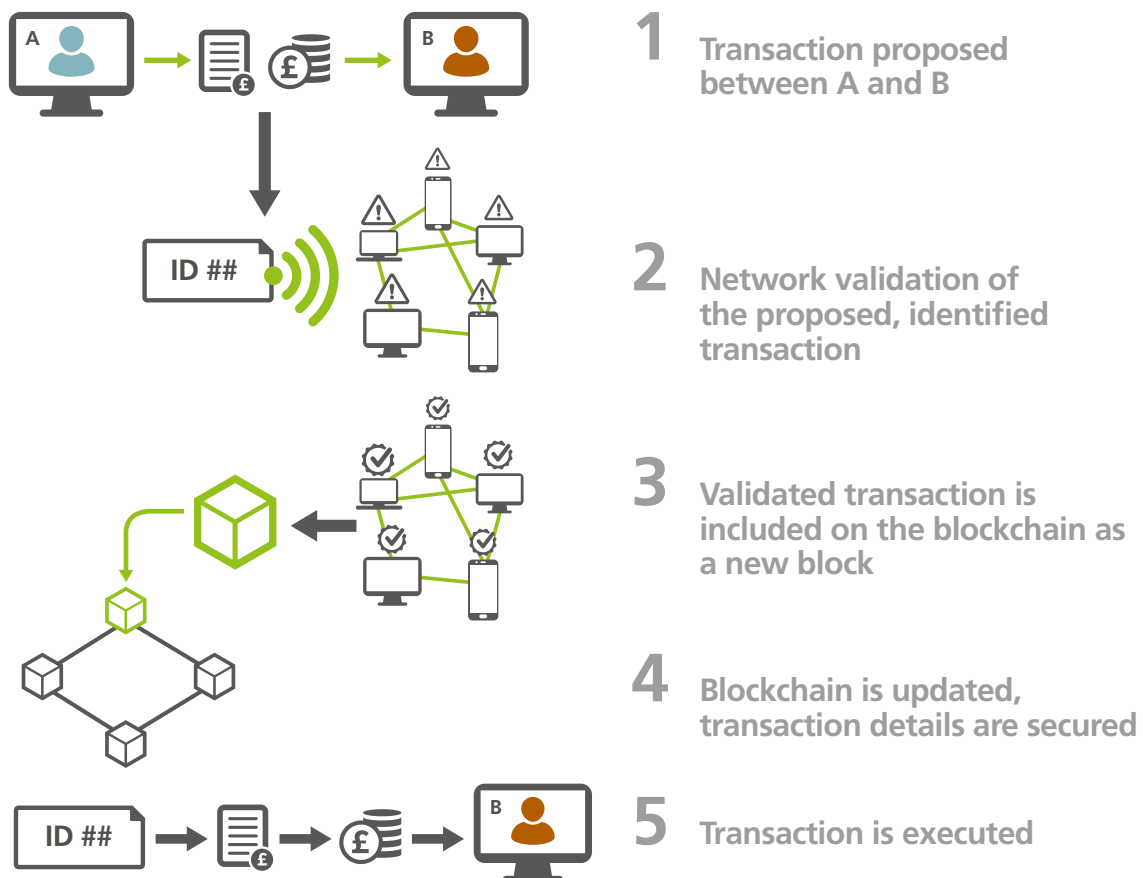
⁹ Listed cryptocurrencies on coinmarketcap.com on 11 November /2018.

¹⁰ BusinessWire (2018): Global Blockchain Market 2018-2024

¹¹ Markets Insider (2017): Global Blockchain Technology Market worth \$12.48 Billion by 2025

¹² Digital Catapult (2018): Blockchain in Action - State of the UK Market

Transaction on the blockchain



Within this process, there is no centralised third party or accountant who can implement any changes to the ledger without requiring consensus and validation from the network. Hence any changes or new transactions need to be approved and agreed by the network stakeholders (nodes).

The mechanism of sharing data and associate immutable uniqueness to information is only possible with strong cryptographic techniques. This enables the embedded algorithm on the blockchain to be certain that transactions are not duplicated. The copies of the blockchain at every node in the network are identical and simultaneously updated. Permissions and accessibility to data is also granted. Inevitably, in order to enable trust in the data recorded on the

blockchain, it has to ensure unprecedented security as well. Nothing can demonstrate it better than the fact that Bitcoin's public blockchain system has never been hacked in its almost ten years of existence.

Now imagine that every key stakeholder of a construction project is part of a blockchain empowered network. In this way the governance of the network is based on the consensus and agreement of all stakeholders.

Each participant would have their own, but same, copy of the blockchain, which includes every interaction and transaction between the parties. Regardless of whether this information is private or fully enclosed for each stakeholder, interactions

and transactions are recorded, tamper-proof and cryptographically signed. This creates an easily traceable record of the past about every business interaction of all stakeholders. In this way, complexity of project control and the risk associated with it could be reduced significantly, and by as much as the cost

of administration. Even smart contracts (self-executing conditions which can be embedded in blockchain-based systems) can be employed to increase further process efficiency and traceability. With such a system, trust and collaboration would be improved fundamentally between all participants.

Collaborative project ecosystem

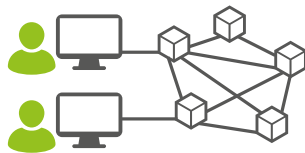


Public and private blockchain types

These functionalities are employed in mainly two types of blockchain system: public blockchains, in

which anyone within the network can participate (e.g.: Bitcoin network, Ethereum) and private or permissioned networks, where the participants are known and listed (e.g.: Hyperledger Fabric, Corda).

Public and private blockchain types



Public

- Anyone can join and transact
- All transactions are public and anonymous
- There is transaction fee
- Relatively slow network
- Difficult scalability
- Very resilient to hacking
- Hard to implement system changes
- Consensus is incentive driven



Private

- Only defined members can join and transact
- Transactions are public and confidential
- Transaction fee can be eliminated
- Fast network
- Highly scalable
- Resilient to hacking
- Easy to implement system changes
- Consensus is based on permissions

The key difference is that the public network participants would need to be incentivised in order to run the network and validate transactions. As an example, in the case of the Bitcoin blockchain, every node competes to validate new transactions and add them to the blockchain. They do it, because once each new block is completed and broadcast to the network, the node who implemented the new block is rewarded by new bitcoins and also from the transaction fees. This process is also known as 'mining', where new bitcoins are created during the validation process.

As the network is public and anyone can be a part of it, it also entails a high level of decentralisation, which makes the network highly resilient against hacking, but also relatively slow and hard to implement entire system changes.

Conversely, the permissioned network is a more centralised solution in the sense that the governance of the network is driven by the members, who are known and validated participants in the network. In this way, the incentive can be eliminated as the participants are incentivised to keep the network up and running based on their business relation.

For example, in the case of a construction project, the client and the contractor originally have different interests in their business relation, hence both of them would be granted the permission to run validation of transactions as nodes of the network. In this way neither of them would have the intention of allowing the other to conduct any wrongdoing.

One example is the Hyperledger Fabric network by the Linux Foundation, which is an open source permissioned blockchain solution. In its development, IBM was a main contributor and created one of the first Blockchain as a Service (BaaS) solution for enterprises¹³.

Hyperledger Fabric is an example of a Permissioned Blockchain, where each network carefully governs who can participate and what they can do within the

blockchain. This contrasts with other open-ended networks such as Bitcoin and Ethereum that are open to all, but which require the resource intensive 'Proof of Work' during 'Mining', to validate transactions as mentioned earlier.

Similar platform type solutions include Corda¹⁴, which is a distributed ledger platform developed by the R3, a consortium of around 200 firms and institutions¹⁵.

Smart contracts on the blockchain to enhance efficiency

There is a key innovation which was brought to life by blockchain technology, the so-called smart contract. It is basically a digital contract, which can execute its terms automatically when the predefined conditions are met. One of the first blockchain related applications was on the Ethereum platform¹⁶ which had the ability to execute computer codes and scripts on the blockchain. As the input conditions came from the blockchain as immutable data, and the code itself was also secured on the blockchain, such conditional functions acted as digitally binding contracts.

Smart contracts are one of the most exciting opportunities presented by blockchain technology, because through them a wide range of processes can be improved, automatised and eventually become more effective.

Let's see a hypothetical example; at a construction site every labourer who enters the site passes its ID card for security, health and safety reasons. The information about who entered and how much time they spent on site working is captured and registered on a blockchain enabled distributed ledger between the client, the consultant and the contractor. In this way there is no additional administration needed to validate this information, as it has already been logged on the blockchain. Based on the agreed terms with

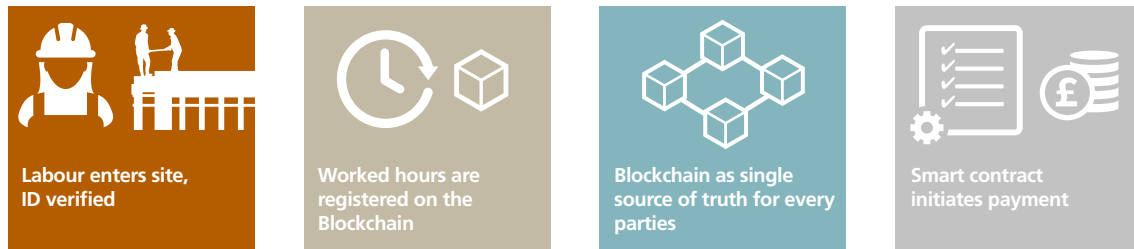
¹³ IBM Blockchain Platform (2018): Technical Overview, Updated March 2018

¹⁴ Brown, R. G. (2018): The Corda Platform: An Introduction, Updated May 2018

¹⁵ Clark, J. (2018): Blockchain Initiative of the Year 2018: The Nominees. Financial News. Dow Jones. Retrieved 26 April 2018

¹⁶ Buterin, V. (2013): A Next-Generation Smart Contract and Decentralized Application Platform, Ethereum Whitepaper. Retrieved 03 Sept. 2018.

Smart contract governed site working hours register and payment system



regards to the number of worked hours on site, a smart contract can initiate payment and send payment certifications for all parties if needed¹⁶.

In this way there are no back and forth queries between the different stakeholders to compare the registered hours in their separate ledgers. It has already been done based on the blockchain enabled single source of truth, which is distributed and updated for every party involved in the process.

This example is fairly simple, but the advantages of such a blockchain system is obvious. It can be scaled up in a way that the execution of payments, submissions and project updates are completed automatically making the whole process more effective.

Nevertheless, in this way all data and information registered (like the number of hours) and transactions initiated (e.g.: payments, project updates sent) are also logged on the blockchain, making the whole system transparent and traceable for the collaborative participants. If any mistake occurs, as a clause in the smart contract with the agreement of all parties involved,

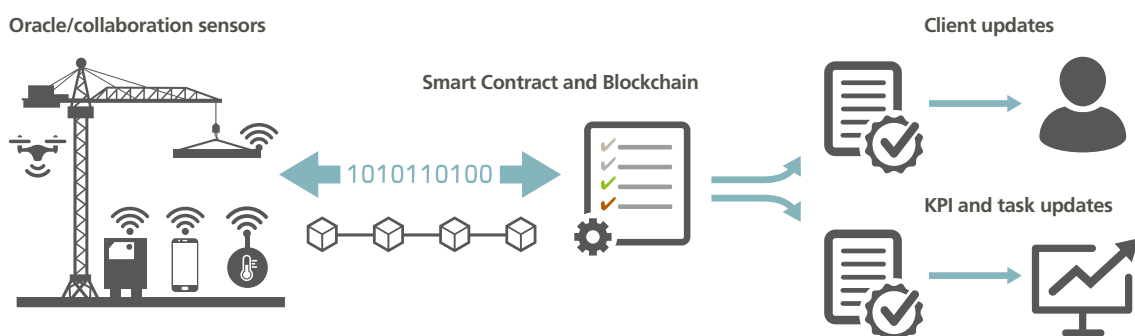
a reverse transaction can be easily initiated. The great advantage is that all these interactions are tamper-proof and transparent for the business participants.

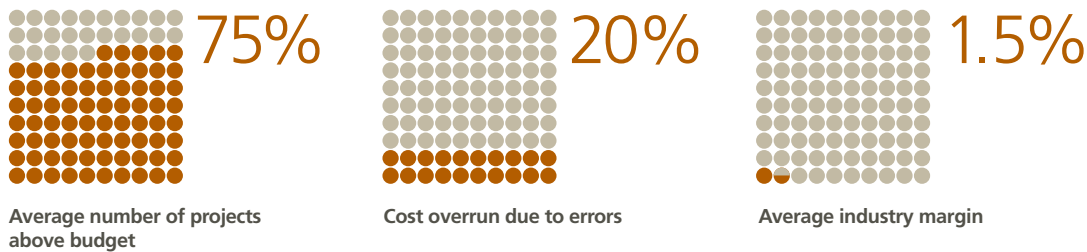
An important aspect of such a smart contract enabled process is that often, external parties or source of information need to be involved as well. These collaborators, also called oracles, ensure the link between the smart contract and the process it manages.

In the previous example such oracle, collaborator system was the ID registering gate, which ensured that the exact person is identified with the time when entering or leaving the site. A collaborator can also be the engineer on site who signs that a piece of work has been conducted with the right quality, or different sensors installed on site.

The key challenge is to make a system as tamper-proof as the blockchain itself, because if the data registered is corrupted, inaccurate decisions can be made. Therefore, as the advent of the IoT is closer, such interconnected sensors can serve as a closed data source for smart contracts, eliminating the potential human errors.

Sensors and collaborators on site informing smart contract





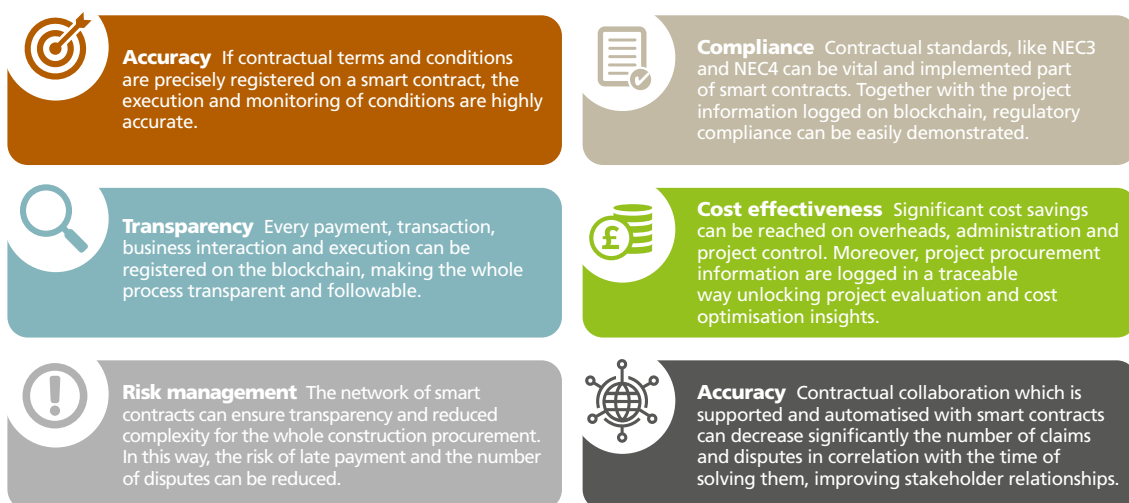
For example, sensors at the construction site can measure temperature, which data is then cross checked with the weather data at that particular part of the city from different websites. This data is periodically assessed by a smart contract and when certain terms are triggered, such as too high or too low temperature, the agreed actions and compensation events can be initiated automatically. Other sensors can send GPS location of structural elements as they are built or RFID (Radio Frequency Identification) information of the arrived materials to update the project plans and monitor progress. Another set of sensors on cranes can update its operational status and its leasing terms which are managed automatically by smart contract¹⁸.

Ideal solution for the construction industry

Efficiency has long been a source of criticism for the construction industry, where 75% percent of capital projects in the UK are over budget and 20% of cost overruns are caused by errors such as inefficient project governance and poor project control^{19,20}. Not surprising then that the average margin for the UK contractors declined below 1.5%²¹.

As the pressure is increasing on contractors and capital projects to deliver on-time and on-budget, optimisation and efficiency are key components. Using smart contracts can reverse and improve this worrying trend in the construction industry²² and unlock the benefits within the Built Environment sector.

Benefits of using smart contracts in the construction industry



18 Wang J., Wu, P., Wang, X., Shou, W. (2017) The outlook of blockchain technology for construction engineering management. *Frontiers of Engineering Management*, 2017, 4(1): 67-75.

19 PwC (2013): Successful capital project delivery The art and science of effective governance

20 PwC (2013): Correcting the course of capital projects - Plan ahead to avoid time and cost overruns down the road

21 The Construction Index (2017): Construction pre-tax margins average 1.5%.

22 Mason, J. (2017): Intelligent contracts and the construction industry. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 9 (3). ISSN 1943-4162.



Payment and Project Management

One of the most applicable uses of blockchain in the construction industry is to embed a blockchain based platform into the project execution practice, which can initiate payments based on digitally approved work, contractual terms and smart contract actions.

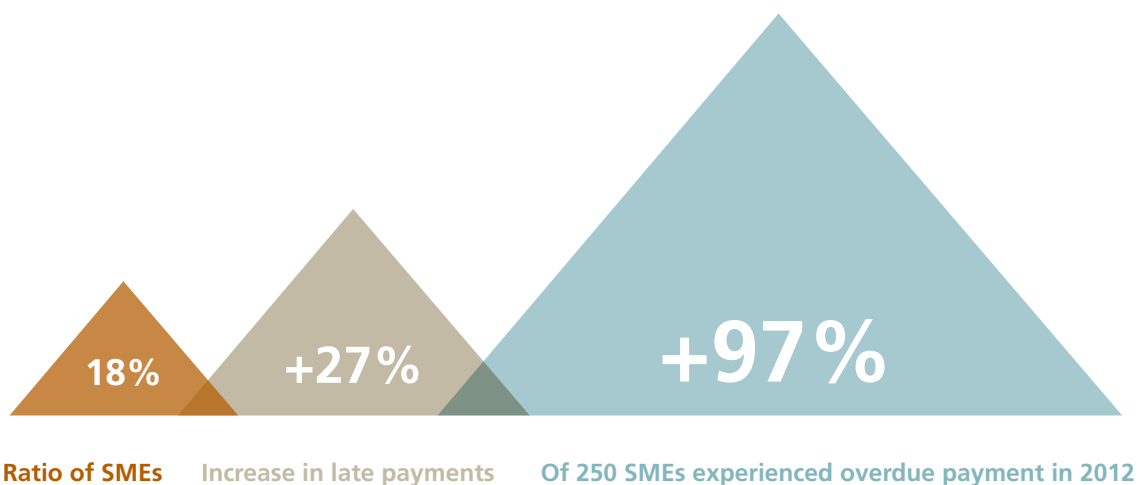
One of the key advantages of such a platform, apart from being very effective, is the high level of transparency for all parties involved. For capital construction projects, complex contracts, terms and conditions are often applied. Through the whole lifecycle of a project it can be a challenge to ensure collaboration on every level between all the parties according to the contract. With such a system and applied smart contracts it can be ensured, that every action always happens according to the agreed terms.

"Establishing the right contracts and managing them effectively is critical. But even if you have got the best contract in the world, it can't deliver unless you have transparency."

Daryl Walcroft - Capital Projects & Infrastructure Lead, PwC US¹⁰

This transparency and effective collaboration can improve many aspects of a construction project. In this part, we discuss how blockchain can help to solve **payment issues** and enhance **project management** efficiency.

Late payments and the relating cash flow issues have been enduring problems in the construction industry. According to the recent Euler Hermes Quarterly Overdue Payments Report, late payments rose by a devastating 27% during 2015. The average payment time for construction companies and SMEs (Small and Medium-sized Enterprises) became 82 days. They could sometimes even rise as high as up to 120 days. Such practice can easily put the whole supply chain at risk. Especially those SMEs who cannot tolerate the large upfront costs without continuous payment and a healthy cash flow. In 2012 a survey showed that 97% of 250 SMEs experienced unfair, overdue payments²³. For a sector, where almost 18% of the participating firms are SMEs, this practice is extremely damaging²⁴.



23 Design Buildings (2018): Remedies for late payment in the construction industry, retrieved in September 2018

24 Farmer, M. (2016): Modernise or Die - The Farmer Review of the UK Construction Labour Model

The industry has tried to resolve this problem and progress has been made. For instance with open source contract standards such as NEC, JCT or FIDIC to implement best practice. The project bank account helped partly to take back control of payments from main contractors. Or with the Construction Supply Chain Payment Charter²⁵ published by the Construction Leadership Council to set out fair payment commitments for companies and to reduce the payment time to 30 days from January 2018 onwards. Despite these efforts, by far one of the largest proportion of uncollectible receivables is still originated from the construction sector²⁶.

This is highlighted by the impact of Carillion's collapse in January 2018, the UK's second largest main contractor company, which resulted in more than 30,000 small businesses at risk of not being paid²⁷. Furthermore, some major publicly funded infrastructure schemes also suffered serious delays due to Carillion's burst.

"Carillion's collapse could trigger a number of insolvencies across the construction sector, in an industry that already experiences the highest levels of insolvency per year in the UK. The ramifications of the failure of Carillion could be huge."

Lee Causer - Partner, Moore Stephens²⁶

It is clear then that there is a high need of transparency and traceability of payments in the industry. Especially with regard to the fact that there is an increasing trend of managing project funding in public-private partnerships (PPPs) which requires more control from the client side and enhanced accountability from every participant.

Blockchain enabled project collaboration

We have seen a straightforward example in how smart contracts can register worked hours on a construction site or how managing inputs from different devices and sensors can make every transaction and interaction more effective and traceable.

Now imagine if the collaboration within a design joint venture (DJV) is enhanced with such technology. In the project planning phase the different design packages and deliverables are defined according to the program. In the underlying blockchain platform similar milestones and packages are added together with smart contracts which are prepared to initiate payments according to worked hours and the submitted deliverables in time.

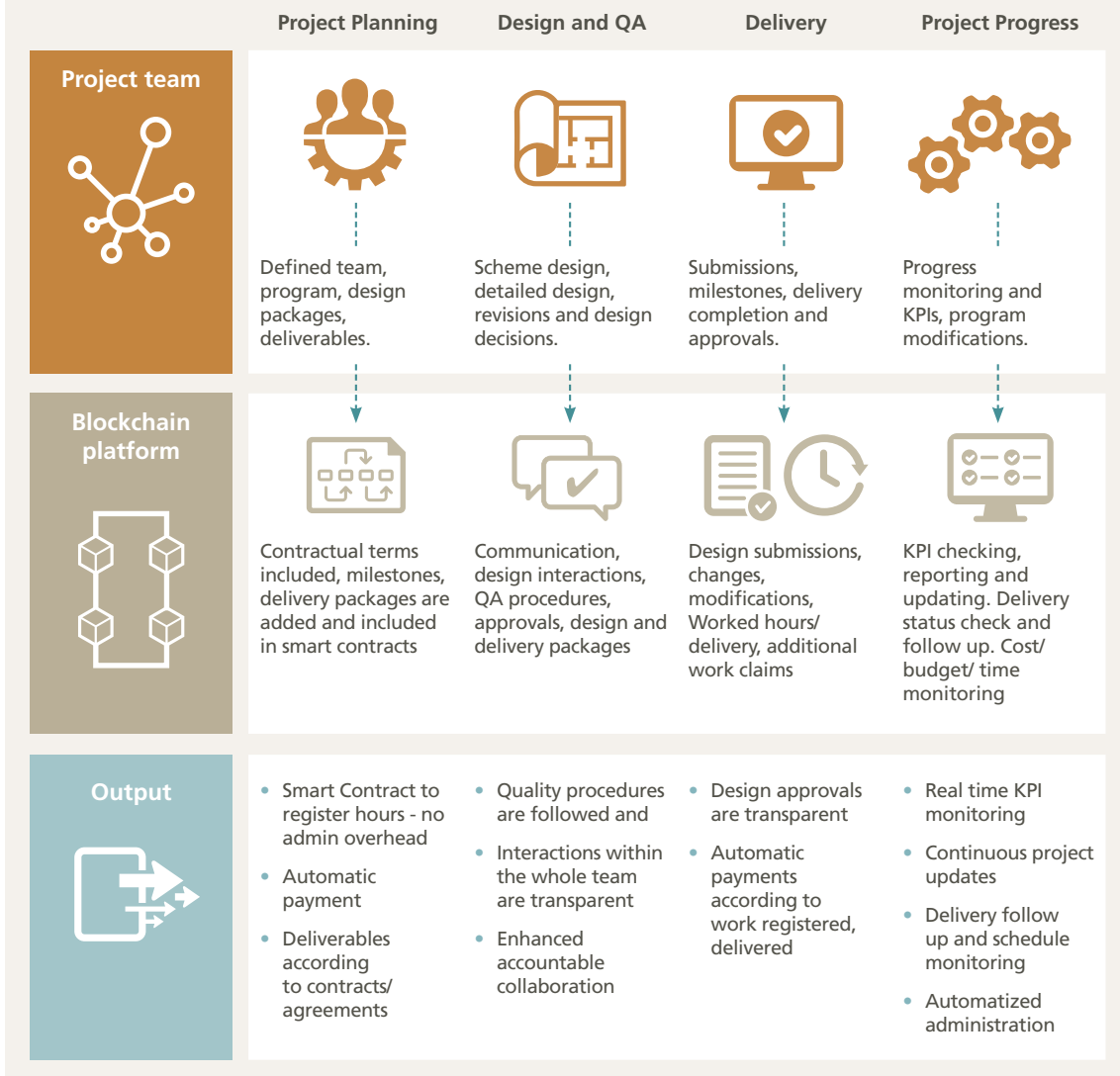
These transparent and faster payments would be activated by smart contracts through blockchain application linked to the project bank account. In this way, payment is still made in normal fiat currency, but initiated by the blockchain enabled smart contract.

25 Construction Leadership Council (2016): Construction Supply Chain Payment Charter

26 Atradius (2017): Payment Practice Barometer UK 2017

27 The Guardian (2018): Carillion: what went wrong and where does it go from here?

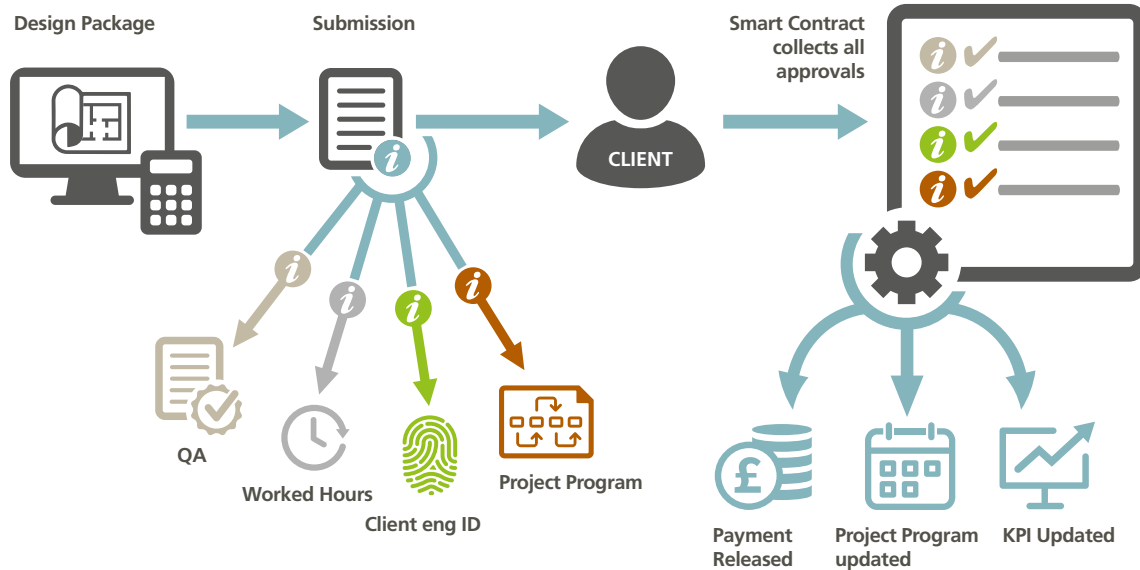
Blockchain enabled designing and project collaboration



As the design process starts, the platform helps to collect and record every necessary interaction within the DJV and/ or between project participants. It needs to be highlighted that in the platform, the different design packages or calculations itself would not be shared, but rather the digital signatures, approvals and quality assurance (QA) steps of developing that design. This allows smart contracts to use these inputs to automatically update project progress measurements

and, because it is a tamper-proof system, the accountability and traceability of design approvals are safeguarded. In addition, all the associated worked hours can be registered and shared on the blockchain across the parties, hence there is no need of valuable time and resource consuming additional bureaucracy. Smart contracts can handle these administrative data and inform each participant through the updated blockchain ledger.

Design package submission through smart contract



When a design is finished, the document control system can inform the smart contract that a design package has been submitted. The necessary parties are then notified to check the document and as their ID is registered as well on the blockchain with their trustworthy digital signature, the document can be signed off. All of these interactions are registered on the same blockchain platform, hence payments and project performance measure updates can then be initiated by smart contracts.

The advantages of establishing such a collaborative system can enhance how a project is managed and monitored. It can help to minimise misalignments of contracts and enable collective corrective actions in the joint venture. Through the traceable data on the blockchain the progress monitoring and the accuracy of cost and schedule estimates can be increased substantially. Just through these advantages up to 9% increase in productivity together with 7% cost savings can be achieved²⁸.

The same concept can be applied not just in the design phase of the project, but at the construction stage as well. There is no substantial difference, because

instead of submitting design packages, the different construction tasks are the deliverables.

Taking the construction of a bored pile as an example. The team who carries out the work has been registered and assigned to the task. These details are registered on the blockchain in a similar way then the hours spent on site. During and after construction of the pile the pre-defined specifications and quality assurance procedure need to be followed, which is supervised by the site engineer, quality controller and the project manager. After their digitally signed approval (with their smartphone or a tablet on site) the smart contract can release payments and update the program.

The process is actually very similar to what is in place on a construction site today. However, because there is an underlying automatic and immutable blockchain layer, every task order, approval and work completion on site with its relating payment are registered and traceable. In this way, the payments can be continuous from the project account and create a transparent flow of value right to the bottom of the supply chain (Example 1).

Example 1: Zeus ecosphere

Zeus Ecosphere is one of the first companies to develop a contract management system which allows that all parties involved in a construction project can enter into a blockchain enabled project and contract management system. The system protects contractors by reminding them what the criteria for contract fulfilment are at any point in time. Payment is made automatically when the contract has been fulfilled and it is registered on a blockchain to create tamper proof record of transactions. Through the developed MVP platform Zeus ensures high visibility as the planned construction tasks can be digitally traced together with the invoices and payment claims.

However, the real innovation of this solution lies within the fact that through such transparent blockchain solution the significant contribution in project management and risk allocation by main contractors is not just strengthened but also properly controlled in order to ensure fair payments and a project delivery which is free from conflicts of interests.

As opposed to the normal 'pyramid flow' chart that would see the client at the top, feeding down to the main contractor and the supply chain below them, this system engages every stakeholder in a collaborative manner to ensure that health & safety, project control and quality remain centre stage.



Within the project management system the main required functions to a construction project are separated, but the governance of the project is shared across the stakeholders through smart contracts and the Zeus Ecosphere blockchain solution. Hence the exchange of information through the system is not directly interparty in order to ensure thorough management of the project,

efficient payment mechanisms and logged information on the irrefutable distributed ledger. Furthermore, together with an automatic warning system in place no parties should fall behind in their obligations.

Through this blockchain enabled system a more transparent and fair project and cost control can be achieved to ensure not just an effective project delivery, but high created value through the whole construction supply chain.

However, construction projects are always very complex challenges hence just the registration of work completion is not always enough. There are usually unforeseen issues, changes in programme or major health and safety aspects involved on site, which can result in additional claims and disputes.

As a direct effect of such shared, the secured record of the past is the enhanced liability. As the transactions, approvals and payments are all immutably registered across all parties on the blockchain, it can dramatically increase the effectiveness of any dispute resolution. This transparency can positively affect not just the

accountability of all parties but also the quality services across the whole lifecycle of the project.

For instance, if a claim is submitted based on instructions issued by the client, or compensation events, they can be assessed and additional or reverse payment can be accommodated through the system. However, it will be still recorded in the same way ensuring a high level of transparency in the industry, which was not possible before.

This example of claims leads us to a very important aspect, namely the health and safety and risk

management angle of projects. It is crucial, that every health and safety related information or incident is also properly logged in order to discover its root cause and to have an immutable record in the case of claims and related issues.

Through a blockchain enabled construction management system, every health and safety incident or record of unsafe conditions (extreme weather conditions, unauthorised actions on site, events logged in the risk register, etc.) can be registered and the risk mitigation can be initiated (See Example 2).

At this stage the use of sensors and the internet of things (IoT) are primarily useful as these tools can act

as a reliable source of data. The critical information from these sensors is then processed in a smart contract. If certain thresholds and trigger levels are reached, the smart contract can notify the appropriate person on site to prepare risk mitigation or to change the construction plan. The important two aspects here are the following:

- the data is fostered and processed automatically;
- all the important information sharing interactions (data from sensors, alarm from smart contract) are registered on the blockchain system.

In this way the system creates a tamper-proof source of health and safety information with accountability.

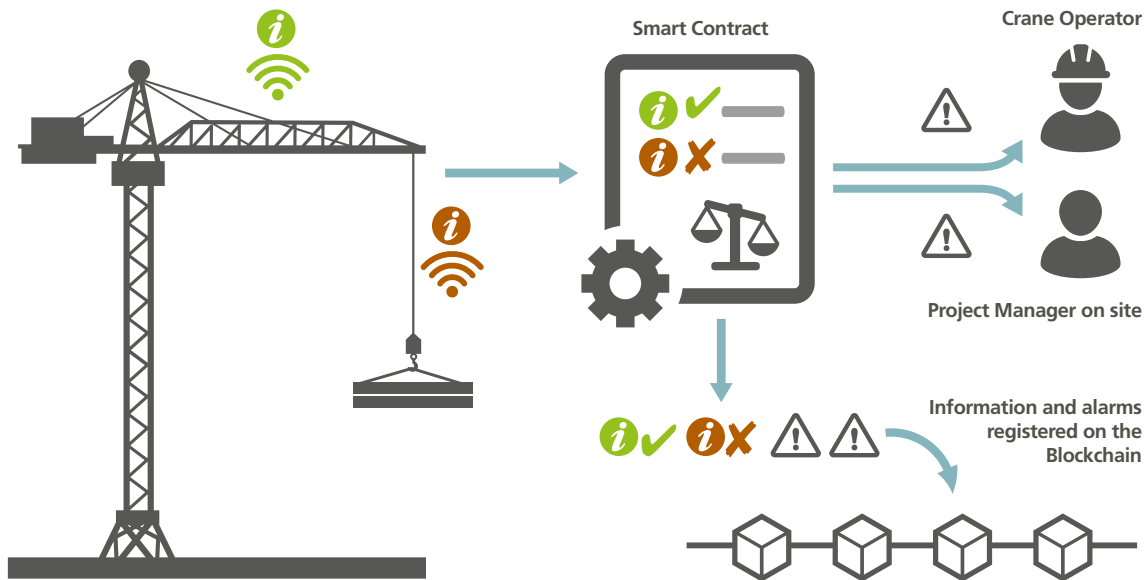
Example 2: 'Lifchain' by Costain²⁹

Costain has also recognised the value of distributed ledgers and blockchain in the industry particularly in the case of health and safety related matters. They have developed a series of blockchain related solutions to bring transparency and security to the rail sector specifically.

'Lifchain' is on these solutions as it collates health and safety data from the whole supply chain. It provides important insights to the project team about emerging trends or potential health and safety issues. In this way it ensures not just an immutable record of these crucial data, but also enhanced trust and accountability across all stakeholders.

²⁹ Costain (2018): Real time data to incentivise behaviour by Damien Canning, Head of technical sustainability

Crane operational risk management with blockchain



For example, if there is a crane on site, its effective operation can be crucial in terms of project progress, costs but also any mistakes can cause serious health and safety issues. Together with sensors installed, the operational status can be easily followed and registered on a blockchain system. If the sensor records high lifting load or extreme wind this data can trigger, by the smart contract, a safety alarm to the crane operator and to the project manager on site in order to prevent any accidents due to overloading or misuse.

construction projects can be improved dramatically and can foster trust between all parties involved.

Route to a transparent construction industry

The implementation of blockchain enabled payment and project management systems can be a significant step which delivers and incentivises a paradigm shift. It could also help to solve the long-standing issue of late payments and cash flow problems, giving the tool for authorities to follow up overdue payments according to relevant regulations³⁰. The transparency and collaboration enabled by this technology in major

"At a micro project level, slow payments introduce risk to suppliers and therefore projects. And then at the macro level, slow movement of cash through businesses and individuals actually prevents economic growth. Now, what blockchain can do is to address these issues by enabling much faster, more transparent and trust-based payments through supply chains."

Matthew Saunders - Senior Manager,
PwC UK Capital Project Services³¹

There is a great opportunity to shape a more trusted business environment and ensure that a transparent flow of value, created by capital construction projects, can be equally beneficial for the whole supply chain.

30 Public Contracts Regulations 2015 Clause 113. Retrieved 11 November 2018

31 Reimagining Capital Projects: Podcast Series (2018): Episode 4: Unlocking the potential of Blockchain



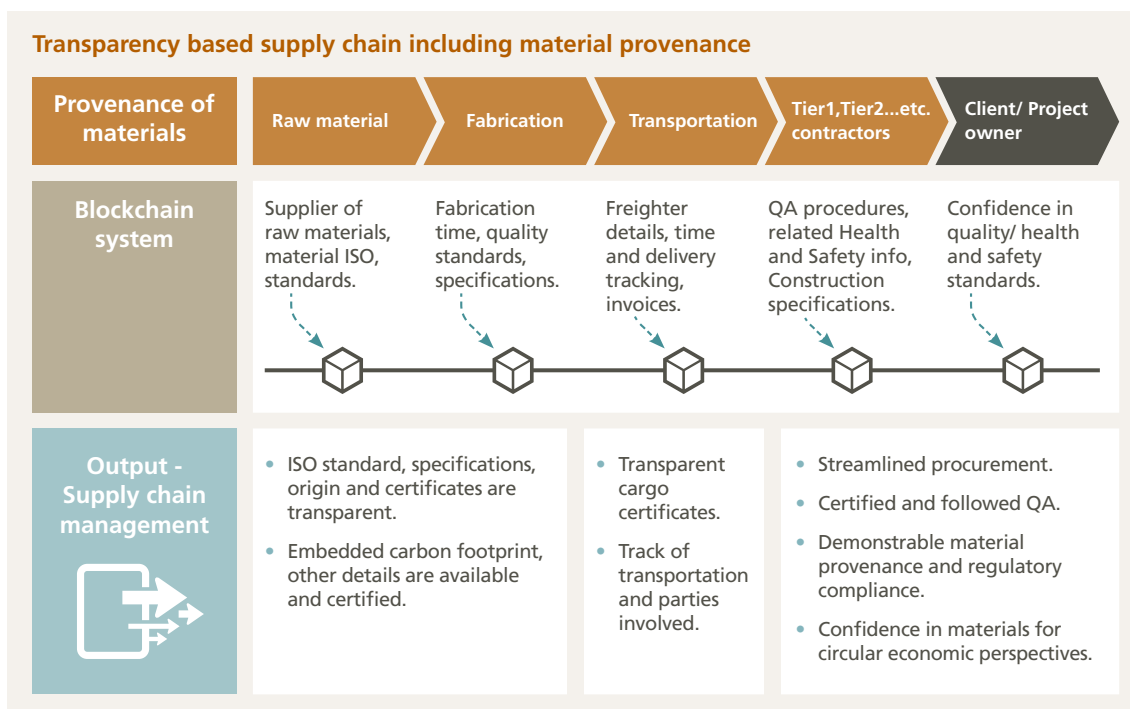
Procurement and Supply Chain Management

The opportunities of blockchain technology do not stop at the payment application. It can also revolutionise the current supply chain management of the construction industry ensuring provenance for structural materials, and to create a verified chain of custody transparent for all parties in the supply chain.

Designers, contractors and suppliers nowadays are far more aware of the provenance of materials used in construction projects for reasons such as strict quality assurance, health and safety, material standards and sustainability. However, the system is still not free from mistakes and negligence. Solving these deficiencies has become increasingly important after the tragic Grenfell Tower fire incident in 2017³². Where the traceable origin of the cladding, associated with the fast spreading of the fire, together with the transparent fact of its inefficient fire specification, would have helped to prevent this catastrophic accident.

Imagine a blockchain system, where the specific structural materials, such as prefabricated concrete or

steel elements are logged and traced along the supply chain until construction. The advantages are significant for all stakeholders in the project. For instance, as client or project owner all information on the materials bought are visible, such as production and quality certificates, together with the track of transportation, until delivery to site. Through this immutable chain of custody at any point of the supply chain, stakeholders can have confidence in the quality, safety specifications and standards of materials. Moreover, as every transaction along the supply chain is also tracked (e.g.: fabrication time, freighter and anticipated delivery time together with the cargo certificates, etc.) keeping track on delivery timing and conditions become easier, quicker and less bureaucratic.



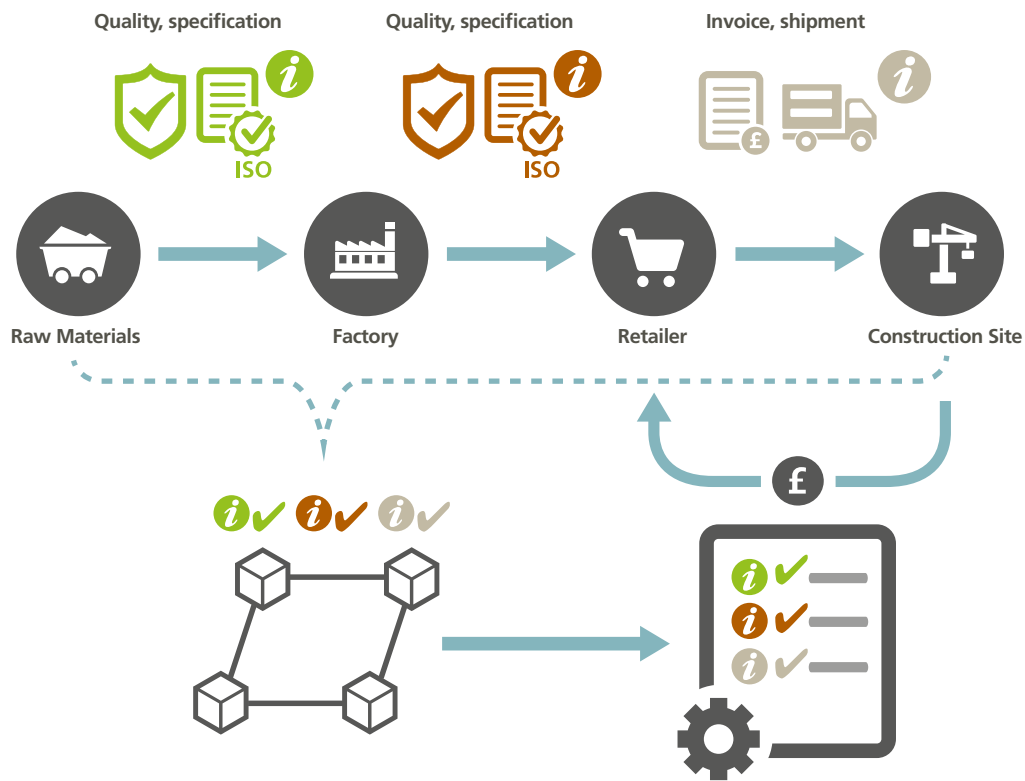
32 Wikipedia (2017): Grenfell Tower fire

Through this blockchain enabled solution the high level of fragmentation in the industry's supply chain can be reduced dramatically with standardised processes and a more transparent procurement operation.

With the real time material provenance, a true track-and-trace application becomes available for the industry,

to reduce waste and improve material streamlining on site, and tackling material counterfeiting. Through a blockchain powered platform, instead of manual paper-based documentation and wet signatures, digital tamper-proof approvals can govern the movements of goods. Moreover, the status of the shipment is updated continuously and shared across all parties involved by the blockchain.

Streamlined procurement and smart contract payment



Because all of the documentation also occurs through the blockchain system, smart contracts can manage invoicing and authorised payments automatically when the certain shipment terms and conditions are met. The cohesion of documents and supply chain management enabled by such a blockchain solution can ultimately create a more accountable system,

in which any issues are identified and solved faster, reducing risks and overall complexity.

For instance, when IBM Global Financing (credit insurer for partners and suppliers) transferred its data (~2.9 million transaction records) to a blockchain system, the annual 25,000 disputes were solved

in 75% less time between partners and suppliers, which also led to a saving of 40% on legal and administrative costs³³. The key aspect of the solution in this example was that the blockchain system as distributed ledger collected all the information from more than 4,000 partners and suppliers who had mostly disconnected systems without interface applications. Hence the shared distributed ledger enabled high visibility of transactions and purchase processes for all participants in real time.

Similar systems have already been employed in different industries. For instance, in the retail industry the UK based company “Provenance³⁴” has initiated decentralised blockchain based services to digitally track the origin and transportation circumstances of goods and products like fresh crops³⁵ and coconut³⁶ with industrial partners like The Co-op or Fairfood. Furthermore, IBM has begun to re-shape the shipping industry through their permissioned blockchain network to create a transparent and accountable blockchain system for the global supply chain with partners like Maersk (Example 3).

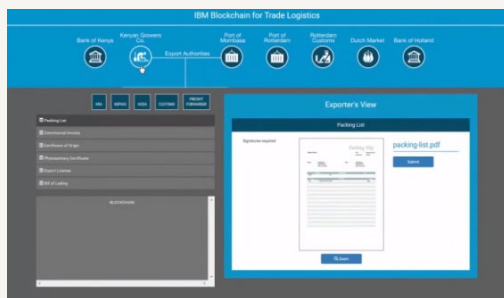
Example 3: Blockchain-enabled shipping platform³⁷

Maersk and IBM have launched a blockchain-based system in 2017 to digitise the whole trade workflow and to create an end-to-end provenance system which can trace millions of shipping containers annually.

One of their recent example demonstrates that transportation of flowers from Kenya to the port of Rotterdam resulted in more than 200 clarification documents and communications³⁸. With the new system the farmer can simply submit a packing list by a

PC or mobile device (visible to everyone immediately). This initiates a smart contract which creates a digital exporting workflow on the blockchain requiring all the agencies, parties to submit certificates and digital approvals as the cargo goes forward along the supply chain. Simultaneously all the transportation conditions, submitted documents and digital signatures are updated and visible to the relevant parties to streamline the process and follow the journey of the shipment.

Credit: IBM (2017): IBM and Maersk demo - Cross-border supply chain solution on blockchain



By this blockchain system friction, delays and fraud can be reduced significantly and billions of dollars can be saved annually with the elimination of costly point-to-point communication and manual administration.

Lenovo (2017) A Server OEM's Perspective on Containers



33 IBM (2017): IBM Global Financing uses blockchain technology to quickly resolve financial disputes

34 Provenance (2015): Blockchain - The solution for transparency in product supply chains, whitepaper

35 Provenance (2017): Case study - Pioneering a new standard for trust in food retail

36 Provenance (2017): Case study - Increasing financial transparency with proof of fair payment

37 IBM (2017): Maersk and IBM Unveil First Industry-Wide Cross-Border Supply Chain Solution on Blockchain

38 IBM (2017): IBM and Maersk demo - Cross-border supply chain solution on blockchain

The principles of tracking goods and registering on the blockchain interactions along the supply chain, together with important documentations, are very similar across the different industries. Hence, the same principles can be used specifically in the construction industry as well. Whether it is a container of flowers, reinforcement rebars or prefabricated construction elements every detail of their transportation, together with the relevant origin certificates, specifications and standards, need to be available in a transparent and accountable way.

Sustainable procurement in the construction industry enabled by blockchain

The optimisation of the industry's fragmented procurement processes and the implementation of the provenance of materials can improve another important aspect of the whole supply chain; sustainability.

Tata Steel conducted a survey about the importance of sustainability and the principles of responsible sourcing in the industry. It found that provenance of materials was particularly crucial as the reuse and recycling of materials can depend on the certified material specifications³⁹.

However, impactful sustainability is often driven by considering the whole lifecycle of a structure. This includes design, construction, its sustainable procurement, operation and maintenance through to demolition.

"Imagine payments for labour and materials being triggered automatically throughout the supply chain as progress is made with zero financial reconciliation required. Thus a client knows the material originator will receive payment for a specific project, ensuring both fairness and completeness of warranty."

Tim Rook - Associate Partner, IBM Blockchain and Digital transformation

Currently, it can be difficult to confirm the specification and origin of materials in the structure after construction. This can complicate decisions on whether a structure's lifespan should be extended or how its maintenance strategy should be designed. If all the material certificates and quality checks during construction are stored and shared through a blockchain system, this makes it far easier to measure the sustainability aspects (total carbon footprint, percentage of reusable materials changing in time, whole life cycle costs, etc.). It can also support the planning of the obligatory Site Waste Management Plan⁴⁰, which usually relies on data from the supply chain (e.g.: invoices, delivery note and material specifications).

To drive the development of construction procurement and material provenance 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 for all resources, with the pilot focusing on steel construction materials (Example 4).

39 Tata Steel (2016): Sourcing responsibly - A market insight into sustainability attitudes and practices

40 Environmental Protection No. 314 (2008): The Site Waste Management Plans Regulations 2008

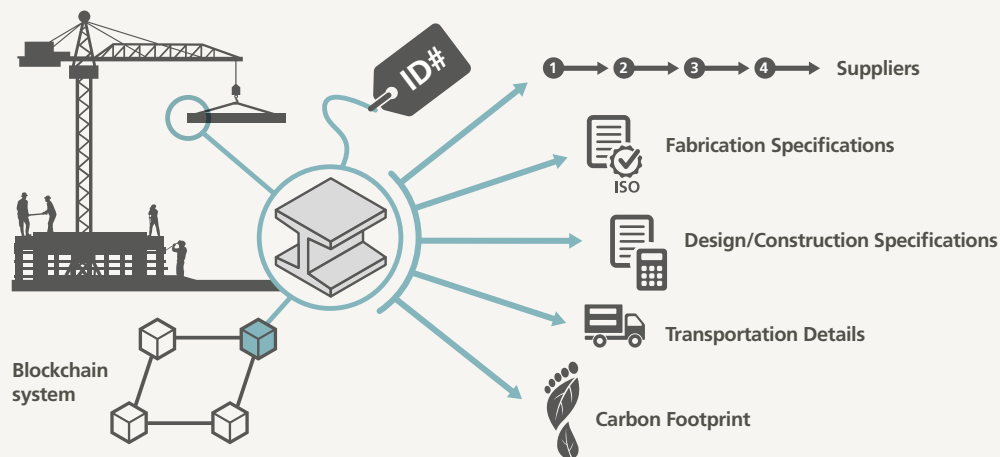
Example 4: Tata Steel pilot with the Construction Smart Contract Committee & IBM

As a manufacturer with Responsible sourcing - BES 6001 certification⁴⁰ Tata Steel has invested in the creation of a traceable chain of custody of its products from raw materials through to in-use, together with the specifications and production conditions related to all relevant standards. However, as is common among manufacturers, this information and supporting documentation has been made available upon request rather than uniquely live-linked to digital data to a particular product.

The initiated pilot is aiming to follow the lifecycle of a steel beam from production, through the supply chain until its reuse or recycle. Every beam will be tracked

through a unique ID, which is registered on a blockchain system. Through this digital identification (also called digital passport of materials⁴¹) all the fabrication and design specifications are available and transparent for the relevant parties. As the steel beam moves through the supply chain every ownership change, transportation details are also added to the blockchain associated with the particular beam. In this way, after installation the beam as a tagged asset can be easily added to the project's BIM model with its special ID and all the details about its production and procurement with an option to live-link to a continuously updated manufacturers specification database.

Blockchain based provenance of a steel beam



Such blockchain implementation creates a very powerful tool to manage steel materials on site and give all future interested parties confidence in provenance and an ability to quickly meet obligations to report on rules of origin, such as fire reports. Furthermore, the new tools.

Credit: Tata Steel Global

⁴¹ BES 6001 (2016): The Framework Standard for Responsible Sourcing - Responsible Sourcing of Construction Products by Bre Group

⁴² Bre Group (2017): Blockchain: feasibility and opportunity assessment

This pilot demonstrates how blockchain can be directly applied to the construction industry. However, it is easy to recognise, that data such as transportation details and specifications are often added to the blockchain system by certified parties, instead of closed, automatic oracle systems (See Understanding Blockchain & Smart contracts). As distributed ledger solutions in construction procurement gain momentum, more and more sensors and the IoT will provide data directly to the blockchain and to smart contracts to create an efficient and robust supply chain system⁴³.

For instance, if RFID tags are added to the steel beams from Example 4 they can be tracked easily from leaving the factory until the point when they are installed in the structure by reader sensors. Moreover, by online sensors implemented after installation the structural performance of the beam can also be monitored over time for future steel applications.

Fostering enhanced efficiency and trust in the supply chain

Clearly the opportunities of utilising blockchain technology are thriving regarding the provenance of applied materials, and how a construction project is procured. The system, with a transparent chain of custody would encourage good behaviour and drive quality throughout the whole supply chain. For example, if structural materials do not meet with quality standards and criteria, regulators can easily identify who is responsible through the blockchain enabled chain of custody. In this way, trustworthy suppliers with high quality products will be recognised and incentivised to maintain quality certificates in order to establish long-term relationships. Such trust can move the supply chain of the industry from one-off transactions to a more integrated, relationship basis.

43 Deloitte (2017): Continuous interconnected supply chain - Using blockchain & Internet-of-Things in supply chain traceability

This new basis for the currently broken supply chain of the infrastructure sector resonates well with the goals of the innovative Project 13⁴⁴ initiative launched by ICE and the Infrastructure Client Group. The project seeks to embed a new business model – based on an enterprise, not on traditional transactional arrangements – that will boost certainty and productivity in delivery, improve whole life outcomes and support a more sustainable, innovative, highly skilled industry. A blockchain enabled procurement is at its core and has the same values and principles as the newly suggested framework, shifting the procurement from the pure cost driven transactional basis to become a value orientated enterprising process, focusing on the demands of clients and the public. Through a blockchain enabled approach, Project 13 could get a strong tool to facilitate its adoption and unlock data which demonstrates how each participant of the supply chain is aligned with the project's goals and requirements.

All in all, with a new blockchain enabled procurement strategy, the transparency of the supply chain together with the provenance of materials would be improved significantly. In this way project owners would have a full view of the quality of materials and the details of transportation at any time. The system permits high level monitoring of shipments and streamlining of constructional goods in a way that information is securely logged ensuring high accountability as well.

Just imagine the potential if all this newly retrieved data from the supply chain could be integrated in a common model, where all the uniquely identified elements of an infrastructure asset is collected and maintained. Luckily, the industry has already started to implement such a system, it is called Building Information Modelling (BIM).

The combination of BIM and blockchain technology offers huge potential and can be seen as the best direction of the development. However, to fully recognise how blockchain can add value, it is important to understand the core concept of BIM and its recent developments.

44 The Institution of Civil Engineers (2018): Project 13 - A new approach to delivering high performing infrastructure



BIM and Smart Asset Management

In its fundamental form, BIM is a process that deals with the digital representations of real-life assets. At its centre is a computer model that holds a wide array of information about the asset such as the 3D geometry, construction management information like time schedules and costs or operation and maintenance metrics.

It is important to note that BIM is a lot more than the computer model itself and it also includes the digital working method which describes how the model fits into the overall project management system, how the incoming and outgoing information is handled and how project participants build, use and manage the models.

While BIM adoption has come a long way in the past decade it is yet to reach its full potential. The

level of information in a model or its development varies greatly from project to project and between the sectors in the construction industry. Based on the types of information used, modeling levels are usually described by assigning “dimensions” to the different information categories. This goes from 3D geometry to, in recent years, 7D which incorporates BIM to asset management to use operational performance data and cover the full life cycle of the asset.

Potential dimensions of BIM⁴⁵



To help realise the benefits of BIM implementation across the industry the UK government introduced a Construction Strategy in 2011, which requires BIM Level 2 usage for all government procured projects with the goal of reducing the cost of public sector assets by 20%⁴⁶.

However, the way to go from a 3D geometrical model to a meaningful BIM utilisation with 4D to 7D (when time, cost and performance is also captured in the model) requires a holistic view and properly digitised processes to interact with any kind of BIM

model. Linking the information and data rich BIM environment with the digitised, immutable and transparent blockchain enabled operation models can provide a wide range of solutions which can benefit the industry as a whole.

Although, BIM as a technology, working method and mindset has already created significant improvements in the construction industry, the combination of BIM and blockchain technology has the capability to facilitate the development of BIM and leverage its full potential.⁴⁷

45 Kevin O’Grady (2018): The age of ‘Total Design’, Passenger Terminal Today, 11th September 2018.

46 BIM Level 2 Mandate.

47 PwC (2017): BIM Level 2 Benefits Measurement - Application of PwC’s BIM Level 2 Benefits Measurement Methodology to Public Sector Capital Assets

BIM and the blockchain

The fundamental concept that can enable the combination of BIM and blockchain technology is their shared ability to serve as a single source of truth. Engineering projects contain vast amounts and types of data and similarly high volumes of corresponding design and managerial decisions. Through the blockchain solutions explained in the previous chapters, not only can additional data be added to the BIM model, but high accountability and transparency can be ensured due to the irrefutable nature of the ledger.

Nevertheless, a sufficiently advanced digital engineering framework can make sure that BIM technology works as a single source of truth for data, while putting the audit trail of design approvals, data verification and project management decisions on a blockchain would result in a combined source of truth that covers all aspects of the project. This single property of these technologies can have significant consequences and provide a tool for creating solutions to the long-standing issue of lack of accountability and

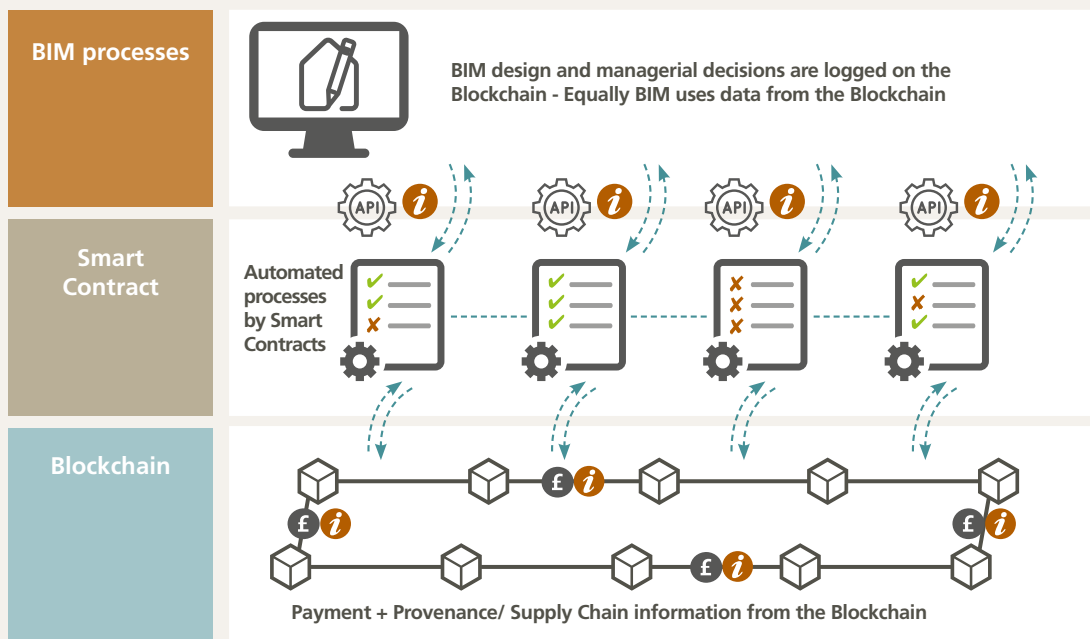
fragmented information sources in the construction industry.

In such a way we can see how BIM can act as a single source and dashboard of all information. The data is not just crucial to deliver the project, but also for its whole lifecycle. Hence, we can distinguish two major ways of utilising BIM and blockchain together:

- BIM can combine information from the blockchain, such as supply chain information, provenance of materials, payment details, etc. particularly during construction; and,
- it can also assign information to the blockchain, like design decisions, source of data or model modification orders. This information can later be used by smart contracts to initiate further action, such as payments or material orders.

To realise these aspects of merging the technologies, a sufficient operating model is required. A demonstrative high-level concept model of one can be seen on the figure below.

Operation model of a blockchain enabled BIM and smart asset



In this proposed model, the blockchain would act as an underlying infrastructure to further strengthen any kind of BIM model and in this way add accountable information. This data exchange process between a BIM model and the blockchain can be automated while automatic payment obligations and task orders can be initiated through smart contracts. The interoperability of information and different software packages can be provided through an API.

One of the main consequences of this blockchain enabled BIM scheme is the introduction of inherent trust within the system. As every decision is logged and traceable on the blockchain, many time-consuming and redundant checks, which emanate from the lack of trust between the project participants, can be eliminated. By capturing a comprehensive collection of datasets, on the blockchain e.g. design decisions, content checks, procurement and transactional data, and linking them to the BIM model, a secure and immutable log can be created that provides detailed information of who did what and what effect it had. This audit trail of design changes will help to create a collaborative environment as liabilities and accountability is clearly established, reducing or eliminating entirely any disputes between the cooperating parties.

A further implication of this approach is that it may be possible to use the ledger data as a basis for calculating the allocation of Intellectual Property Rights (IPR) to the collaborating parties. Innovation in construction is suppressed mostly due to the increased risk of trying new things, but another significant factor is that businesses working in collaboration sometimes withhold innovative ideas out of a fear of not being able to secure the rights associated with a new product or service when implementing them as part of a team. This is especially the case with BIM and digital models, hence blockchain could act as a record of which parties brought the innovative design features

to a project and enable them to propagate those ideas to other projects as well.

The holistic solution for project delivery: from 'designed' to 'as built'

All the above-mentioned benefits combining BIM and blockchain are particularly apparent during the delivery phase. In general, model-based deliveries offer significant improvements over paper-based forms ranging from higher quality to a faster and more streamlined operation model. However, the greatest potential this process holds is a fully digital and potentially automated delivery. Although, as it is present for many automation processes, this too faces obstacles in its application precisely because it requires another level of trust. But this trust can be provided by blockchain technology, and by smart contracts employed upon it.

The combination of model-based deliveries and smart contracts could allow for the complete automation of the delivery process. Due to the nature of a smart contract, i.e. it would only initiate transactions once certain predefined criteria are met, both sides of the delivery process can be assured that their needs are satisfied. From the client's side, the quality of the deliverables can be guaranteed by an appropriately designed criteria set that the contractor would have to adhere to. These criteria are directly related to the model content which is accepted upon validation and design changes may or may not be requested. Based on previous agreement, a smart contract can initiate further time allocation for the design changes, update the schedule within the BIM model with regards to that specific delivery package and notify the relevant parties about the design decisions. This way quality checks are highly transparent, and combined with all the design changes, model-based deliveries and smart contracts can create a more effective way of collaboration.

Example 5: BIMCHAIN

The French start-up BIMCHAIN is developing a similar blockchain application that was described above. The main concept is to deploy blockchain together with BIM processes and data making the BIM data and model contractual. Through smart contracts BIMCHAIN would like to validate models, initiate automatic payments and enhance collaboration with blockchain enabled proof

of consistency, publication and approval. The project developed plugins for software such as ArchiCAD and Revit in order to integrate its blockchain solution to the main Autodesk BIM software. A Beta Program is due to be launched in December 2018 in order to support the development of the company's first product.

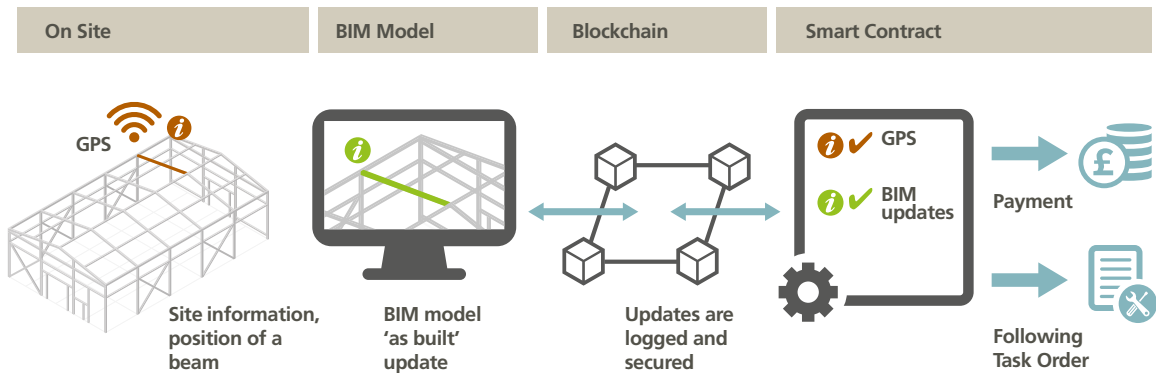
Following the delivery, one of the key challenges BIM is facing is to make sure that information during construction (whether it is about a structural change, or information regarding cost and time) is also properly captured in the model.

We have already discussed that by enabling the previously explained blockchain solutions, the provenance of materials is properly recorded on the blockchain and a BIM model can retrieve this information according to the proposed operating model. But the BIM model also needs to be updated during construction to make sure everything is built as planned, or if there are necessary modifications, then those are implemented in the model. Many times, the 'as built' state is not accurately captured, which is one of the main obstacles for a BIM model to become a "Digital Twin" of the real asset (this concept will be

elaborated upon in the following section).

A possible way of incentivising this behaviour, and the progress of BIM development, is again to use blockchain and smart contracts to partly govern payments and project progress. For instance, a certain precast concrete beam arrives to the site and positioned. However, this part of the construction will not be marked as completed in the BIM model until the position is checked with a certified GPS machine. The GPS machine in this way acts as a trustworthy oracle system which gives information to the BIM model. As for a smart contract this information and construction updates from the BIM model are obligatory to initiate payment and to unlock the next step task order in the program, such as ordering the next set of precast beams to site automatically.

Using 'as built' BIM model by smart contracts



Such processes can start early on, and, for example, as soon as the structural material leaves the factory. In the next example we will discover how blockchain

can improve further Laing O'Rourke's industry leading manufacturing and assembly center.

Example 6: Laing O'Rourke's DfMA approach combined with blockchain

(This theoretical example is built upon the Laing O'Rourke DfMA approach with the intention to show where blockchain can add value to the original process.)

In their Explore Industrial Park Laing O'Rourke is applying their Design for Manufacture and Assembly (DfMA) concept to produce precast concrete elements in a highly automated way to reduce cost and increase quality while facilitating the modular building principle. The advanced level of the facility ensures that based on the production level of the required structural materials the BIM model can be updated automatically. In this way engineers can see whether a component, such as a concrete column is awaiting manufacture or if it has already been manufactured.

By combining this highly automated system with blockchain technology, not only can the provenance of materials be easily added to the BIM model, but many project management related processes as well. For instance, if the BIM model is continuously refreshed to the as built state, while it is also being fed data from



Credit: Laing O'Rourke - Explore Industrial Park

the factory about elements' availability. Smart contracts can streamline the material orders to site, but also manage payments upon delivery keeping all the relevant information and transaction (specifications, standards, invoices) recorded on the blockchain and available through the BIM model as the single source of truth.

Considering that this data collection would run throughout the whole lifecycle of an asset a blockchain enhanced BIM framework could also facilitate a circular economy. Certain features of the data captured about the building during construction could be retained in a blockchain in order that the materials and components can be maintained, replaced and eventually removed throughout the lifecycle. The important point is to maintain a good record of the condition of materials, components and the maintenance activities performed. In this way, buildings could act as materials banks and enable a considerable reduction in waste⁴⁸.

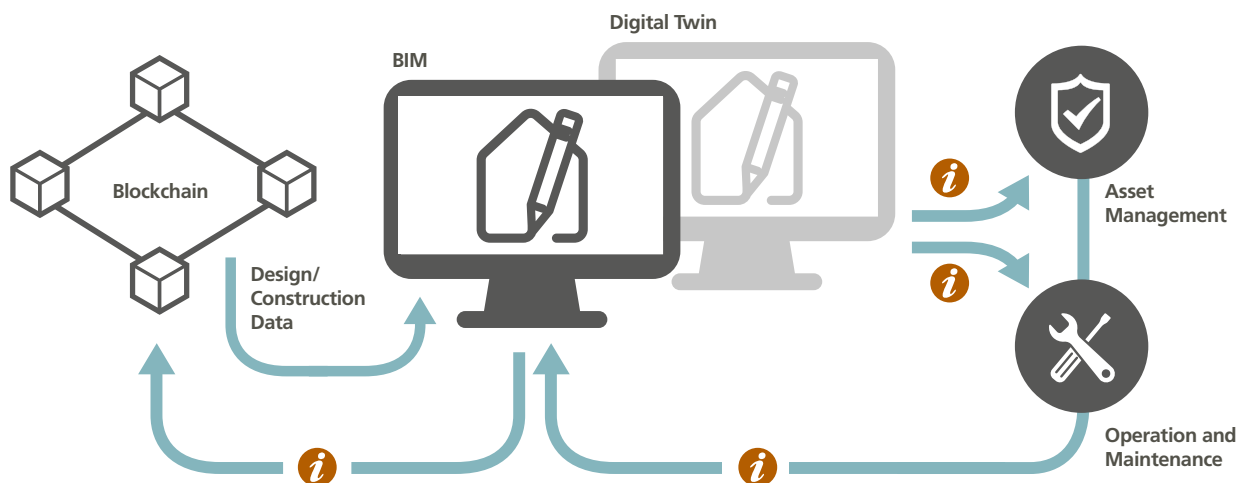
The way BIM and blockchain together leads to Digital Twin and Smart Asset Management

As most projects do not stop at the delivery of the asset but transform and continue until the end of the life cycle, Smart Asset Management (SAM) systems gain ever more traction in the industry.

An emerging field within SAM is a concept called the “Digital Twin”. At its basic level a digital twin is a digital representation of a real-life asset. It embodies a holistic view where the asset management is performed throughout the whole lifecycle of an asset from initial concept to decommissioning and recycling. In order to achieve this, a sufficient BIM framework is required from the inception of the project so that the delivery of models can provide the basis of the operation & maintenance (O&M) phase.

This approach is highlighted within COBie (Construction Operations Building Information Exchange) which is the BIM specification of collecting data during design and construction in order to support the operation and maintenance⁴⁹. Such information can be the design lifetime of structural parts specified by the factory, preventive maintenance required by the designer or the data about the embedded carbon footprint in the structural materials.

Blockchain empowered Digital Twin enables whole lifecycle Smart Asset Management



48 Chris Gage (2016): Circular Construction. Insight on Business - IBM Manufacturing Blog, Published 16 November 2016.
 49 East, E. W. (2007): Construction Operation Building Information Exchange. USACE ERDC. Retrieved 10 October 2018.

Through blockchain a Digital Twin not only contains all the relevant information to define operational strategies, preventive maintenance or a decommissioning plan, but it also ensures traceability of these data. For instance, if a certain part of the structure has an unexpected failure, through the Digital Twin it is easy to identify exactly which elements caused the issue, who was responsible for its assembly, and for its procurement. Through such a system, the time and cost of insurance disputes and warranty claims can reduce significantly, not to mention the inherent incentives of every participant in the project to deliver quality products and services.

To continue from this stage a Digital Twin system does not have to be limited to the 'as built' state. It can incorporate Internet of Things (IoT) data services which provide vast amounts of data from highly specialised

devices and sensors. This is the key step that turns the Digital Twin into a live and information rich dashboard and reporting tool for asset management. However, as with any data science application the insights and knowledge gained from a Digital Twin are only as good as the data that has been fed in to it.

Using blockchain to continue the development of the log of actions taken during O&M can make sure that the quality of the data from the IoT services are appropriately verified and adhere to the client's requirements. The log can provide the same benefits that it did for the design and construction of the asset. On one hand, it can enforce higher quality services by introducing unavoidable accountability, while on the other hand, it can serve as a legal tool and/or deterrent against project participants not playing by the rules.

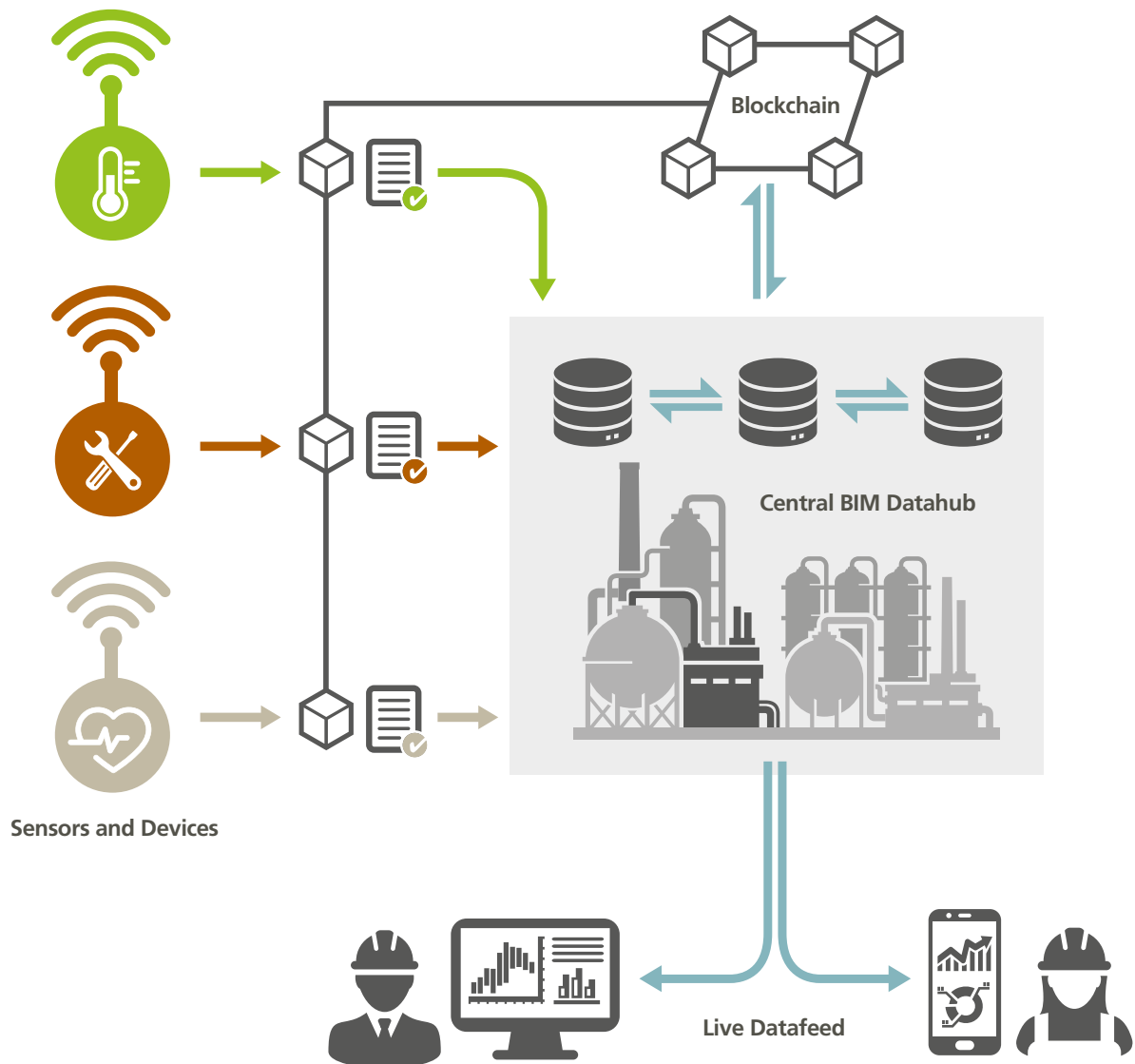
"Economic growth can be supported by monitoring and measuring performance over the duration of an assets life – and the circular economy benefits can be realised. We can all see the value of service records when purchasing pre-owned cars, similarly in the future, infrastructure assets will have increased value if they have immutable records of composition, manufacture and service history.

In 2013, Arup started our Blockchain journey with the birth of OvaCoin in 2017 to better understand the tokenisation and integrated platforms. With current developments within the material supply chain, EPD data and smart contracts domain; we are on a journey - building the digital infrastructure which we believe holds significant value for our clients".

Kevin O'Grady - Associate Director, Arup⁵⁰

⁵⁰ The second issues of the Arup Blockchain report for the AEC will be issued soon.

BIM operating as a central live dashboard enabled by blockchain and IoT



Together with the live data, COBie parameters and O&M action logs it would be possible to build a database in the blockchain empowered BIM model, which can serve as a basis for gaining new insights into design and project management practices. This database can accumulate data over the whole life cycle of an asset, and it can connect the decisions made that are logged on the blockchain to their effect in the models, and in the real-life asset as well. Valuable

insights can be gained by analysing such datasets, such as the time until maintenance, potential to reduce the carbon footprint, or whole life cycle costs.

Consider a bridge deck for example, which is fitted with sensors measuring vehicle load and other traffic conditions. Connecting these measurements to the central model can provide an always up-to-date and optimal "time until maintenance", which can in turn

serve as an input condition for triggering automatic repairs via smart contracts. Finding actionable insights such as this would be a crucial tool in improving project performance, especially for high profile clients where the productivity of projects is critical, like Highways England, Network Rail and other government bodies.

As a closing thought, this chapter demonstrates how the combination of BIM and blockchain technology can bring value in two main ways to a project. On one hand BIM can incorporate data e.g. provenance

of materials or confirmation of element placement from the blockchain to serve as a central datahub; while on the other hand, it can send information to the blockchain such as model modifications which can later be used by a smart contract to handle payments or material orders. From these examples it can also be seen that the foundation for the required digital ecosystems and the willingness to invest in development are already present in certain businesses. As the development projects mature, the integration of blockchain technology with BIM can be a very promising step in the evolution of the industry.



Challenges and Implementation

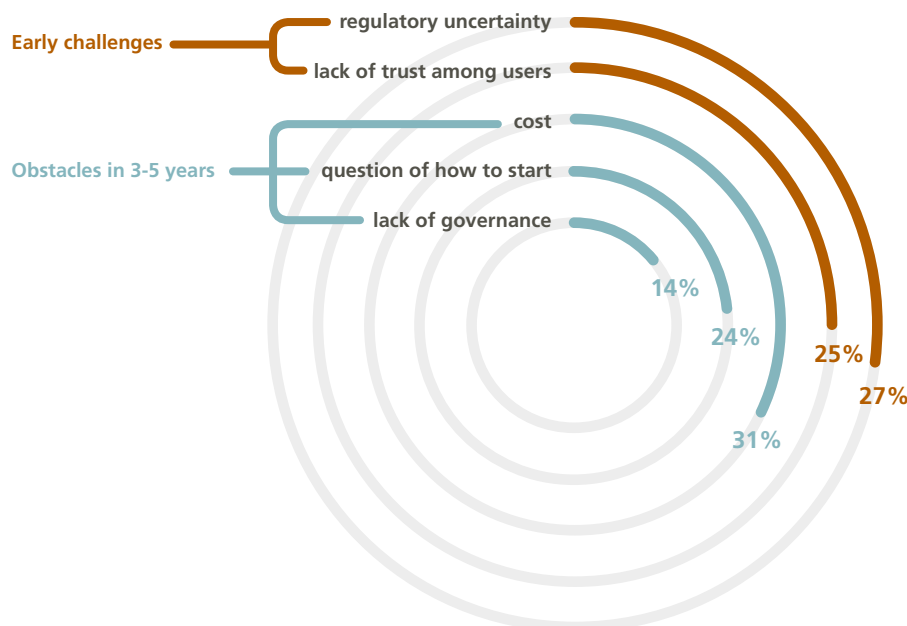
In this report, we have discussed how blockchain is a business tool, not just a new technological innovation, which has the potential to facilitate a paradigm shift in the industry towards effectiveness, accountability and transparency.

We have demonstrated the potential of this technology through the examples presented in this report and how this immutable shared record together with smart contracts can affect not just payments, project management, and the procurement of construction projects, but the future development of BIM as well.

These advantages have also motivated other industries to investigate the feasibility of blockchain. According to a recent PwC study⁵¹ roughly 86% of 600 major companies globally have some involvement with blockchain (e.g.: research, development or pilot). The report identified some of the main early obstacles for these companies; 27% of the organisations selected regulatory uncertainty as the most important. Not far behind, 25% of them marked the lack of trust among users as the most critical early challenge.

Interestingly, for the question of what the biggest obstacle in 3-5 years will be to adopt blockchain, cost (31%), the question of how to start (24%) and the lack of governance (14%) became the main concerns. These challenges are very much aligned with many reports^{52,53} which tried to assess distributed ledger technologies and blockchain in the context of engineering and industrial challenges.

Main barriers to blockchain adoption identified by industry leaders



51 PwC (2018): Global Blockchain Survey 2018 - Blockchain is here. What's your next move?

52 Lloyd's Register Foundation (2017): Insight report on distributed ledger technologies - Safety of engineered systems, Report series: No. 2017.4.

53 Li, J.; Greenwood, D.; & Kassem, M. (2018): Blockchain in the construction sector: a socio-technical system framework for the construction industry.

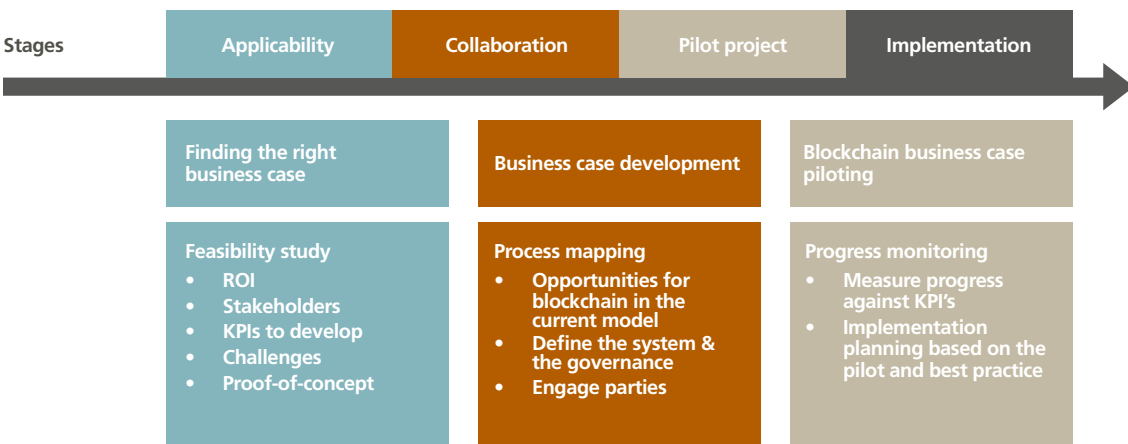
However, the construction industry has its special business environment, hence it has some specific challenges:

1. **Regulatory** the implications of a blockchain system on contract structure and the current Construction Design and Management Regulations (CDM). Contracts and defined CDM roles are the main framework for how risk is distributed between the parties involved in a construction project, hence any adopted blockchain system needs to support and complete these existing regulations.
2. **Vested interests** as blockchain has the technological potential to eliminate intermediaries, it could influence the overall business model of construction projects as well. It could be a major challenge for an organisation to understand how they apply this emerging technology for a more effective and transparent business model. This could eventually move their project model from a highly hierarchic main contractor model towards a more integrated project management system, where risks are shared in established long-term relationships (Project 13 model42).
3. **Cultural** organisational structures and the skills employed will need to change to release the full potential of a new blockchain-based business model.
4. **Narrow margins** the average profit margin has decreased substantially in the past years, which reduced further the anyway low investments into research and development. The significant cost optimisation enabled by blockchain can enhance this narrow margin and turn the extra revenue back to industry wide development.
5. **Knowledge sharing** innovation usually stays within project boundaries, which is a major boundary of industry wide knowledge sharing and development. As blockchain can secure intellectual property rights and digital ownership it can facilitate how knowledge and best practice is shared across the industry.
6. **Fragmentation** construction has a number of legacy systems and practices, which need to be aligned and better cooperate for successful delivery of major projects. Blockchain together with interface applications can act as a single source of truth to over bridge such fragmentation.

Stages of blockchain implementation in the industry

Before the actual journey starts towards implementation, organisations need to carefully scrutinise their current business and ask the right questions - do they need a blockchain solution or not? Hopefully the examples and cases in this report have already helped the reader in this regard.

Stages to move towards the implementation of a blockchain solution

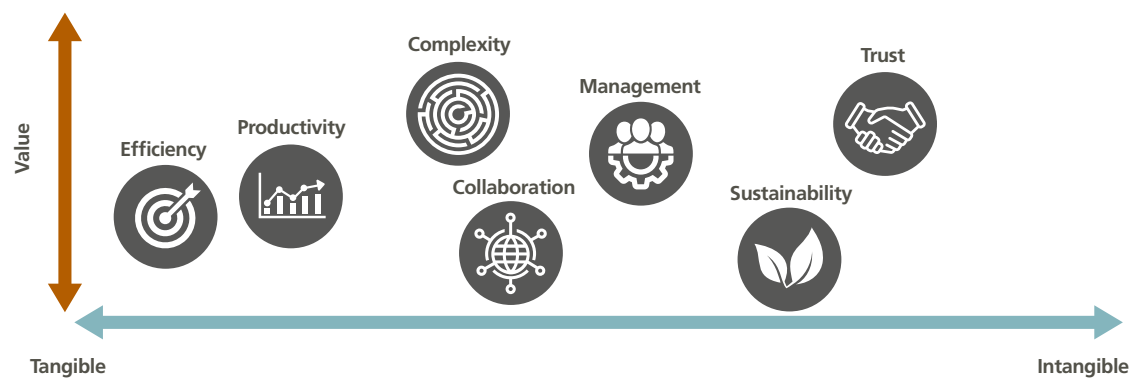


The first step after identifying the relevant business case where a blockchain solution will be implemented is to discover its **applicability**.

In order to do that within a feasibility study the organisation needs to define the potential return on

investment (ROI), who are the stakeholders, what are the key performance indicators (KPI) that they try to improve with the new system and the challenges associated with it.

The different ROI angles of a blockchain solution



The ROI does not necessarily mean just financial advantages, it could also be realised with reduced complexity and in this way decreased risk and enhanced collaboration with trust. However, some of the intangible benefits, like enhanced collaboration, and reduced complexity in procurement can be transferred into financial benefits as up to 10-15% savings on project costs²⁷.

Furthermore, research⁵⁴ by Forrester on the economic impact of blockchain predicts that the enhanced efficiency, savings on operational costs, etc. could result in a range of 43% to 590% ROI for a sample organisation. This wide range of potential benefits represent mainly two things: this exercise is fairly difficult, and every company needs to adjust their metrics to their business, but also that the potential advantages of the new technology can be very significant.

As mentioned, it is important to define who the project stakeholders are early on and what their main success criteria are to enable measurement of just how effective the new system is. With regard to the flow

of payments there needs to be a confident method of measuring the value earned against the actual time and effort invested in the new blockchain and smart contract system. These KPIs can be the cost saving per transaction, administrative time saving per design package or the reduced complexity with the decreased number of disputes. For instance, Crossrail could save almost 60% on cost just by making the drawing review process digitally more streamlined⁵⁵.

During this proof-of-concept stage, stakeholders need to learn as much as possible about the technology and the proposed application. The development of the business case can only start through internal and external **collaboration**.

At this stage, all stakeholders need to be involved to map out the current processes within the selected business case and point out where and how a blockchain solution can improve them. This phase is the use-case design when high level processes and technical details are also discussed, including the governance of the blockchain network and which stakeholder will be part of it. For instance, defining

⁵⁴ Forrester (2018): Emerging Technology Projection - The Total Economic Impact™ Of IBM Blockchain.

⁵⁵ The Institution of Civil Engineers (2017): State Of The Nation 2017 - Digital Transformation.

the scale of the application, choosing which type of blockchain will be used, and what are the basic rules of the employed smart contracts, are all part of this phase.

Blockchain may require different parties within industry to collaborate in a new way to solve industry wide issues. Therefore, it could also be advantageous to share risk and gain of blockchain related experience through partnerships and common pilot projects. Furthermore, as there are more partnership organisations who have started to discover blockchain opportunities specifically for the built environment - such as the Construction Blockchain Consortium⁵⁶ or the Construction Smart Contract Committee in partnership with The Helium Blockchain Alliance⁵⁷ - it is expected that best practice and implementation experiences will be published more frequently in the near future.

In the **pilot project** stage stakeholders and partners should test the application on a defined small scale, where performance can be easily measured, and the different network participants can also test the system. The pilot project should run for an appropriate time and extended in sequences to test a larger network of clients and contractors. Apart from the performance it is important to measure how the pilot project influences collaboration across the network and its compatibility with legacy ERP systems (Enterprise Resource Planning). After considering all the measured benefits and comparing them against the effort, time and investment, the decision can be made whether the pilot can move forward and be scaled up to **implementation**.

However, the above described process is suitable to assess the benefits and risks associated with the implementation of a blockchain solution. Comprehensive advantages and uncertainties may be covered until the application is tried in a large scale according to long-term strategic goals.

"We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run."

Roy Amara - President of Institute of Future⁵⁵
(between 1970-1991)

Blockchain technology is here and although we are at an early stage with multiple challenges it does present an exciting opportunity for all companies in the construction industry, both large and small, to emerge as more effective, transparent, productive and sustainable entities.

Its careful implementation is not just about leveraging a new software. It is more about employing a new business technology and philosophy. According to Amara's law⁵⁸ it will not necessary give immediate advantages but can reshape the construction industry dramatically over time.

⁵⁶ Construction Blockchain Consortium.

⁵⁷ The Helium Blockchain Alliance.

⁵⁸ Searls, D. (2012). The Intention Economy: When Customers Take Charge. Harvard Business Press. p. 257. ISBN 978-1-4221-5852-4.

Conclusion and Future work

Our industry is going through a revolution. This transformation is partly digital, in order to improve efficiency and digital workflows, partly a business practice change, as the current hierarchy-based status quo model is not sustainable. Blockchain technology has the potential to affect both changes and facilitate this innovation.

This report demonstrated how it can shift the current payment and project management system towards a more transparent and fair practice. By reducing late payments, remediations and disputes, small and medium enterprises are no longer placed in continuous cash flow risk. Instead, the industry as a whole can become a more trusted entity.

Through smart contracts, business processes and administrative tasks can be automatised to increase efficiency and always be aligned with the agreed contractual terms. This can result in significant cost savings, increment in the low margins of the industry and better control project costs.

Blockchain can deliver a more streamlined procurement process, reducing the high level of fragmentation and complexity of major projects. The provenance of the materials can reduce waste and drive quality of products and service forward with high accountability. Such systems can enhance predictability with regards to procurement, but also in the case of the whole project delivery.

Together with BIM, blockchain can create the single source of truth for all aspects of a construction project. Such a model can become the trusted digital twin of an asset supporting not only its design and construction, but its operation and maintenance along the whole lifecycle.

The technology is new and there are several early challenges to tackle, but the potential of reshaping the industry for the better is simply too great to miss. Construction is one of the largest industries in the world and the infrastructure it creates is the backbone of economic growth and productivity. It is our inherent responsibility to facilitate its digital transformation to make it ready for the challenges of the 21st century.

Next steps on the journey

The Institution of Civil Engineers holds a unique position as a trusted independent body in guiding the industry and showcasing good practice. Blockchain technology can become part of the industry's digital transformation process and will require strategic and agile thinking. ICE will continue to provide guidance for the industry as a whole in this matter, and provide a platform for understanding and knowledge exchange for built environment professionals.

The author and the contributors of this report together with ICE are keen to drive further a collaborative industry research within the topic of blockchain usability in the construction industry. Framing and facilitating pilot projects and best practices to be able to leverage the full potential of this emerging technology.

Glossary

Distributed Ledger Technology (DLT): Distributed ledger is 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.

Blockchain: It is 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: These are packages of cryptographically secured, which carry transaction information occurred on a blockchain network.

Node: Members of a distributed ledger network, which store independently a copy of the ledger. Nodes may also validate and secure transactions of the network by cryptographic hash functions.

Cryptographic hash function: It is a mathematical algorithm which transform a data with an arbitrary size, or in case of a blockchain network a transaction between two parties, to an output string with fixed size (hash). Such function is a strong data encryption tool and infeasible to invert or hack.

Consensus: This is the process when all nodes of a distributed ledger network agree on the validity of a transaction and ensuring that the stored individual ledgers are exact copies of each other.

Cryptocurrency: A form of digital cash or digital asset, which exist as an encrypted, unique, digital information registered on a blockchain or distributed ledger. It uses sophisticated mathematical algorithms to control its creation (Mining), incentives this creation and the validation of the distributed ledger (e.g.: Proof of Work process) and to secure its transfers across the network. The most well-known examples are Bitcoin and Ether.

Mining: It is basically the process of getting new cryptocurrencies, after Proof of Work and the validation of transactions on the network, as a reward.

Proof of Work (PoW): Is part of the Mining process, when the miner node is required to demonstrate its contributed computational effort to approve a transaction. The provenance or proof of the fact that the computational work has been done is added to the hash of the encrypted transaction, which is included in the block.

Smart contract: Secured computer code applied on the blockchain. A programmed contract which can execute itself automatically when predefined conditions are met.

Oracle: It is a system which send data and information to and from the smart contract in order to create connection between the contract and the blockchain network with third parties and external information sources.

Internet of Things (IoT): Usually it is described as a network of sensors that can capture data automatically and distribute across the network to support decision processes in various public, commercial and scientific systems.

Building Information Modelling (BIM): It is the process of designing and or operating a building or infrastructure asset using digital object-oriented information.

Enterprise Resource Planning system (ERP): Software system which manages in an integrated way an organisation's customer relationships, sales, engineering, production, procurement and finance related processes.

One Great George Street
Westminster
London, SW1P 3AA

ice.org.uk

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