POLITECNICO DI MILANO

Scuola Master F.lli Pesenti

Postgraduate Professional Degree
BIM MANAGER

New Technologies in the Construction Industry

Blockchain and Smart Contracts

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Contents

Abstract

In the last decades several new technologies have changed the way we approach and undertake business models and processes. The Construction Industry, even though always unwilling to change, is now facing revolutionising transformations — undoubtedly the introduction and the adoption of Building Information Modelling (BIM) has already had a huge impact. Currently new technologies like blockchain[1] and smart contract[2], among other smart technologies, are being investigated for possible applications in the construction industry. The adoption of distributed ledger technology (DLT) could be addressing the openness, transparency, honesty and immutability in complex data transactions. *Data* is being placed at the centre of the scene, due to its added value in the Digital Asset Management and Building Lifecycle Management (BLM). Consequently, new technologies are gaining relevance in all different phases to better deal with the huge amount of Data generated and to automate processes. The ability to build and deliver a digital twin — in other words exchanging relevant Data with a Single Source of Truth (SSOT) — is assuming significant importance for the Building Construction Industry. At this point in time, it is vital for companies, to understand the impact of these technological advances to better adapt themselves to the new circumstances and undertake the right adjustments in their business strategy.

"The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn."

—Alvin Toffler[3]

"The first generation of the digital revolution brought us the Internet of information. The second generation — powered by blockchain technology — is bringing us the Internet of value: a new, distributed platform that can help us reshape the world of business and transform the old order of human affairs for the better."

—Don Tapscott[4]

Key words: blockchain, smart contract, distributed ledger, Data, digital twin, Single Source of Truth, SSOT, trust, encryption, transparency.

[1] *A **Blockchain** is a growing list of records, called blocks, which are linked using cryptography. Source: Wikipedia.*

[2] *A **Smart Contract** is a computer protocol intended to digitally facilitate, verify, or enforce the negotiation or performance of a contract. Smart contracts allow the performance of credible transactions without third parties. These transactions are trackable and irreversible. Source: Wikipedia.*

[3] ***Alvin Toffler** (October 4, 1928 – June 27, 2016) was an American writer, futurist, and businessman known for his works discussing modern technologies, including the digital revolution and the communication revolution, with emphasis on their effects on cultures worldwide. Source: Wikipedia.*

[4] ***Don Tapscott** (born June 1, 1947) is a Canadian business executive, author, consultant and speaker, who specializes in business strategy, organizational transformation and the role of technology in business and society. He is the CEO of the Tapscott Group and the co-founder and Executive Chairman of the Blockchain Research Institute. Source Wikipedia.*

Executive Summary

The aim of this paper is to introduce readers to the distributed ledger technology paired with blockchain, its possible applications in the building construction industry and an evaluation of potential advantages and disadvantages.

Ledgers have been at the heart of transactions since ancient times and used with the purpose to record most commonly assets such as money and property. Blockchain is introducing revolutionary elements that will change radically how these transactions can take place. Those characteristics will be explored trough user cases[5] with intention to better understand limits and benefits applying this technology.

Undoubtedly it is an emerging technology [6] that offers the possibility of rethinking and reengineering business models (Business Process Reengineering) having at its core decentralised ledgers and two main aspects: blockchain (the ledger) and the digital currency (the units on the ledger). These aspects together make transactions possible without an intermediary.

To truly appreciate the complex technology and the impact it will have, we will have a look at various topics such decentralisation, consensus mechanism, incentives, encryption, peer-to-peer systems, immutably, miners, double spending problem, concept of trust, network effects and economics.

Focus will also be on another revolutionary aspect of blockchain, observing legal benefits and implications: the adoption of smart contracts. These are purely digital contracts that can mimic the terms and conditions of traditional contract, but they are enforced by computer code and can self-execute. Concept as micro-transaction will also have a great influence on how the supply chain could be reorganised around blockchain.

A survey on the BIM Maturity and awareness of new technologies was also undertaken to have a better overview, results are published in the first section of this paper.

It is fair to say that blockchain and smart contracts are clearly here to stay and will doubtless have a major impact in the construction industry.

Will the construction industry benefit from these technologies? And how? How will the entire supply chain react to the adoption of these technologies? How can BIM, blockchain and smart contracts interact?

The adoption and the validity of these emerging technologies will be evaluated taking as reference real processes in the construction industry and reanalysing them through *Use Cases* together with BIM methodology, blockchain and smart contracts trying to give an exhaustive answer to the questions above.

"Bitcoin is a remarkable cryptographic achievement and the ability to create something that is not duplicable in the digital world has enormous value"

—Erich Schmidt, Former CEO, Google

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[5] *[..] a **use case** is a list of actions or event steps typically defining the interactions between a role [..] and a system to achieve a goal. Source: Wikipedia*

[6] ***Emerging technologies** are technologies whose development, practical applications, or both are still largely unrealized, such that they are figuratively emerging into prominence from a background of nonexistence or obscurity. These technologies are generally new but also include older technologies that are still controversial and relatively undeveloped in potential [..]. Emerging technologies are often perceived as capable of changing the status quo. Source: Wikipedia*

Introduction

The first ever blockchain was introduced beside bitcoin[7]. The cryptocurrency had the intention to be an alternative to the existing financial system and it was structured to allow transfer of ownership of anything of value, by tying the rights to an asset to a unit of digital currency.

Ledger system that record debits and credits have been used in Italy and date to 13th century. Older forms of ledgers, recording assets or ownership, go back to classical Greece and Rome until the ancient Mesopotamia[8]. The grow in complexity and in volume of transactions, made it more efficient to centralise the ledgers of these transactions in the hand of intermediaries, a trusted third party.

In all this time the only notable innovation has been computerisation. Now, for the very first time a technology could disrupt the scheme, bringing properties and capabilities that go far beyond traditional paper-based ledgers.

A distributed ledger is essentially an asset database that can be shared across a network, all the participants within a network own an identical copy of the ledger and all the changes are reflected throughout the copies in a short while. The security and accuracy of the assets stored in the ledger are maintained cryptographically using "keys" and signature to control who has access and the right to modify the entries; this is made possible using blockchain technology.

One interesting application of blockchain are smart contracts. Such agreements which may be concluded between two or more individuals are based on a peer to peer (P2P), person to organisation (P2O) or person to machine (P2M). Smart contracts run on a blockchain environment and make it possible to automatically execute a contract after conditions are met (e.g. if-then principle) without third parties being involved in the transaction, they are then replicated and validated on a Blockchain.

This new approach opens the possibility to rethink the entire legal and management system based on the intermediaries acting in the agreement processes leading to a new form of self-executing virtual agreements.

To validate the effectiveness of new technologies it is meaningful to simulate the potential adoption analysing a *Use case*; an existing process is then investigated applying the emerging technology. This operation allows to validate the new approach and to reach significant conclusions for a future and possible use.

[7] *https://bitcoin.org/bitcoin.pdf*

[8] *Lee, Geoffrey. "The Oldest European Account Book: A Florentine Ledger of 1211". Nottingham Mediaeval Studies 16 (60):28-60*

Emerging technologies

The path to innovation developments is driven by a hype cycle initiated by a very high expectation. It is all mainly based on the fact that the technology can solve human problems in a more efficient manner offering social and economic added value. According to Deloitte Switzerland [9] this process includes three-phase maturity processes: *Early development*, *Standardisation Phase* and a *Value Creation Phase.* The first expectation phase is converted into a realistic development at the early stages. Later a business prototype tries to give a solution to the supply and demand interaction and evaluates the proposal that could generate added value. The final phase sees the application of the new technologies and significant benefits with its adoption.

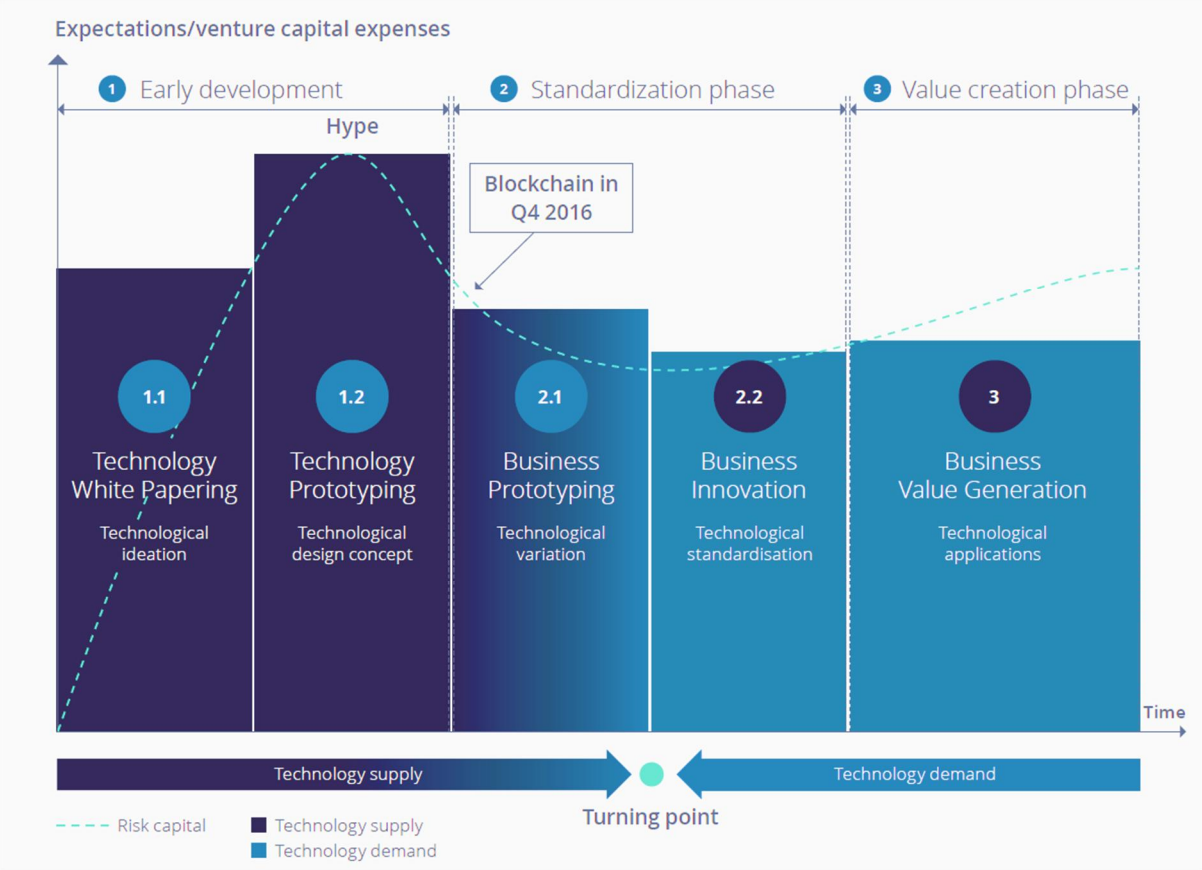


Figure 1: Technology-driven business innovation model. Source: Deloitte Switzerland Blockchain Team

Another similar analysis is also given by other organisations. According to Gartner, blockchain is an emerging technology that in their graphical representation it is currently facing the *Peak of Inflated Expectations* phase. This phase is characterised by a number of success stories accompanied by scores of failures.[10] That phase precedes the *Trough of Disillusionment* period where the interest wanes as most experiments and implementations fail to deliver.[11]

[9] *https://www2.deloitte.com/ch/en.html*
[10] *Source: Wikipedia*
[11] *Source: Wikipedia*

An earlier phase called *Innovation Trigger* is also defined for the processes when an emerging technology spreads out. It is an initial phase where the potential technology kicks off with proof-of-concept stories and media and social-media make significant publicity.[12]

After the technology has been tested for some applications and results are promising two later phases close the Hype Cycle: *Slope of Enlightenment* and finally, for a consolidated technology, the *Plateau of Productivity* describes the final phase.

The same researcher identifies Blockchain, the related smart contracts technologies and the concept of Digital Twin[13], more inherent to the construction industry, as two of the top ten strategic technology trend for 2019. (Figure 3)

At the time of writing, it is not clear how long will these phases last, due also to the technology's complexity. The construction industry, always criticised for being slow to embrace the change, has been already invested by many radical changes that will undoubtedly require some time to be catalysed.

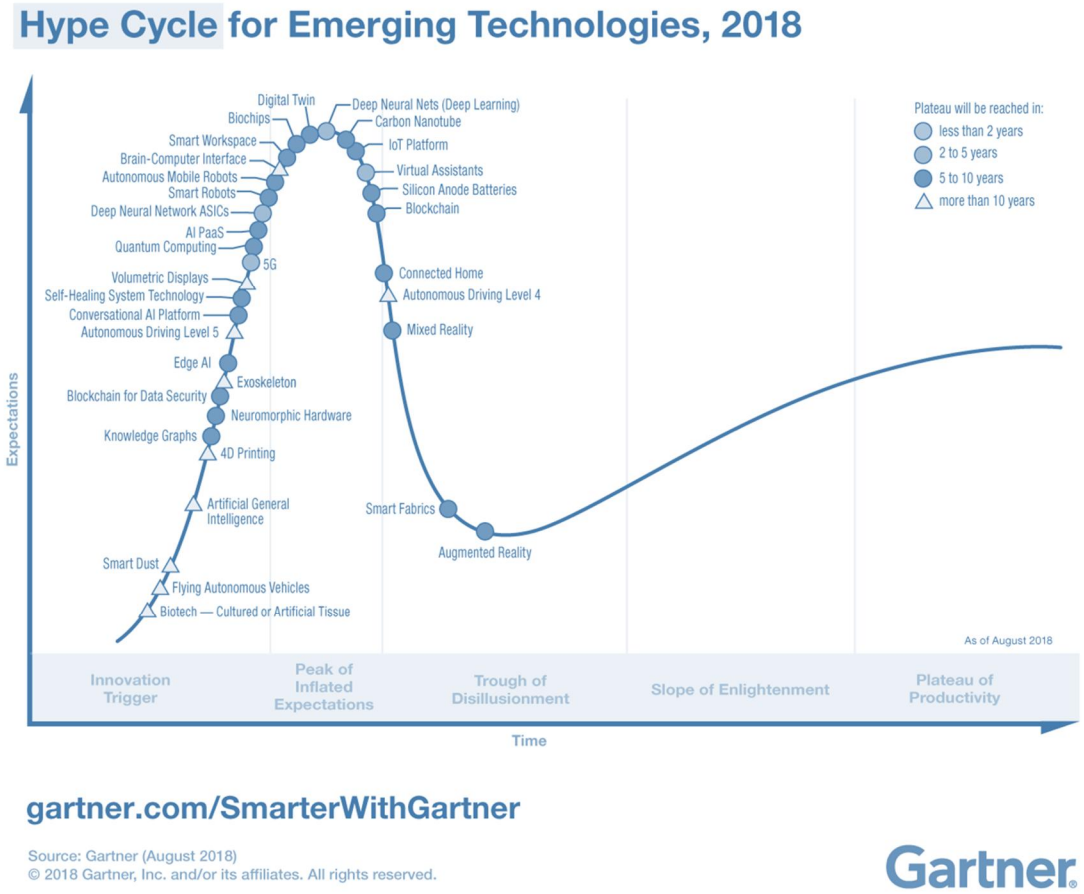


Figure 2: Hype Cycle for Emerging Technologies

[12] *Source: Wikipedia*

[13] *A **digital twin** is a digital replica of a living or non-living physical entity. [..] Source: Wikipedia*

Figure 3: Top 10 Strategic Technology Trends for 2019. Source: Gartner

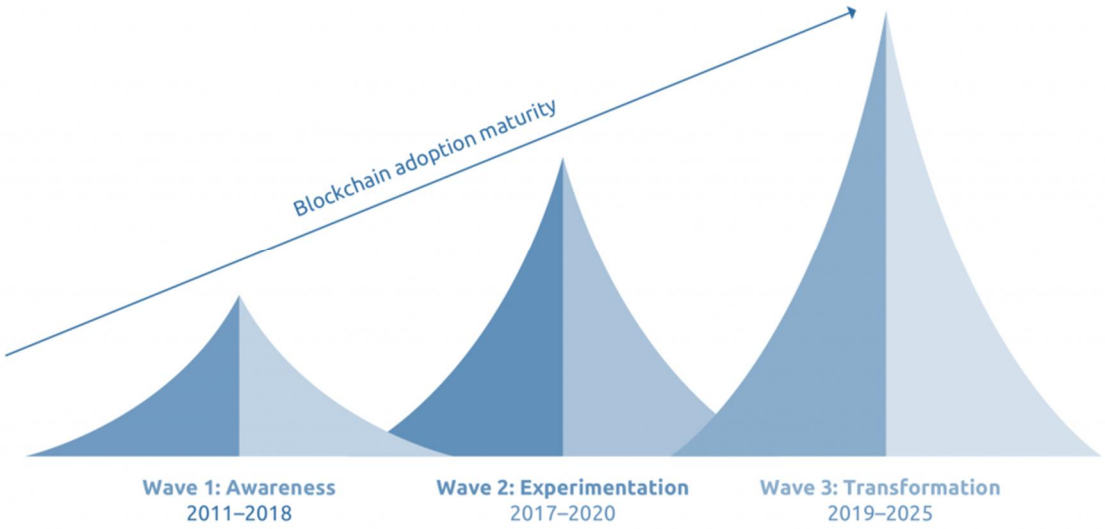


Figure 4: Blockchain adoption maturity. Source: Capgemini and Swinburne University of Technology

Survey /ˈsɜː.veɪ/

Survey

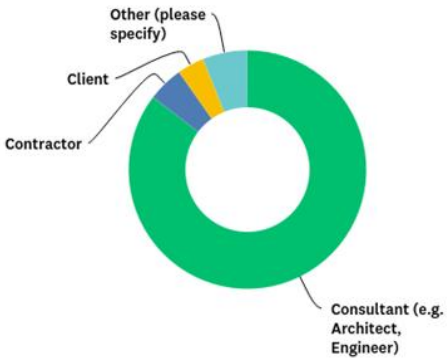
Before approaching the complex theme of blockchain and its potential adoption in the construction industry, I will present the Survey results of the starting point of this work. The aim was collecting significant Data to better understand how the new technologies are conquering the Building Sector and to have an overview on BIM Maturity and interests on new technologies.

The survey consisted of 20 questions and the time required to be complete was circa 3 minutes. It was published on my LinkedIn profile and directed emailed to a list of contacts.

In the following pages the result of the survey.

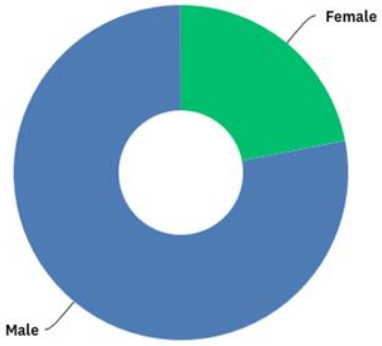
Q1: Which of the following best describes your organisation's role in the construction industry?

Answered: 82 Skipped: 0



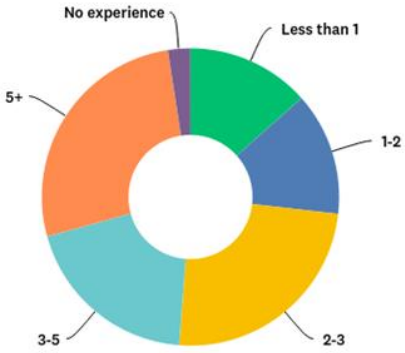
Q2: What is your gender?

Answered: 82 Skipped: 0



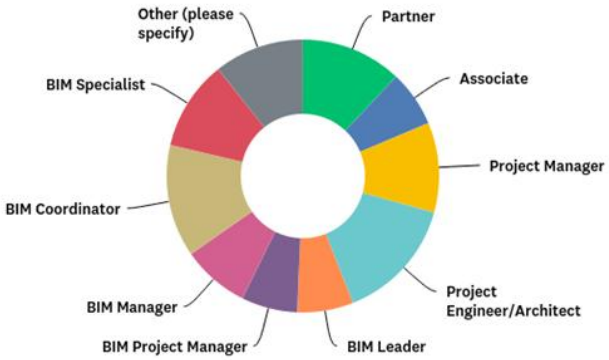
Q3: How many years of experience do you have in BIM (Building Information Modelling)?

Answered: 82 Skipped: 0



Q4: Which is your role within your organisation?

Answered: 75 Skipped: 7

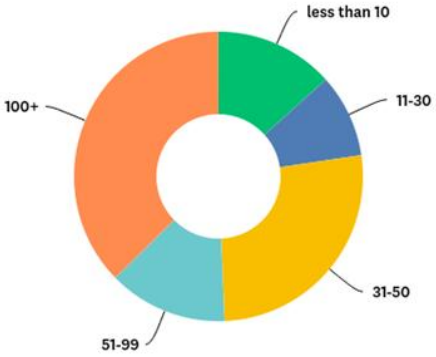


Q5: Is your organisation public or private?

Answered: 75 Skipped: 7

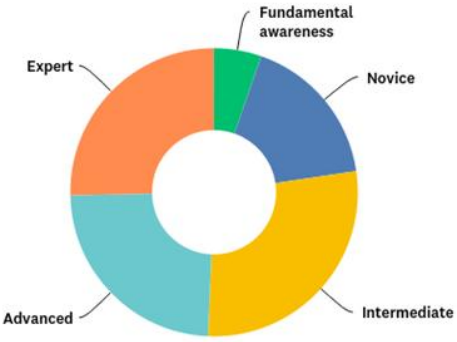
Q6: How many people work for your organisation?

Answered: 75 Skipped: 7



Q7: Which of the following best describes your organisation BIM Maturity?

Answered: 75 Skipped: 7

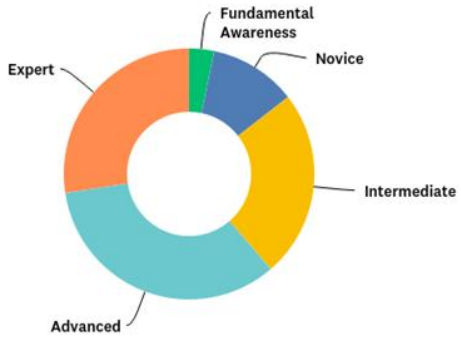


Q8: Does your company have a person responsible for BIM technologies and Digitalisation Process?

Answered: 75 Skipped: 7

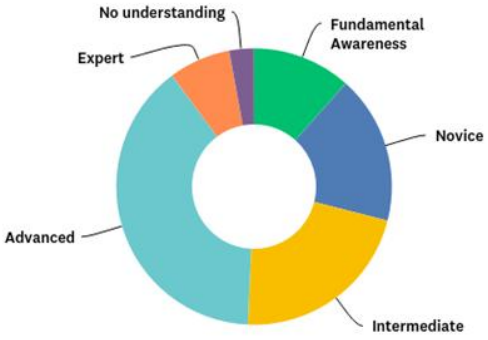
Q9: How would you describe their knowledge relating to BIM processes, software and technologies?

Answered: 62 Skipped: 20



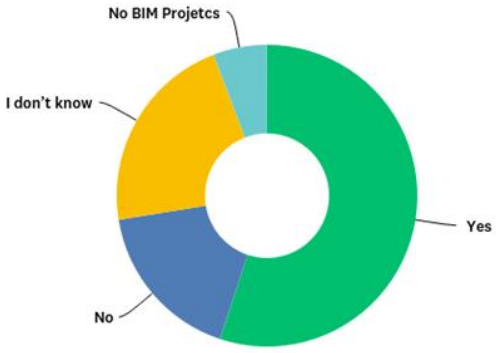
Q10: How would you describe your understanding and use of IFC (Industry Foundation Classes) format?

Answered: 69 Skipped: 13



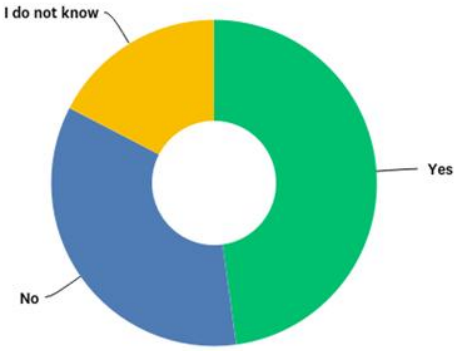
Q11: Are the BIM services your organisation is offering regulated by a contract?

Answered: 69 Skipped: 13



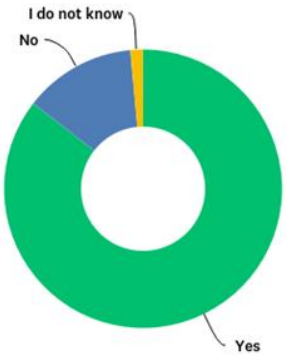
Q12: Do you have concerns about Intellectual Property related to BIM methodologies?

Answered: 69 Skipped: 13



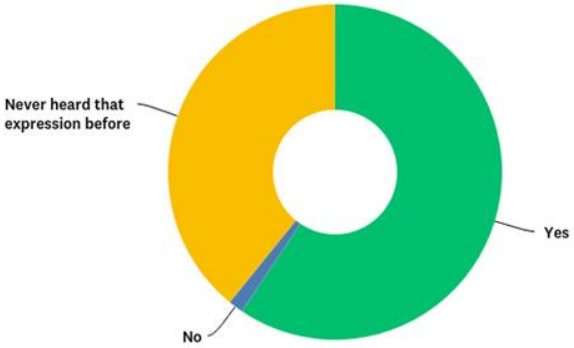
Q13: Does anybody within your company have a good understanding about coding and programming?

Answered: 69 Skipped: 13



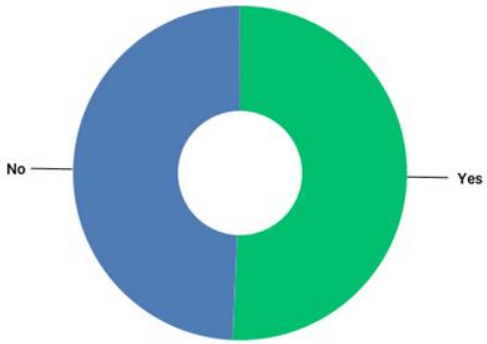
Q14: Do you think a "Digital Twin" is something achievable in the Construction Industry?

Answered: 69 Skipped: 13



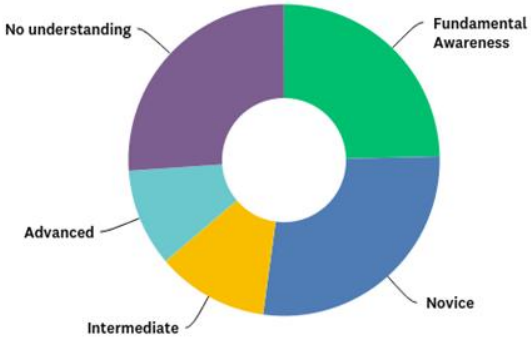
Q15: Have you already heard about Blockchain applications in the construction industry?

Answered: 69 Skipped: 13



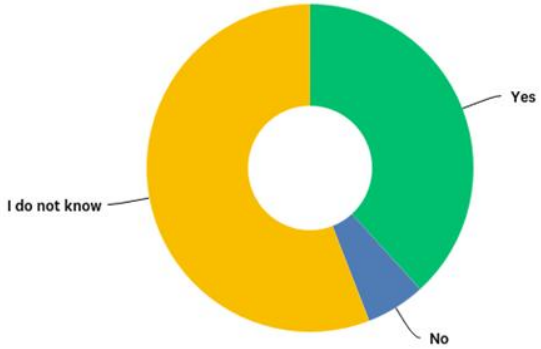
Q16: How would you describe your understanding about Blockchain?

Answered: 69 Skipped: 13



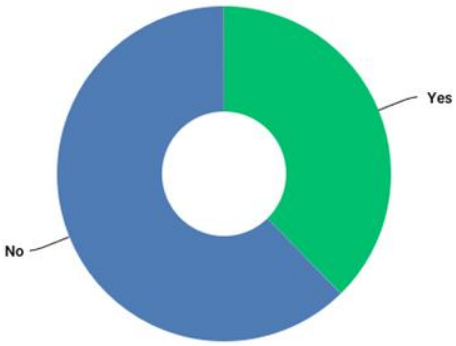
Q17: Do you think Blockchain could address the "Trust" issues in the construction industry?

Answered: 68 Skipped: 14



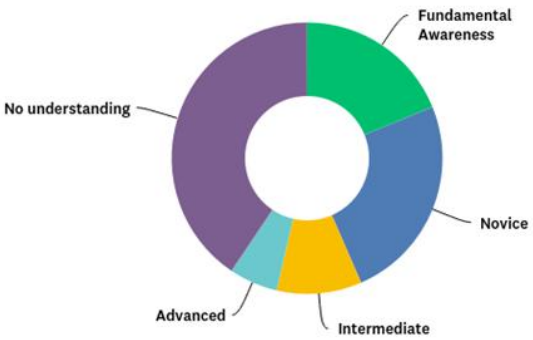
Q18: Have you already heard about Smart Contracts applications in the construction industry?

Answered: 69 Skipped: 13



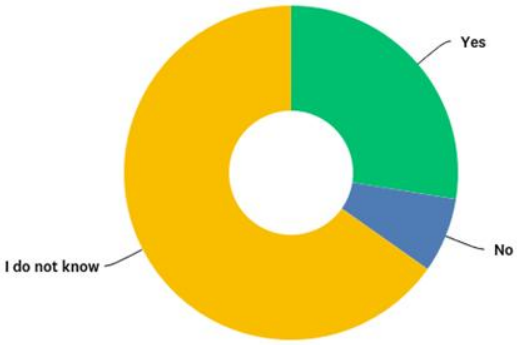
Q19: How would you describe your understanding about Smart Contracts?

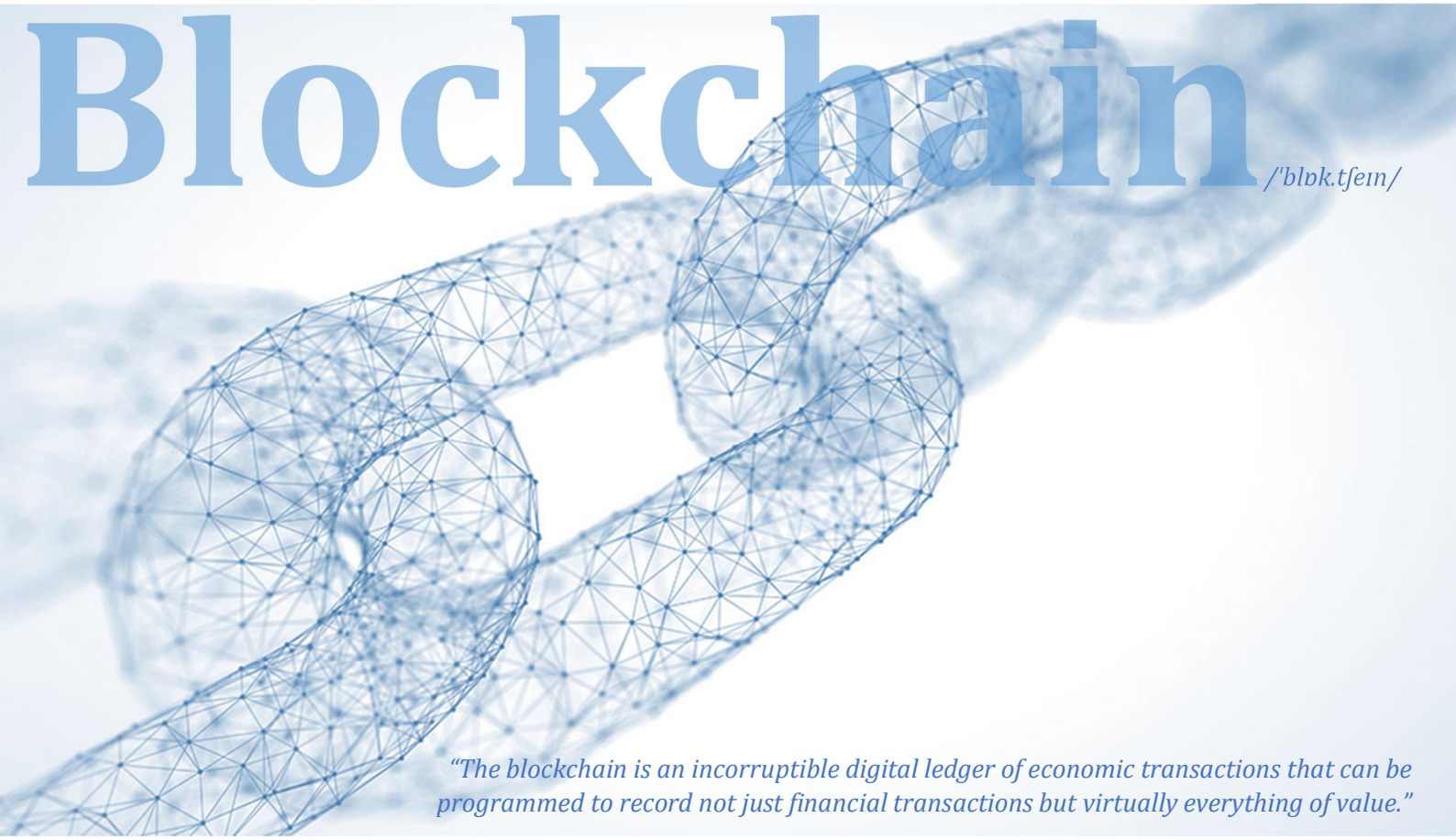
Answered: 69 Skipped: 13



Q20: Do you think Smart Contracts could address the legal issues arising in the construction industry?

Answered: 69 Skipped: 13




Blockchain
/'blɒk.tʃeɪn/
"The blockchain is an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value."
– Don & Alex Tapscott

Blockchain

History of Blockchain

Blockchain was invented by Satoshi Nakamoto – whose real identity remains a mystery to this day – to serve as the public transaction ledger of the cryptocurrency bitcoin ( ). The invention of the blockchain for bitcoin made it the first digital currency to solve the double-spending problem without the need of a trusted authority or central server.

Although the first work on a cryptographically secured chain of blocks started 1991 by pioneers of the industry, Stuart Haber and W. Scott Stornetta and continued throughout the mid 2000's. The first blockchain was conceptualized by Satoshi Nakamoto in 2008, which was later implemented as a core component of Bitcoin.

The creation of Bitcoin in 2009 by Satoshi Nakamoto can be viewed as a pivotal moment in the evolution of digital currency. Although revolutionary, because it was the first decentralised cryptocurrency, Bitcoin's most substantial contribution to the world is that it brought to the mainstream concepts like blockchain and smart contracts.

A cryptocurrency is basically a currency which, rather than being issued and controlled by a central bank, such as US dollars or British pounds, uses an encrypted, mathematical blockchain model, as described below, to track exchange of value and ownership. Since then, thousands of other cryptocurrencies based on the same principle have emerged and the bitcoin design has also inspired other applications using the technology's benefits.

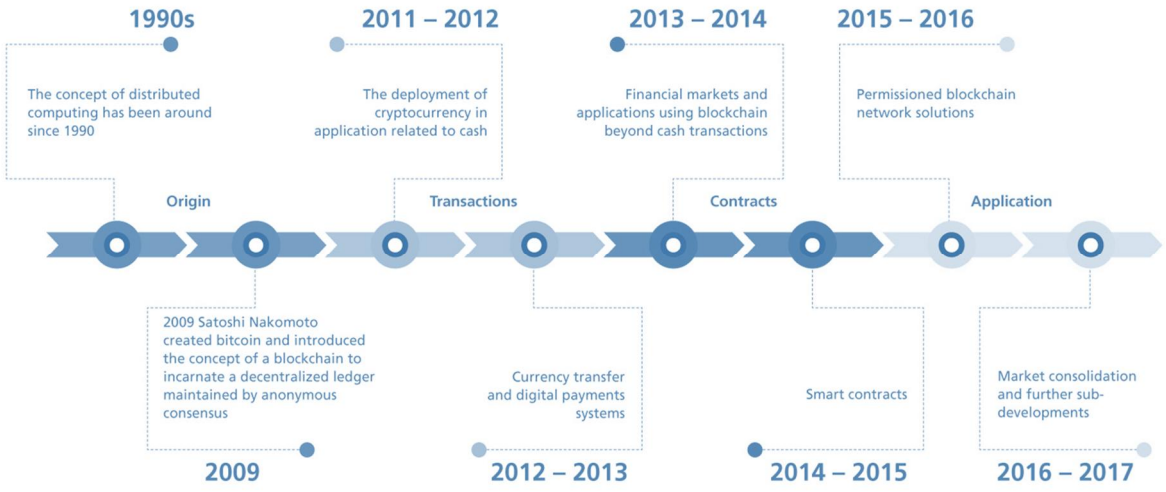


Figure 5: Blockchain History. Source: Accenture

What is blockchain technology?

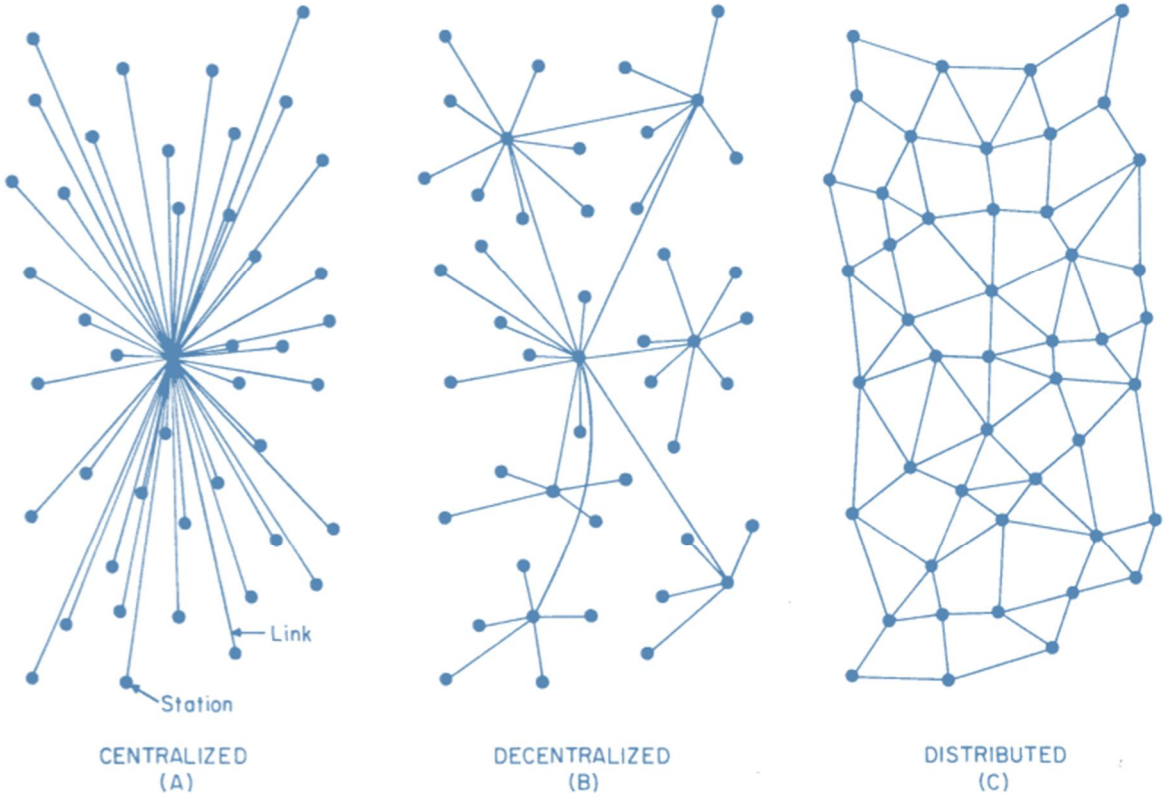
A blockchain is a decentralised, distributed und immutable database on a peer-to-peer (P2P)[14] network in which a block, containing a certain number of records, is chained chronologically to a previous one using a cryptographic signature.

Blockchain definitions slightly vary among all sort of documentation and online sources, it is then important to focus on the fundamental main properties which have helped it widely to spread.

The technology allows to register secure transaction with a timestamp between two parties on a digital decentralised ledger without intermediary authorities being involved. The ledger is then distributed across the network in identical copies and the verification process comes from the consensus of multiple users. It also possible to set rules for a single transaction in contrast with the conventional database, which rules are often set at the entire database level.

The technology solved for the very first time the double-spending problem leading to concepts of Internet of Value (IOV) and Single Source of Truth. (SSOT)

Like the Internet reinvented communication, blockchain may similarly disrupt transactions, contracts, and trust — the underpinnings of business, government, and society[15].



[14] Peer-to-peer (P2P) computing or networking is a distributed application architecture that partitions tasks or workloads between peers. Peers are equally privileged, equipotent participants in the application. They are said to form a peer-to-peer network of nodes.

[15] *Deloitte University Press, Tech Trends 2016: Innovating in the digital era*

Properties of blockchain technology

Decentralisation

One of the most exciting aspects of blockchain technology is that it is entirely decentralised[16], rather than stored in one central point. This removes the need for powerful central authorities and instead hands control back to the individual user. This means that no one person, or entity such as a corporation or government, has control over the content of the file. Blockchain applications could replace centralised systems with decentralised ones, where verification comes from the consensus of multiple users

Distribution

A blockchain is *duplicated* in its entirety across many computers, each one has a record of all the transactions, even those that happened in the past.

Identical versions are stored on each computer connected to the network and changes are only possible if there is a consensus between the majority of participants. Access is through cryptography and public/private keys regulated.

Rules can be built into each transaction to create automatic responses to agreements or contracts. There are no administrator permissions within a Blockchain that allow editing or deleting of data.

Immutability

The immutably is critical to the functioning of any blockchain and is what differentiates them from a traditional database. It is designed to store information in a way that makes it virtually impossible to add, remove or change data without being detected by other users. In a database, data can be easily modified or deleted. However, in the case of blockchain, modifying or deleting data is almost impossible. In fact, unalterable data entries are one of the defining features of the blockchain.

Transparency

Blockchain technology includes mechanisms to ensure stored records are accurate, tamper-evident, and from a verifiable source. Thus, instead of multiple parties maintaining (and altering) copies of their own dataset, now every stakeholder receives controlled access to a shared dataset creating a single source of truth. This gives confidence to everyone working with this data that they're using the most recent, accurate, and reliable dataset.

Those peculiarities allow the blockchain to be more than a simple Database and introduce the concept of Trust in the digital ledgers helping to lay the foundations for what it thought to be the internet of value and the concept of single source of Truth.

Security

Blockchain is designed to store information in a way that makes it virtually impossible to add, remove or change data without being detected by other users.

[16] Decentralised and not distributed ledgers maintain a local level authority to control the transactions.

Blockchain Core Components

Node is a user or computer within the blockchain

Transaction is the smallest building block of a blockchain system

Block is a data structure used for keeping a set of transactions which is distributed to all nodes in the network

Ledger a database of records on a network

Chain is a sequence of blocks in a specific order

Miners are specific nodes which perform the block verification process

Blockchain Terminology

Consensus is the status of the network where all (or a majority) of participants agree on the current status of the ledger.

Digital currency (cryptocurrency) has two meanings: 1. A native token of a blockchain that is required for all types of transactions processed by the blockchain. 2. A specific use-case of blockchains where the native token is assigned market value and used as a medium of exchange or storage of value.

Distributed ledger technology *(DLT)* is the concept of spreading and splitting a ledger of transactions across multiple instances that precedes the concept of blockchain technology but does not have the same emphasis on the decentralisation of control and risk.

Initial coin offerings *(ICO)* are a use-case of blockchain technology that allow entrepreneurs to attract investment to fund projects. This is often done by selling blockchain tokens for digital currency prior to the launch of an actual product. Due to the nature of blockchains and digital currencies, this is a high-risk investment often with no product delivery after the end of the funding round.

Mining is a mechanism to ensure the validity and security of the transaction stored on the blockchain. Miners are awarded with a defined amount of native blockchain tokens when valid transactions are added to the ledger.

Peer-to-peer *(P2P)* is a network with equal user rights across the network nodes and when cryptocurrency is sent directly from one user to another with no intermediary.

Permissioned blockchain relates to a set of permissions that can be applied to specific network participants, such as the right to read, write or delete data on a blockchain. This allows for administrative control while remaining decentralised.

Private blockchain means access must be granted to join the network.

Proof of authority *(PoA)* is a security mechanism that is validated by approved accounts, known as validators.

Proof of stake *(PoS)* is a security mechanism that incentivises users of the blockchain to write only valid transactions to the blockchain by awarding the participants with new tokens for each

valid block they find. This system would result in the loss of the award if the participant acts dishonestly and risks the value of their stake in the system.

Proof of work *(PoW)* is a security mechanism that incentivises users of the blockchain to write only valid transactions to the blockchain by awarding the participants with new tokens for each valid block they find. This system would result in the loss of the award if the participant acts dishonestly and are not compensated for the computational work they have provided to the network.

Public blockchain (or open) relates to the archetype of blockchains that aim at the highest possible degree of decentralisation by allowing every individual to act as a node in the network.

Smart contracts are computer programs or functions run by the decentralised blockchain network and whose outcome directly triggers transactions on the blockchain.

How does it work?

A blockchain is a sequence of blocks which archives validated transaction using the network consensus. Every single block contains a hash function[17] that identifies uniquely the block and its content allowing it to be chained and Timestamped to a previous identified block.

The picture below explains graphically what happens in a blockchain transaction.

A transaction is requested and a block containing the information about the transaction is created. The block is sent to the network and reaches all the nodes. Computational power is then at this point used to find the solution to a mathematical problem that will generate a checked, validated and cryptographed block. The network accepts the solution through the consensus process and the Proof of Work is reworded. The block is then added to the previous one with its unique hash ID. The transaction is completed and a record on the blockchain is now stored.

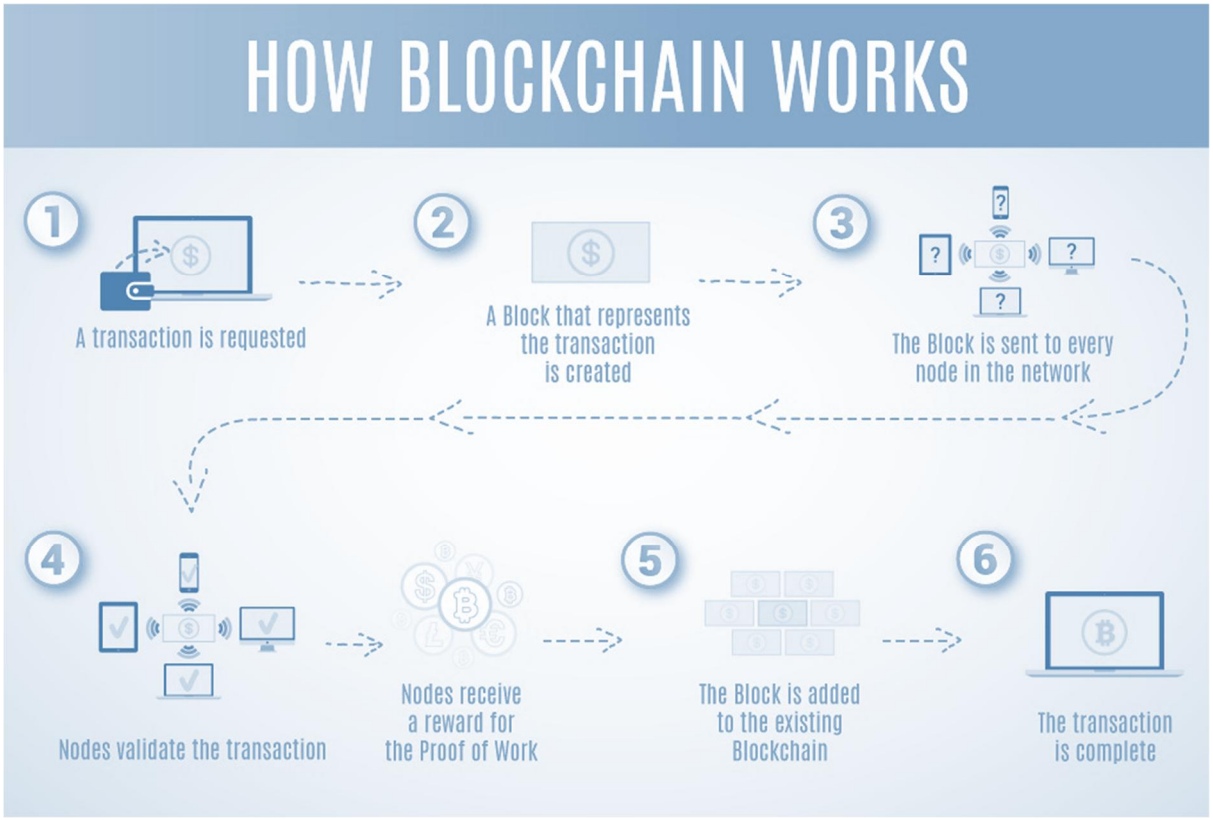


Figure 6: Source Medium

Digital Record

At its heart, a blockchain is a record of transactions, like a traditional ledger. These transactions can be any movement of money, goods or secure data.

[17] A hash function is any function that can be used to map data of arbitrary size onto data of a fixed size. The values returned by a hash function are called hash values, hash codes, digests, or simply hashes. Source: Wikipedia.

Asymmetric Encryption

One of the most important mechanism used in blockchain technology is asymmetric or Public Key cryptography. That allows to encrypt Data without the need to share it, keeping its integrity. In a blockchain, the public key is represented by a public address, which can be shared with anyone but only the owner of the corresponding private key can access the asset.

Hashing

Hashing has truly been fundamental in the creation of blockchain technology. In simple terms, hashing means taking an input string of any length and giving out an output of a fixed length.

To give an example the title of this thesis *New Technologies in the Construction Industry: Blockchain and Smart Contracts* run through the SHA-256 (Secure Hashing Algorithm 256) hash function results in the code:

0168b002dbb4f3e99ac9decd9a4cb126593ff130853b99c06d30d47ed77ade8c

Just adding a space at the end of the sentence will result in the code to change in:

0133bebeadca2fc9625a623396e1b9de7de02871645b39365b6242325a6c8517

This shows how the output is always a random 64-character text string even though a simple space was added and that one cannot reconstruct the input data by looking at the hashed-out data. Even though this is theoretically possible, it results impossible to achieve due to the amount of effort – computing power-required to reverse such hash.

Consensus mechanism

There are several ways a blockchain network could reach consensus on the validity of transactions in the digital ledger. The process of mining is central to reach a consensus and it carries out two functions: (a) It validates and adds transactions to the blockchain securely, (b) It generates and issues the network's native token, which also functions as a reward for securing the network.

The nodes of a mesh network are all the participants who run a full node on their device. They are able to validate the transactions by checking the current state of the blockchain ledger against the local copy on their hard drive. If the transaction is deemed valid the nodes broadcasts the transaction to the network. Some nodes on the network are "miners" and not only validate the transaction and relay them to the network but also assemble the valid transactions into blocks and permanently write them into the constantly growing ledger – the blockchain.

Miners must expend computing power to perform hash functions and generate a unique code for each block following the protocol that defines the blockchain rules. The idea behind this complex task is that it is a time consuming and costly endeavour for the participants. The rewarding mechanism incentives honest participants to perform this task - after the validation process, they are entitled to claim the reward - and will rejects the blocks from dishonest miners - they will not be able to receive a reward, their blocks won't be validated. This process is called Proof of Work (PoW) because computing power is required to find a specific hash, suppling the hash code proves that a certain amount of work has been done. Consensus can also be achieved with another kind of algorithm called Proof of Stake (PoS); the node which is allowed to add the next block is randomly chosen among the network nodes and their stake are evaluated (i.e. network reward token) for undertaking the task.

Proof of Work vs Proof of Stake

In order to add data to the blockchain, it needs to be validated and accepted by the network. Validating the data is done using cryptography and via consensus, meaning that 50% +1 of the network need to agree. There are two ways to achieve this consensus, being Proof of Work and Proof of Stake.

Proof of Work Consensus Algorithm

Proof of Work it refers to participating users (or nodes) solving difficult mathematical problems to validate the blocks. The node that publishes the solution first, 'wins' and receives a token as a reward. The mathematical problem works like a crossword puzzle; it is difficult to solve, but once it is completed, you instantly know if it is correct. Once accepted by the majority of the network, all the nodes in the network will start working on the next block, thereby repeating the process.

The disadvantage of Proof of Work is its inefficiency in terms of computing power. It requires real-world resources to validate transactions and it requires a lot of it. However, this is also what makes the blockchain immutable, as it requires a tremendous amount of computing power (a.k.a. as money), meaning 51% of all resources in the Blockchain, to alter transactions.

Proof of Stake Consensus Algorithm

Proof of Stake solves a major problem of the Proof of Work consensus algorithm, which is the computing power that is required to keep the Blockchain working. The most important difference is that with a Proof of Stake consensus algorithm, the amount of computing power is not the requirement for validation, but the amount of stake owned. In order to validate, 51% of the digital currency in the network needs to agree on the current state. As a result, the more digital token a node owns, the higher the stake in the success of the blockchain. The rationale is quite simple; the higher the stake in the system, the higher the incentive to maintain a secure network, because of the pain felt when the reputation and price of the token is damaged due to attacks.

As a result, Proof of Stake requires significant less energy and can be seen as a greener option. The problem, however, with Proof of Stake is, that it becomes easier for a small group of people owning a majority in the token, to alter the blockchain.

Trust

Trust is a foundational element of business and an integral part of any dealings between two or more parties. Intermediaries are often currently involved and responsible for *Trust* aspect. The events linked with the last financial crisis, the volume and the complexity of the transactions in general are now questioning this approach describing also as time-consuming costly and thus inefficient[18]. The adoption of Blockchain technology represent a promising alternative to the current organisation and technical infrastructure, one that is needed to rebuild the trust between organisations, companies and private individuals.

[18] *Deloitte 2017: "The Blockchain (R)evolution - The Swiss Perspective" White Paper*

Distributed Ledger technology (DLT)

Distributed ledger technology (DLT) is a database of records that is not stored or confirmed by any central body. In DLT, the implementer has greater control over how it is in fact implemented. They could, in principle, dictate the structure, purpose, and functioning of the network that underpins its service. That said, DLT is technologically decentralised and relies on similar principles of consensus to blockchain. But, an instance where one body has control over that supposed decentralised network, by principle, is not decentralised – from an ideological point of view at least.

A DLT can be considered a first step towards a blockchain, but importantly it will not necessarily construct a chain of blocks. Rather, the ledger in question will be stored across many servers, which then communicate to ensure the most accurate and up to date record of transactions is maintained.

Blockchain is in fact a form of distributed ledger with a very specific technological underpinning. As we all know, it is one that creates an unchangeable ledger of records that is maintained by a decentralised network, where all records are approved by consensus. Cryptographic signing and linking groups of records in the ledger, to form a chain is what sets blockchain apart from DLT.

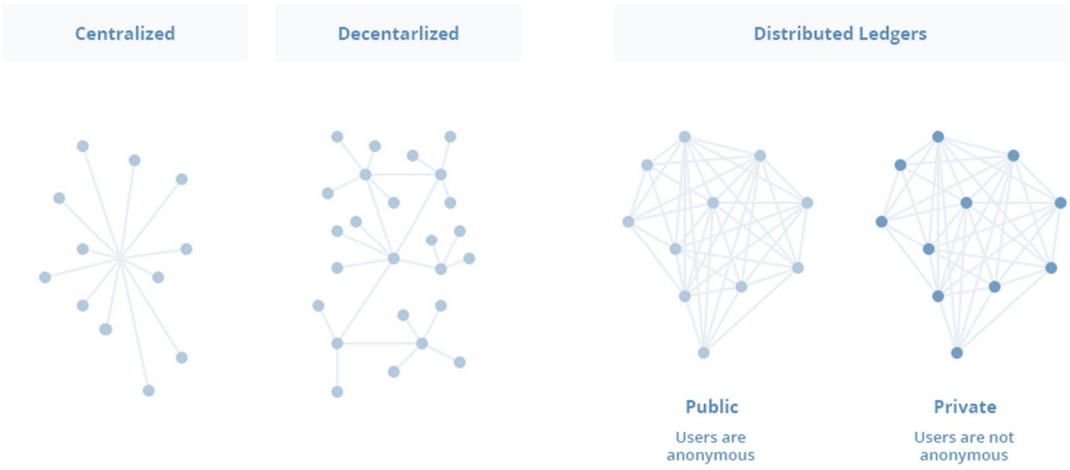


Figure 7: Centralised, Decentralised and Distributed Ledgers architecture. Source: MLSdev

Permissionless Ledger and Permissioned Ledger

Permissionless Ledger (public blockchain) are not centrally controlled by any authority and are based on the concept of digital *Trust* through *Consensus*. A Permissionless blockchain offers open invitation to all participants to join the network and all the members have the right to perform all the actions, including adding and validating transactions, having an identical copy of the ledger, smart contracts, and much more. Bitcoin[19] is the classical example. Anyone interested to join the

[19] Bitcoin ( ) is a cryptocurrency, a form of electronic cash. It is a decentralised digital currency without a central bank or single administrator that can be sent from user to user on the peer-to-peer bitcoin network without the need for intermediaries.[7] Transactions are verified by network nodes through cryptography and recorded in a public distributed ledger called a blockchain. Bitcoin was invented by an unknown person or group of people using the name, Satoshi Nakamoto,[9] and released as open-source

bitcoin blockchain, can do so by simply hooking-up their computer to the decentralised Blockchain network, download the Blockchain and contribute to the processing of transactions. It is not required to have a previous relationship with the ledger, and you do not need to be approved to join. A Permissionless Ledger is not owned by anyone and everyone can contribute.

Permissioned Ledger (private blockchain) are more suitable for specific uses. They introduce some limitations in comparison with the previous one and the blockchain Governance for the ledger. For their nature they are built on a private network and the need to be strongly protected from external access and attacks. This means that only those that are identified and approved by the Blockchain network, can join the Blockchain and start processing transactions. A private Blockchain is commonly used by a group of companies that want to keep a shared ledger, like for example financial institutions. These Blockchains are owned by an organisation or a group of organisations and you must be approved if you wish to join. All the participants must be trusted, authorised and have different operational rights. A protocol of governance is required, the control is back to a control authority. A permissioned blockchain, like a centralised database, can be both write and read-controlled. But, if confidentiality is the only goal, blockchains have no advantage over centralised databases.

The difference between Permissionless and Permissioned Ledger is basically the different type of permission to participate in the network, execute the consensus mechanism and access the shared ledger.

There are some similarities. Both ledgers are unalterable digitally signed, distributed through peer-to-peer network, updated through a protocol named as consensus and both claim to maintain an immutable ledger.

A combination of both (Consortium blockchain) is also possible: the access is limited to a group of authorised participants and the consensus is obtain like to the public ledger.

Property	Public blockchain	Consortium blockchain	Private blockchain
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Could be public or restricted	Could be public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

Figure 8: Blockchain Properties

software in 2009.[10] Bitcoins are created as a reward for a process known as mining. They can be exchanged for other currencies, products, and services. Source: Wikipedia

Pros of a Private Blockchain

- In a private blockchain, the validation is carried out by the network creator and therefore no miners are hoping to profit on network facilitation. As a result, there are very low fees or no fees at all.
- When a consensus mechanism is centralised, it is much faster, and unnecessary altogether. The network nodes do not need to agree with each other when they are all owned by the same entity. Instead of waiting for a network consensus, information can be recorded immediately. That is not so different from a database.
- The owner of the network can control who is able to record information and to whom the recorded information is visible.

Cons of a Private Blockchain

- The blockchain can be manipulated since it is centralised. The 51% attack, mentioned earlier, illustrates this exact issue. When someone owns the majority hashing power of a blockchain network, they can rewrite the data within it, and therefore the information is not immutable or secure.
- Blockchains are far more complicated and expensive to maintain than a traditional database.
- In order to run a blockchain, a business needs to employ distributed validation nodes that will constantly validate data, incurring electricity and hardware costs along the way.
- There is always a point of failure in a centralised system. If the company maintaining the blockchain loses power, the blockchain shuts down.

Database vs Blockchain

A database often uses a client-server network architecture. There are database administrators who may make changes to any part of the data and its structure at any given point in time. Administrators are the central authority that maintains control of the database and they are the ones who decide who else gets access and permissions.

Centralised databases record present information only. They do not trace information that was previously recorded. With blockchains, the case is different. They not only keep information that is relevant in real time but also can trace back information of transactions that have come before. Blockchains can create databases that have histories of themselves, i.e., they grow like ever-expanding archives of their own history.

Blockchain itself is a database in the form of digital ledger. It combines the Internet and cryptography to cater information registration and distribution, thus, eliminating the need for a trusted party. Records are arranged in 'blocks' of data and each block is connected to the previous one by a hashing function. It forms a chain of blocks that cannot be changed.

In a database, data can be easily modified or deleted. However, in the case of blockchain, modifying or deleting data is almost impossible. In fact, unalterable data entries is one of the defining features of the blockchain.

Blockchain has a write-only data structure. Every new block gets appended to the blockchain by linking to the previous block's 'hash'. There are no administrator permissions within a Blockchain that allow editing or deleting of data. This hash includes the Merkle root [20] hash of all the transactions in the previous block.

If a single transaction were to change, not only would the Merkle root hash change but so would the hash in the changed block. In addition, each subsequent block would need to be updated to reflect this change. This means that each user maintains, calculates and updates new entries into the database. All nodes work together to ensure they are all coming to the same conclusions.

This feature makes blockchain immutable and provides in-built security.

In a database, an intermediary maintains a private database of records. However, blockchain technology makes all records public. Effectively killing the need for a middleman. Since a complete copy of the chain with every transaction is held by the entire network, everyone can access that information.

While this means that if someone attempts to cheat the system or steal, they can be easily identified, blockchain may not be suitable for those who prioritise confidentiality.

In a competitive marketplace, businesses will prefer the privacy of a centralised database, rather than reveal their activities to each other. Particularly, if a trusted central party already exists and can provide the neutral territory in which that database can reside. It all comes down to what the priorities for your business are.

Blockchain removes a lot of the complexity of setting up your own distributed database. This, in turn, helps cut down costs drastically since you will not be the only one paying for electricity and

[20] A Merkle root is the hash of all the hashes of all the transactions that are part of a block in a blockchain network.

computer, everyone that is connected to the network would be too. If you are on a budget, then blockchain might be your preferred digital ledger.

While blockchains are used as systems of records and are ideal as transaction platforms, they are considered slow as databases when considered for digital transaction technology. There will certainly be improvements to the performance and nature of blockchain technology, no doubt, but databases are offering the same anyway. They have been around for decades and have witnessed their performance surge in multi-folds.

The right choice out of the two would depend on your business use case and preferences. If you want to do something within your network with your data and with computers that you control, then databases are more suitable. On the other hand, if you need a setup where the data is highly available, but you are not the only one paying for it, would not need to modify past data, need it to be immutable, and publicly accessible then blockchain is a better choice. It will also provide more transparency and reliability.

On the following pages graphical representation will help to better understand the main differences between the two kind of technology and when to use them.

Do we even need a Blockchain?

How to determine a real blockchain use case.

Before embarking on a blockchain project, it is important to have a very clear idea of why using a blockchain. There are conditions to be taken on board and that need to be fulfilled.

1. The database

Blockchain is a technology for *shared databases*. Storing data is a peculiar aspect of the project.

2. Multiple writers

Blockchain is a technology for databases with *multiple writers*. In other words, there needs to be more than one entity which is generating the transactions that modify the database.

3. Absence of trust

If multiple entities are writing to the database, there also needs to be some degree of *mistrust* between those entities. In other words, blockchain is a technology for databases with multiple *non-trusting writers*. Mistrust not only arises between separate organizations, such as companies involved in a supply chain, but it can also exist *within a single large organization*; for example between departments or the operations in different countries, perhaps when one user is not willing to let another modify database entries which it "owns". Similarly, when it comes to reading the database's contents, one user will not accept as gospel the "truth" as reported by another user, because each has different economic or political incentives.

4. Disintermediation

Blockchains remove the need for trusted intermediaries by enabling *databases with multiple non-trusting writers to be modified directly*. No central gatekeeper is required to verify transactions and authenticate their source. Instead, the definition of a transaction is extended to include a proof of authorization and a proof of validity. Transactions can therefore be independently verified and processed by every node which maintains a copy of the database.

5. Transaction interaction

Blockchain makes sense for databases that are shared by multiple writers who do not entirely trust each other, and who modify that database directly and when there is some interaction between the transactions created by these writers. Because of this dependency, the transactions naturally belong together in a single shared database. One nice feature of blockchain is that transactions can be created collaboratively by multiple writers, without either party exposing themselves to risk.

6. Set the rules

If we have a database modified directly by multiple writers, and those writers do not fully trust each other, then the database must contain embedded *rules restricting the transactions performed***.**

These rules are fundamentally different from the constraints that appear in traditional databases, because they relate to the legitimacy of transformations rather than the state of the database at a particular point in time. Every transaction is checked against these rules by every node in the network, and those that fail are rejected and not relayed on.

Asset ledgers contain a simple example of this type of rule, to prevent transactions creating assets out of thin air. The rule states that the total quantity of each asset in the ledger must be the same before and after every transaction.

7. Pick your validators

A Blockchain is described as a distributed database in which transactions can originate in many places, propagate between nodes in a peer-to-peer fashion, and are verified by every node independently. The blockchain's job is to be the authoritative final transaction log, on whose contents all nodes provably agreed.

The existence of log enables newly added nodes to calculate the database's contents from scratch, without needing to trust another node. Second, it addresses the possibility that some nodes might miss some transactions, due to system downtime or a communications glitch. Without a transaction log, this would cause one node's database to diverge from that of the others, undermining the goal of a shared database.

It is also possible for two transactions to be in conflict, so that only one can be accepted. A classic example is a *double spend* in which the same asset is sent to two different recipients. In a peer-to-peer database with no central authority, nodes might have different opinions regarding which transaction to accept, because there is no objective right answer. By requiring transactions to be "confirmed" in a blockchain, it ensures that all nodes converge on the same decision.

A blockchain is literally a chain of blocks, in which each block contains a set of transactions that are confirmed as a group. But who is responsible for choosing the transactions that go into each block? In the kind of "private blockchain" which is suitable for enterprise applications, the answer is a closed group of validators ("miners") who digitally sign the blocks they create.

Because of these problems, when deploying a blockchain-based database, you need to have a clear idea of *who your validators are and why you trust them***,** collectively if not alone. Depending on the use case, the validators might be chosen as: (a) one or more nodes controlled by a single organization, (b) a core group of organizations that maintain the chain, or (c) every node on the network.

8. Back your assets

Generally, it is more appropriate to refer to blockchain as shared databases rather than the more common shared ledger. As a technology in fact, blockchain can be applied to problems far beyond the tracking of asset ownership. Any database which has multiple non-trusting writers can be implemented over a blockchain, without requiring a central intermediary.

By using a blockchain as an asset ledger, it is crucial to understand who stands behind the assets represented on the blockchain.

The answer, of course, will vary by the use case. For monetary assets, one can imagine custodial banks accepting cash in traditional form, and then crediting the accounts of depositors in a blockchain-powered distributed ledger. In trade finance, letters of credit and bills of lading would be backed by the importer's bank and the shipping company respectively.

Conclusion

In the absence of any of the first five scenarios, instead of a blockchain one of the following it should be considered: (a) regular file storage, (b) a centralised database, (c) master–slave database replication, or (d) multiple databases to which users can subscribe.

When the first five are fulfilled, it is important to be able to express application's rules in terms of the transactions which a database allows, have a degree of confidence about who can be trusted as validators and how the disturbed consensus is defined. Finally, in creating a shared ledger, it is essential to understand who will be backing the assets which that ledger represents and its relevance.

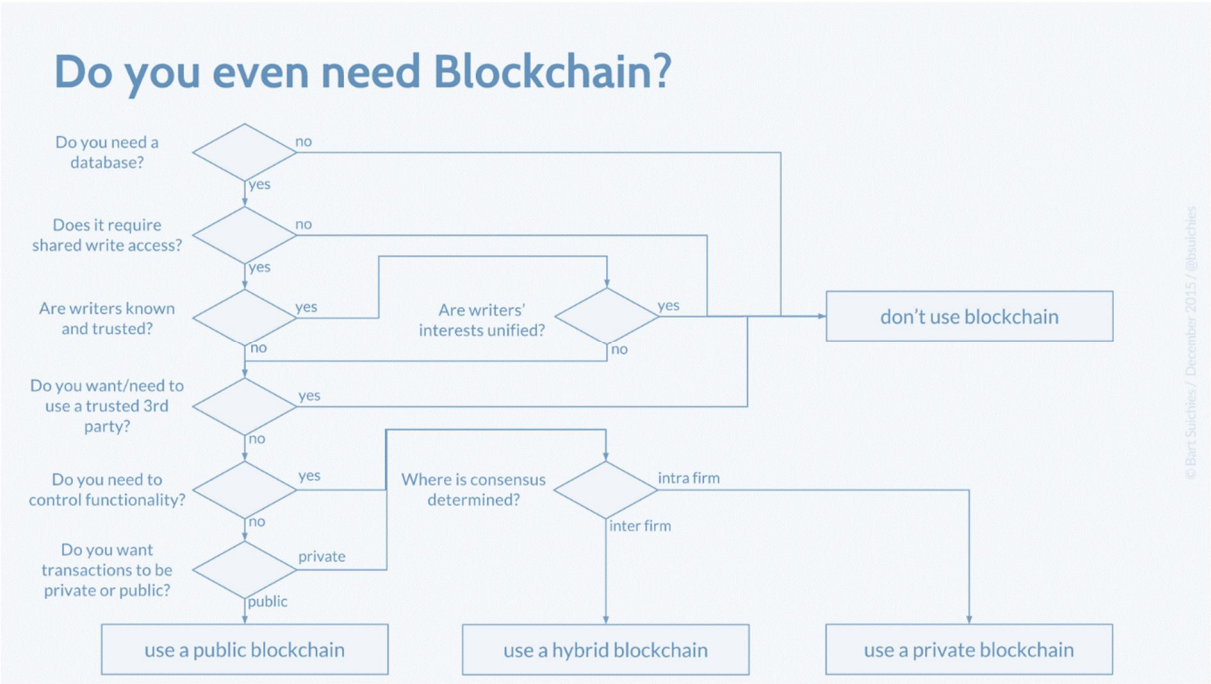


Figure 9: "Do we even need a Blockchain?" flowchart. Source: Suichies

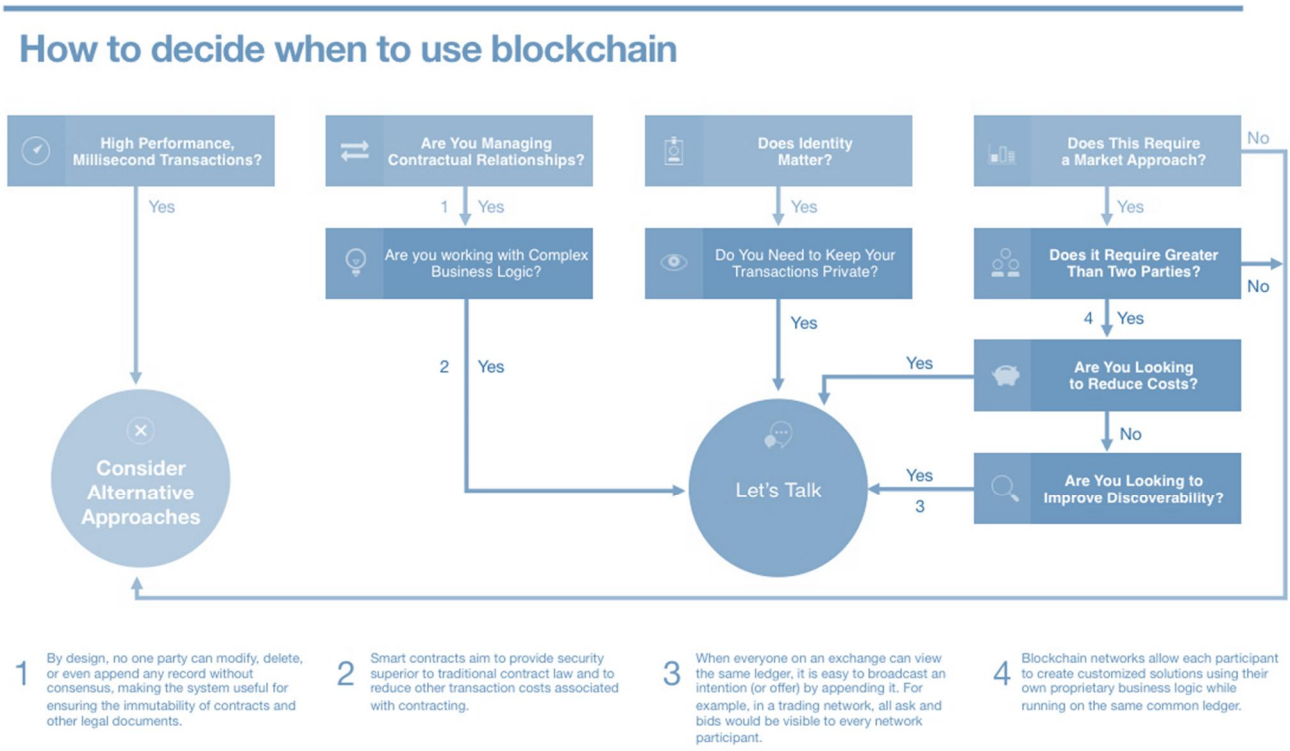


Figure 10: How to decide when to use a blockchain. Source: IBM

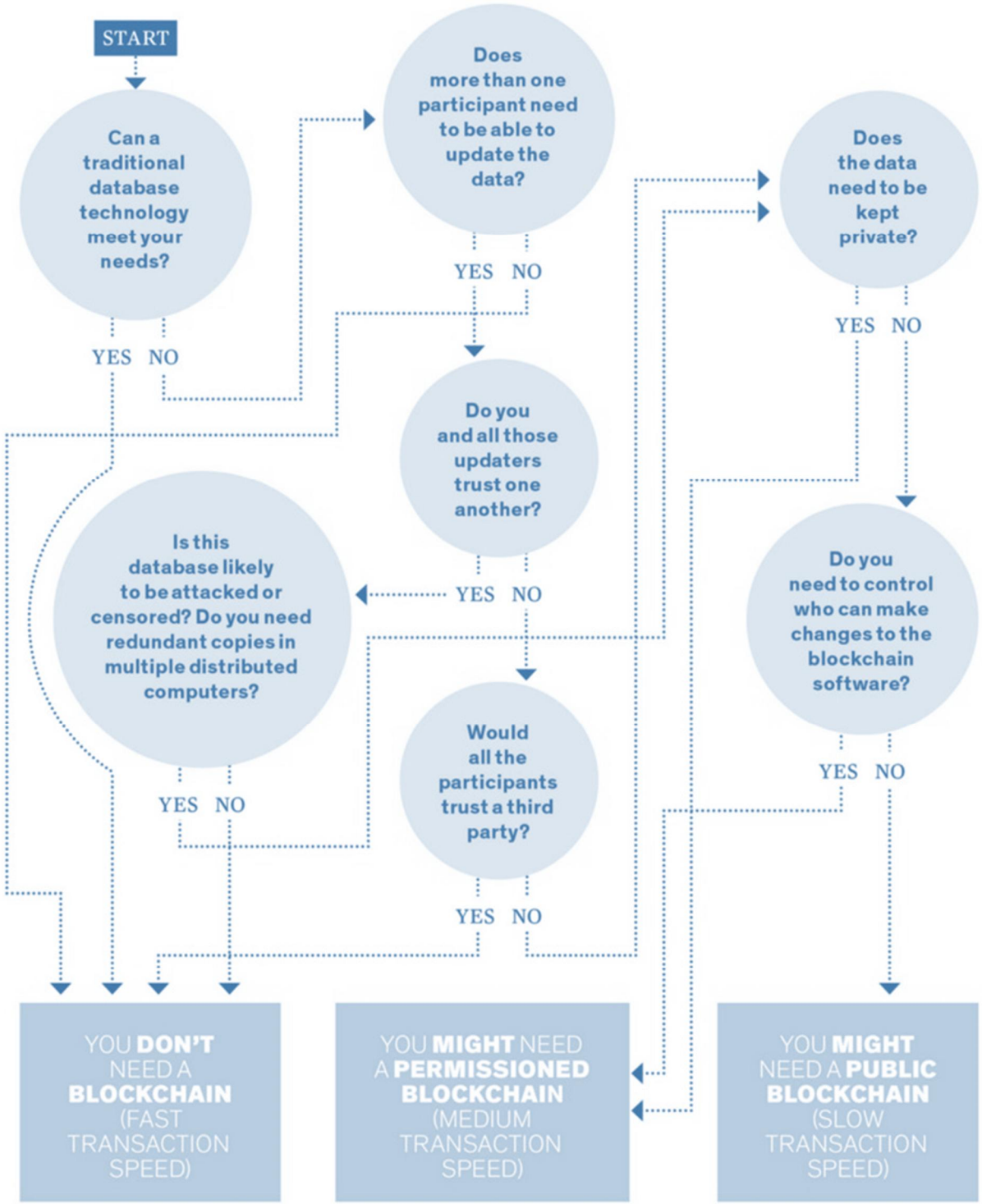


Figure 11: "Decision Tree" Morgen E. Peck model. Source: Spectrum

Different Transactions with Blockchain

A key characteristic of the blockchain is that it removes the need for trusted intermediaries, centralised organisations that take a fee for verifying transactions. Removing the middlemen, completely changes the game for organisations that want to do business with each other.

Bitcoin transactions are still the majority of transactions being registered on the blockchain, but the possibilities of the Blockchain go a lot further. Basically, any financial transaction, whether these are financial contracts, settlements, transactions related to other currencies or exchange of assets can be recorded on the blockchain. In fact, any type of deal can be recorded on the blockchain, ranging from exchange of ownership of physical products such as houses art or rental cars, exchange of ownership of digital assets such as domain names or patents, land registration, attestation documents such as notarised documents, tracking of products within the global supply chain, connected devices or copyright of digital content, the list is endless.

In the case of physical products being recorded on the blockchain that use smart contracts to automatically exchange ownership when certain pre-conditions, subject to existing law, are met, we are talking about smart property. An example is the ownership of a car being automatically transferred from a car leasing company to the individual owner when all monthly instalments have been completed. Smart property works with public/private keys and ownership is exchanged by transferring the private key that is linked to a physical asset from one owner to another owner. Smart property is transferred using smart contracts, which are a special type of 'transaction' recorded on, for example, the Ethereum blockchain.

Blockchain recap:

- Blockchain is shared database of any type of information.
- The information recorded on blockchain is stored in lots of different places at once, so it is always safe; this is called a P2P network.
- The identity of everyone who uses blockchain is hidden behind random numbers and letters, through cryptography.
- Blockchain is kept honest through special computer programs that reward people who keep it honest, these are known as consensus protocols.
- The information is always true because of special codes that show if anything is changed when it should not be, so you can always believe what you are looking at thanks to hashes.
- Blockchain is special because it means you can deal with anyone without the need for a big company telling you who you can or cannot trust. This allows for a new, trustless world.
- Blockchain is distributed and decentralised, making it cheaper, faster and more secure than any centralised system.

Blockchain Technology recap:

Several properties must be present and coexist for a blockchain-bases database to function:

- A peer to peer software client that builds and connects to a decentralised network of nodes
- A validation method that clearly defines which transactions are valid and which not (e.g. Hash protocol)
- A technique to reach consensus in the decentralised network
- A mechanism that secures data on the network, such as mining, minting, proof of work, proof of stakes, etc.
- An incentive, or reward, for participants who contribute to the health of the network
- A data structure to store network information such as Merkle hash trees, pointers or a blockchain
- Security Cryptography

Smart Contracts /smɑːrt//ˈkɒn.trækts/

Smart Contracts

What are Smart Contracts?

Smart contracts are traditional contracts but written in computer-code. An agreement between two or more parties that is defined and executed automatically, once certain pre-defined conditions are met. Smart contracts are like *If This Then That* statements. The term was first coined in 1994 by computer scientist and cryptographer, Nick Szabo who defined it as follows 'A smart contract is a set of promises, specified in digital form, including protocols within which the parties perform on these promises.' A smart contract is a set of executable code that runs on top of the blockchain that facilitates, executes and enforces an agreement between untrusted parties, without the need of a trusted third party. Compared to a traditional contract that defines the rules and penalties around an agreement, a smart contract automatically enforces the obligations on the parties involved. By eliminating the need for a trusted third party, smart contracts significantly reduce the transaction costs which in turn facilitate more advantageous trades.

Basically, Smart Contracts are small software programs, which are hashed using the *SHA-256 algorithm*. As a result, as is with any data that is recorded on the blockchain, once a smart contract has been deployed on the blockchain, it can no longer be changed. Therefore, it is vital for organisations to ensure that the code is 100% correct and that no bugs or errors remain in the smart contract when it is recorded on the blockchain. Mistakes can be extremely costly and the only way to fix a bug in a deployed smart contract, is through a hard fork[21] on the blockchain. As soon as multiple smart contracts are linked and combined with big data analytics and artificial intelligence, it becomes possible to create complex structures that execute automatically once multiple pre-conditions are met. As explained by Vitalik Buterin, founder of Ethereum, in most modern office buildings, such smart contracts are already in place; access is controlled by access cards and whether you are allowed entry to a certain area is pre-defined by a piece of code, linked to a database.

The example of the access card shows that smart contracts have been around for a long time already. The only difference now is that when they are deployed on the blockchain, they remain accessible indefinitely and will carry out their pre-defined tasks whenever certain conditions are met. Smart contracts offer tremendous opportunities for organisations, but it is vital that they are deployed on the blockchain only when they are correct. In the coming years, we will likely see a wide variety of applications using the smart contracts that will change how we work, how we do business and how we run our daily lives, resulting in so-called Decentralised Autonomous Organisations, Decentralised Autonomous Corporations or even Decentralised Autonomous Societies. At this stage, the benefits are largely theoretical because the technology of smart contracts is still in its infancy, and sometime away from widespread deployment. If a blockchain is the database, then the smart contract is the application layer that makes much of the promise of blockchain technology a reality.

In order to be developed and deployed, smart contracts require a blockchain platform. The most well-known public blockchain platforms are Bitcoin, NXT and Ethereum. The Bitcoin platform is mainly used to process cryptocurrency transactions. One of the major drawbacks is that due to its limited computational capability, it cannot handle contracts with complex logic. NXT is also a

[21] A *hard fork* is a rule change such that the software validating according to the old rules will see the blocks produced according to the new rules as invalid. In case of a hard fork, all nodes meant to work in accordance with the new rules need to upgrade their software. [..] Source: Wikipedia

public blockchain platform that has built-in smart contract templates from which the users can choose. The disadvantage is that it does not allow users to customize the templates.

Ethereum, currently the most common platform for developing smart contracts is a platform that makes use of the Turing-complete programming language which supports advanced and customized smart contracts.

Example of a simple Smart Contract

```
pragma solidity ^0.4.0;

contract SimpleStorage {
    uint storedData;

    function set(uint x) public {
        storedData = x;
    }

    function get() public view returns (uint) {
        return storedData;
    }
}
```

The smart contract "SimpleStorage" above, wrote in Solidity[22], allows anyone to store a single number that is accessible by anyone in the world without a way to prevent you from publishing this number. The simple example shows already the complexity of the programming language.

[22] ***Solidity*** *is an object-oriented programming language for writing smart contracts. It is used for implementing smart contracts on various blockchain platforms, most notably, Ethereum. Source: Wikipedia.*

Properties of Smart Contracts

Transparency

One of the basic characteristics of blockchain technology which is also shared by smart contracts is transparency. As previously stated, smart contracts are filled with terms and conditions in absolute detail which are also checked by the parties involved in the agreement.

This eliminates the chance of dispute and issues at the later stages as the terms and conditions are thoroughly checked and put into place only when all the participants agree to those. This trait of smart contracts allows the involved parties to ensure transparency during transactions.

Moreover, need for precision in contract detailing keeps all the information open with everyone which ultimately resolves anything related to miscommunication issue. Therefore, with the aid of smart contracts, efficiency lost in communication gaps can be restored.

Time-efficient

In order to go ahead with any process involving documentation, it usually takes more than at least a couple of days. The delay in processes is due to a lot of intermediaries and unnecessary steps along the way. On the other hand, smart contracts are run through the aid of the internet as they are nothing but pieces of software code.

Therefore, the speed of completing transactions through smart codes is way too fast. Smart contracts can save hours or even days as compared to any traditional business process. Moreover, the time delay due to manual involvement is also eliminated.

Precision

A smart contract is coded in an explicitly detailed form. It requires to holds all the terms and conditions in it before it is finally put to work. Any condition that is left out of the contract might result in an error while execution, therefore while creating smart contracts, all the conditions are put in the detailed form.

Due to this, the smart contract becomes a comprehensive agreement which when gets executed automatically, gets almost everything done. In the case of manual contracts, there are chances of errors as the person who is responsible for making a contract might miss one condition or the other. Moreover, there is no way of even tracking it until the error is made. Therefore, smart contracts are a better alternative when it comes to achieving accuracy and precision.

Safety and Efficiency

Smart contracts with automated coding features are the safest options when it comes to data encrypted technology in the current times. Since they match the highest safety standards, the level of protection involved in them allows them to be secure to use for critical processes.

Moreover, since the smart contracts are so accurate and secure, their level of efficiency is way too high which generates more value in transactions.

Data Storage

Smart contracts are accurate and precise to the minutest level of the agreement. All the details of any transaction are stored on the contract and anyone among the involved parties can access it at any given time. Moreover, these transactions are stored on the blockchain in the form of future

records. This is particularly helpful in terms of any dispute regarding the contract terms in the future.

Savings

Using smart contracts in place of traditional agreements can result in a lot of savings. First and foremost, as smart contracts only involve parties that are the part of the agreement; the need for middlemen is eliminated and the money involved in that is also saved.

All the lawyers, witnesses, and intermediaries have no role when smart contracts are used. Moreover, as stated earlier, smart contracts also save money as paper-based documents are not involved in any processes.

Trust

The properties of transparency and security make smart contract trustworthy in businesses. They obliterate any probability of manipulation as well as manual errors and establish confidence in their execution. Upon agreement on all the conditions, the contract automatically executes itself.

Another unique feature of these contracts may be their capability to significantly lessen the requirement of litigation and courts. Self-executing Smart Contracts allow parties to commit and bind by the conditions and rules written inside.

Paperless

As smart contracts are computer coded documents, the use of paper in the entire processes is eradicated. On one hand, this saves the cost while on the other, this is useful for companies globally as it helps them to save their bit of paper usage in terms of contracts and promotes their contribution towards the society.

How do they work?

In order to understand how smart contracts work, it is important to first make the distinction between the smart contract code and how the code is being applied to. A smart contract can be broken down into two separate components:

Smart Contract Code – The code that is stored, verified and executed on a blockchain.

Smart Legal Contracts – The use of the smart contract code that can be used as a complement, or substitute, for legal contracts.

Because smart contracts work like computer programs, it is very important that they do exactly what the parties want them to do. This is achieved by inputting the proper logic when writing the smart contract. The code behaves in predefined ways and does not have the linguistic nuances of human languages; it works with the automated logic "if this happens then do that".

The code is then encrypted and sent out to other computers via a distributed network of ledgers (i.e. Blockchain). If this is done via public permissionless blockchain such as bitcoin, the contract is sent out similar to the way that a network update of a bitcoin transaction would occur. This can also be done in a permissioned or hybrid blockchain platform.

One the computers in this network of distributed ledgers receive the code, they each come to an individual agreement on the results of the code execution. The network then updates the individual ledgers by recording the execution of the contract, and subsequently monitors them for compliance within the terms of the smart contract. In this type of system, single party manipulation is obverted because control over the execution of the smart contract is no longer possible because execution is no longer in the hands of a single party.

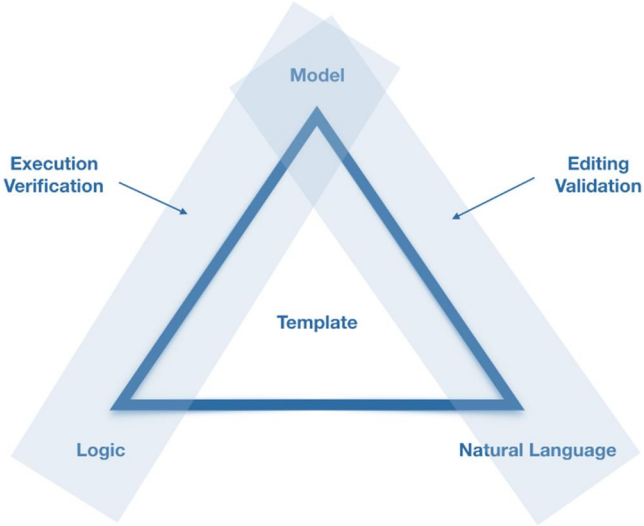


Figure 12: Smart Legal Contracts combine a legal template with a business logic and aim to digitize legal contracts. Business concept. Source: Accord Project ¦ Natural Language, the grammar for the legal text of the template ¦ Model, the data model that backs the template ¦ Logic, the executable business logic for the template.

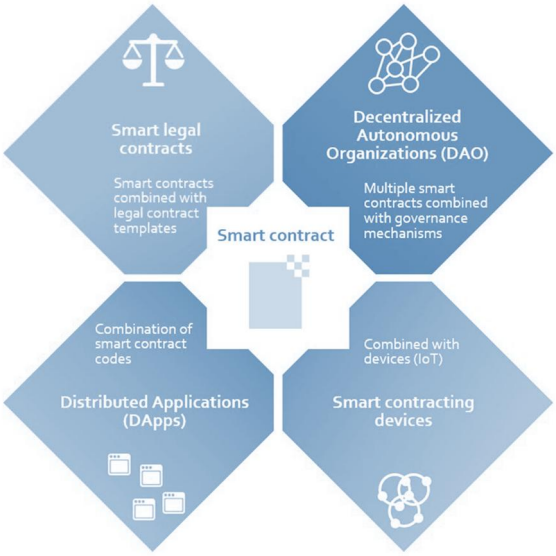


Figure 13: Types of Smart Contracts based on application. Source: Everest Group

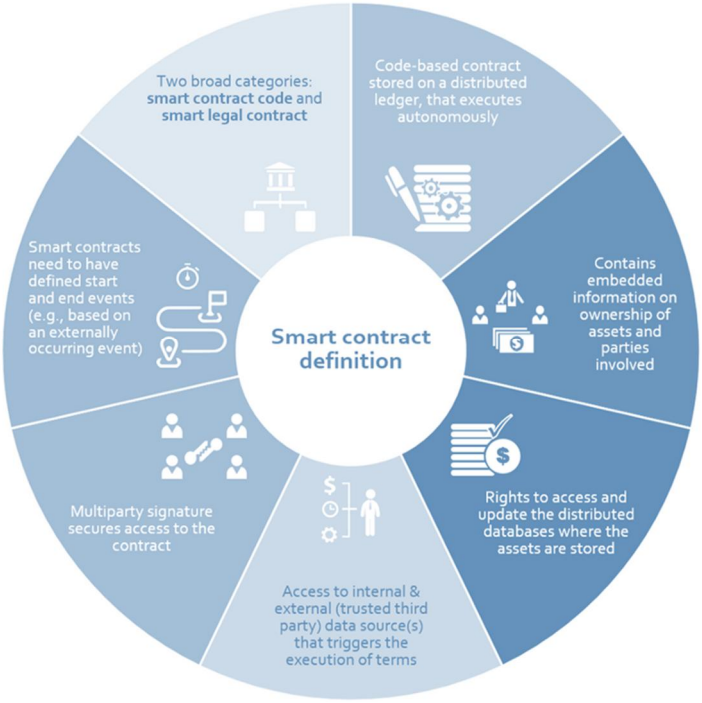


Figure 14:Smart Contracts realising true benefits of blockchain. Source: Everest Group

Figure 15: How does a smart contract work?

Applications

DAO (Decentralised Autonomous Organization)

DAO aims to encode the rules of an organization in a computer program to achieve transparency. Since such an organization is controlled by shareholders and not influenced by a central government, the transaction records are facilitated using the Smart Contracts system.

DApps (Distributed or Decentralised Apps)

These software applications run on a P2P environment and are not hosted on a central server. They use blockchain to store data, and as such the program is designed in a way that it is not controlled by any single entity. Smart Contracts need a network to function on, and DApps helps integrate their usage efficiently.

IoT-combined Contracts

IoT-combined Smart Contracts allow for commercial transactions via IoT-enabled products and are used to govern and manage interactions between multiple devices, satisfying the needs of monetization or security for the Internet of Things.

Potential Advantages with smart contracts adoption

Autonomy

There is a sort of autonomy degree on making the agreements. There is no need for intermediaries. Since the execution is managed automatically by the network, rather than by one or more, the mistakes rate is also reduced.

Trust

Documents are encrypted on a shared ledger. Difficult to manipulate and no need for a trusted third party.

Backup

The database is duplicated many times over the blockchain, each computer connected to the network detain a copy.

Safety

Cryptography keeps the documents safe and identify the participants

Speed

Smart contracts use software code to automate tasks saving hours in document processing

Savings

Smart contracts save money since they knock out the presence of an intermediary

Accuracy

Automated contracts are not only faster and cheaper but also avoid the errors that come from manually filling out paper forms.

Audit processes

Simple audit trails and records in real time can simplify the resolution of claims and disputes.

Blockchain in the construction industry

Construction is a highly regulated industry by necessity. While many workplaces are experiencing game-changing disruption thanks to new technologies, processes in construction have remained broadly the same.

Blockchain has been around for a decade – it came about as a method to support the digital currency Bitcoin. While it is still used for this purpose, many industries are looking to incorporate blockchain technology in other ways.

It quickly became apparent that the applications of the blockchain technology could go far beyond cryptocurrency and could be extremely useful for a host of other applications, across many different industries, affecting many different aspects of our lives in business and elsewhere among endless potential applications.

In fact, blockchains can be used for anything which requires transactions to be recorded in a secure manner. Blockchain and distributed ledger technology have a tremendous potential in several sectors and considerable attempts have been undertaken to explore its possible application. How could this technology have an impact on the building construction sector?

Its adoption in conjunction with BIM could be incredibly beneficial, including the potential to digitally link model component to their physical counterpart. This could allow for *live* BIM models, whose components could continuously be fed using data from the real buildings throughout their construction and operation — a digital twin.

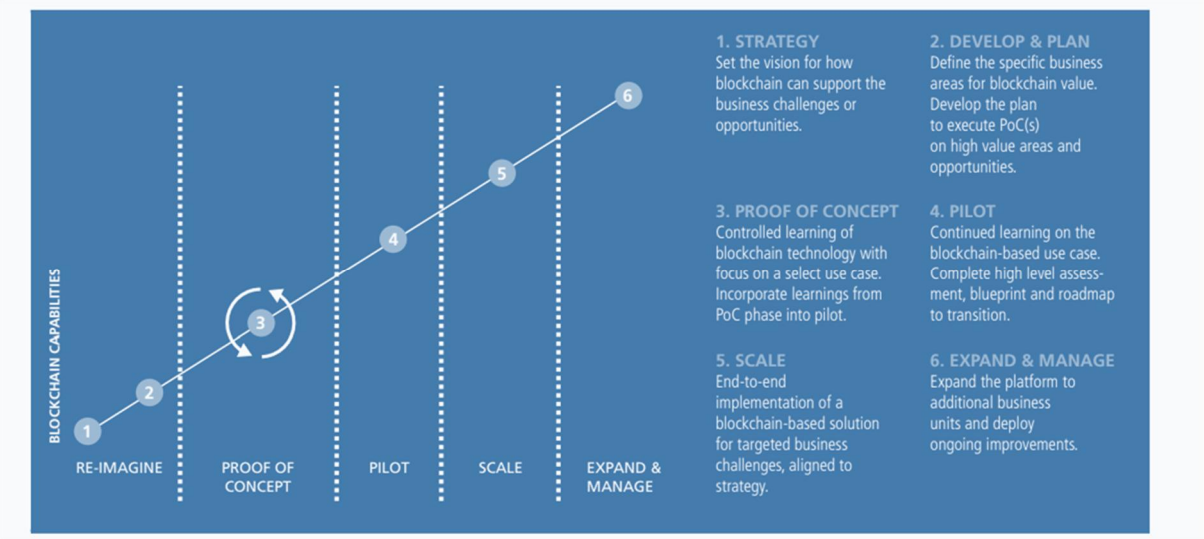


Figure 16: The steps for blockchain implementation. Source: Accenture

Blockchain infrastructure carries a lot of potential in this regard – all data and necessary documents could theoretically be held within the blockchain. This information would be encrypted, incorruptible and easily viewable by every party involved. Disagreements about a variation notice being issued or changes to a works program could quickly be solved with a public blockchain ledger.

As for the movement of materials through the supply chain, blockchain can be used to trace physical items from their origin through to their current ownership status. This transparency could greatly improve the supply chain, allowing everyone involved to keep track of statuses to avoid shortfalls and oversights.

It is important to note that these ideas are purely speculative at this point. Successful implementation of blockchain in construction is predicated on everyone trusting a digital system. This could prove to be a difficult sell, especially given the financial implications of delivering major construction projects. If there is a collective swell of industry support for the technology, we might just see construction processes change to benefit all the stakeholders involved.

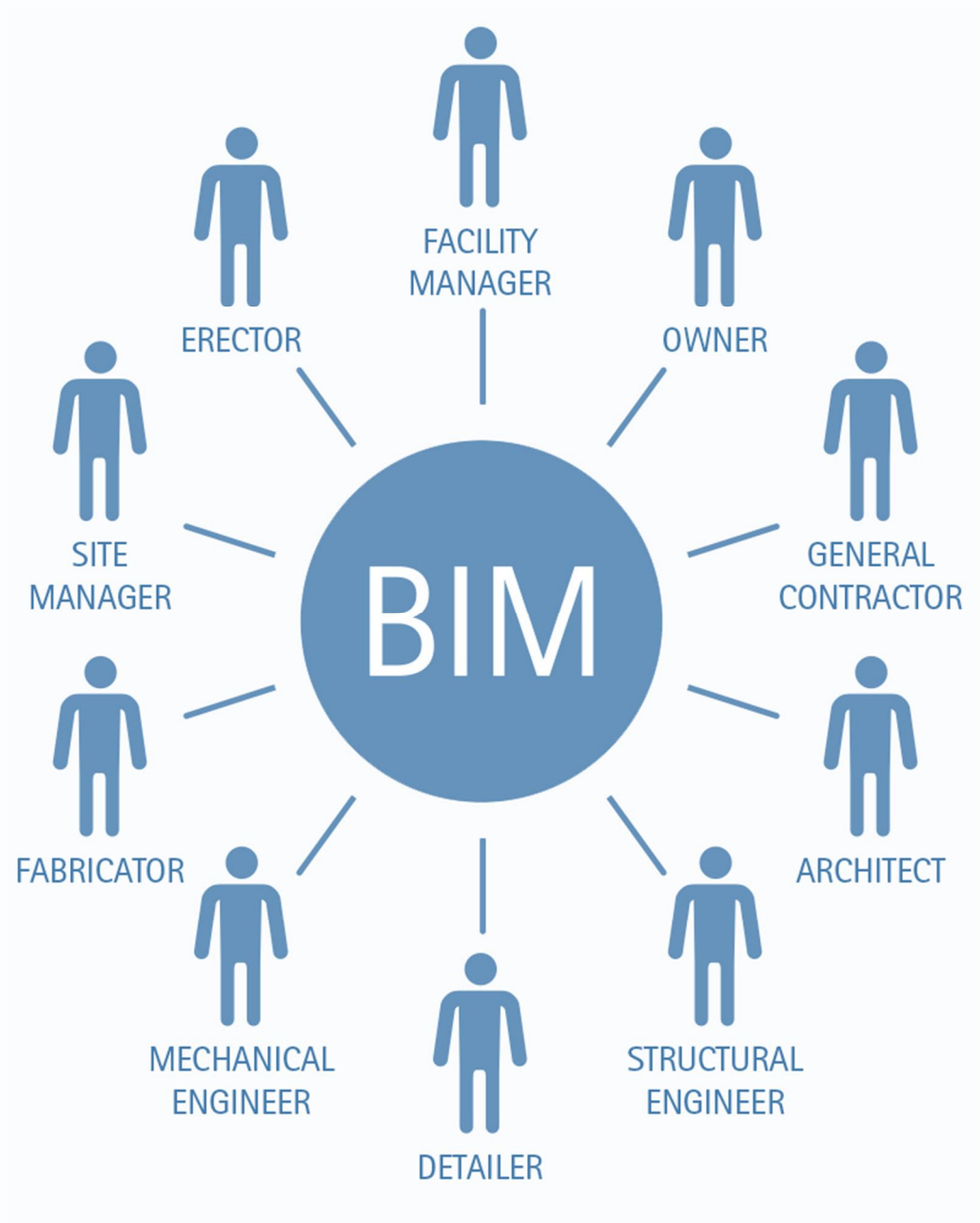


Figure 17: An open approach to BIM connects different stakeholders to each other. Source: Tekla

OpenBIM: Why is it important?

- supports a transparent, open workflow, allowing project members to participate regardless of the software tools they use.
- creates a common language for widely referenced processes, allowing industry and government to procure projects with transparent commercial engagement, comparable service evaluation and assured data quality.
- provides enduring project data for use throughout the asset lifecycle, avoiding multiple input of the same data and consequential errors.
- Small and large (platform) software vendors can participate and compete on system-independent, 'best-of-breed' solutions.
- energizes the online product supply side with more exact user demand searches and delivers the product data directly into the BIM. [23]

Smart contracts in the building industry

Blockchain could facilitate the introduction of smart contracts in the construction industry. In simple terms, a smart contract uses automation to speed up and streamline payment processes. Project managers can set up a system that self-executes payments to eliminate the current gaps and delays that hold construction up at various stages.

Relating to construction, a smart contract would work by setting up prerequisites that trigger a certain action once met. For example, if an inspection takes place on a section of brickwork and the inspector approves it, payment will automatically be sent to the bricklaying contractor.

These automatic triggers could apply to more than just payment. By removing the need for human input at several stages of the construction process, quicker project delivery is theoretically possible.

New business models could be thought with technology support. We could think about a blockchain in an engineering contest with the adoption of a currency specifically design for the sector. A currency that would allow engineers to connect on a global level, providing assistance to others, such as specifications, documents or solutions and receiving a compensation for the contribution to the project.

[23] Source:buildingSMART

Use cases

The whole construction industry offers several possible applications for blockchain and this would certainly contribute to revolutionise the entire supply chain. It is probably not difficult to understand that its application can impact several processes in all phases. The procurement, the planning, the submission, the tendering, the construction, the management, the demolition and the refurbishment, to mention a few, all offer the conditions for the adoption of blockchain and smart contracts. Several are the situations where two parties need to interact with lack of trust using a database to exchange digital assets. In the following page I will focus the attention on typical processes in the construction industry and introducing the blockchain and smart contracts technology.

Having partners doing business without mutual trust is the optimal setting for blockchain use cases!

Figure 18: OpenBIM and Stakeholders. Source: buildingSMART

#1

Design Phase Validation

A first use case where the benefit of the blockchain and smart contracts could be applied, in conjunction with BIM, it is the design phase. Following the Client's requirements several consultants interact each other exchanging a notable volume of data and information. The different design packages and deliverables are defined according to the program. On a blockchain platform similar milestones and packages are added together with smart contracts which are prepared to initiate payments according to the submitted deliverables in time. These transparent and faster payments would be activated by smart contracts through blockchain applications. Client's requirements could also be verified automatically through Smart Contracts directly from the BIM Model and validated. The whole process recorded on a blockchain would enhance transparency and efficiency, helping the client to have a major control of the investment and at the same time allowing a better cash flow for the planners. All the relevant information on the blockchain contribute to create a digital asset to use at the end of the planning phase for tendering. The technology would also help the consultants to better interact and adopt a more collaborative approach thanks to the blockchain properties. The company BIMCHAIN is developing and a service allowing to develop this kind of process. The "proof "concepts like the ones below are then introduced to regulate the planning phase and the interaction between planners.

Proofs of Ownership

It gives the ability to register and sign a digital asset to create digital proofs of authenticity and anteriority of publication preventing dispute around copyright and ownership.

Proofs of Context

It certifies that your contribution has been produced based on verifiable external inputs and scope the liability.

Proofs of Approval

The stakeholders are working on synchronized and current versions and this can be easily proved. These electronic agreements in the design process avoid paper signature, stamping and approval.

Proofs of Consistency

Prove the deliverables source and make them a single source of truth.

Proofs of Certifications

The BIM objects and components could require a certification by the Issuer. Proof the compliance to Regulations and codes by getting your model certified.

Proofs of Publication

Certificates the deliverables in relation with deadline.

Those are just examples how some transaction could be regulated through computer coding allowing to release micropayments with every transaction. Planners need an incentive to place the data and the blockchain and this could be achieved dividing their fees in tokens and connecting them to BIM model components and package of data.

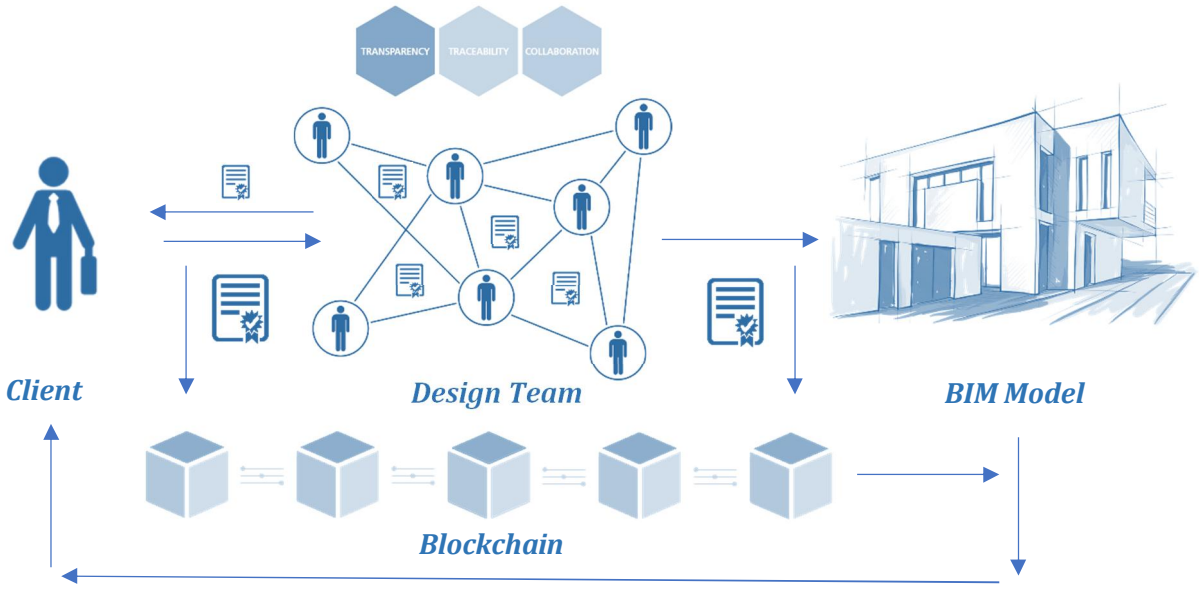


Figure 19: Planning Phase Validation. Source: Author

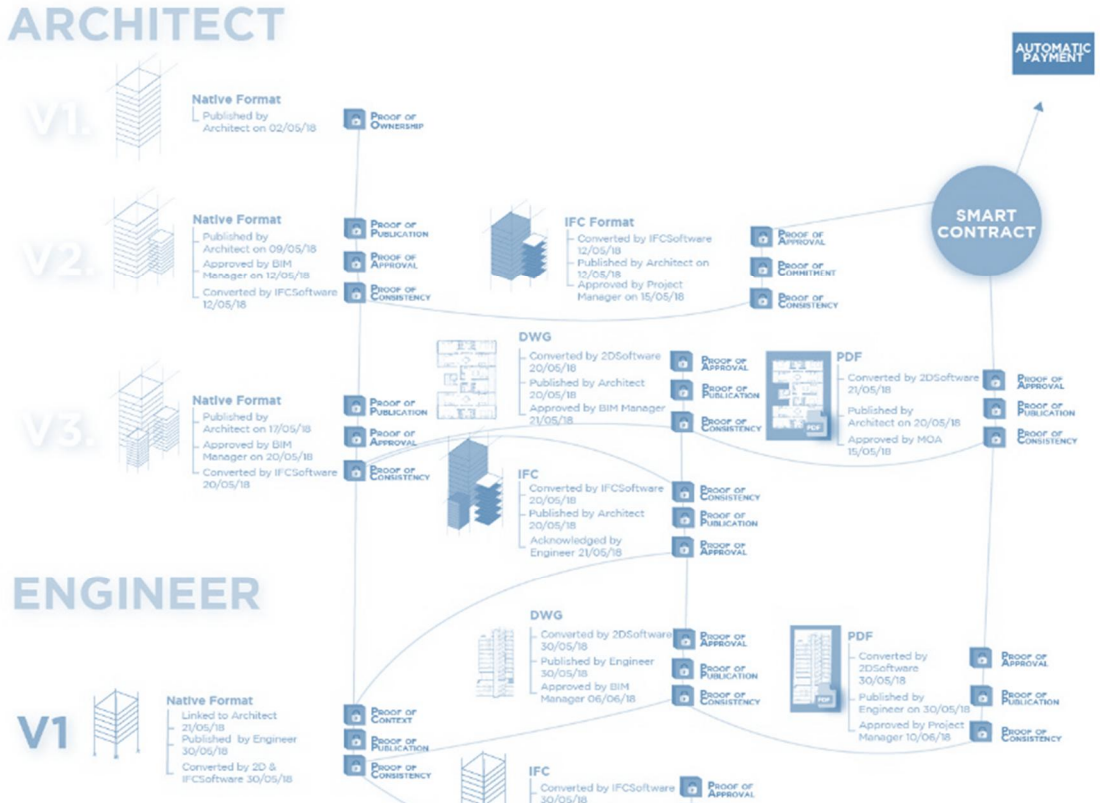


Figure 20: Graphical representation in the design phase: A proven track records of BIM processes Source: BIMCHAIN

#2

Structural Health Monitoring

Structural Health Monitoring (SHM) is a tool used to ensure the safety and soundness of structures. It uses an assortment of sensors to collect and analyse data pertaining to any damage or deterioration that a structure may receive over the course of its life. The data that structural health monitoring systems acquire can help its users avoid structural failures. Monitoring the structure through a data acquisition using sensor, a DLT and a digital twin combined will allow Smart contracts to automatically schedule site inspections on a dedicated blockchain for maintenance. All the transactions and contracts would be running on a blockchain platform becoming part of the building information asset. Certification would be reflecting the actual status of a building performances and the owner will have a better understanding of the whole building management. Structural behaviour could be monitored and recorded immutably on a ledger, in transparent manner and without intermediaries, failures could be prevented, alerts automatically issued and legal contract automatically finalised.

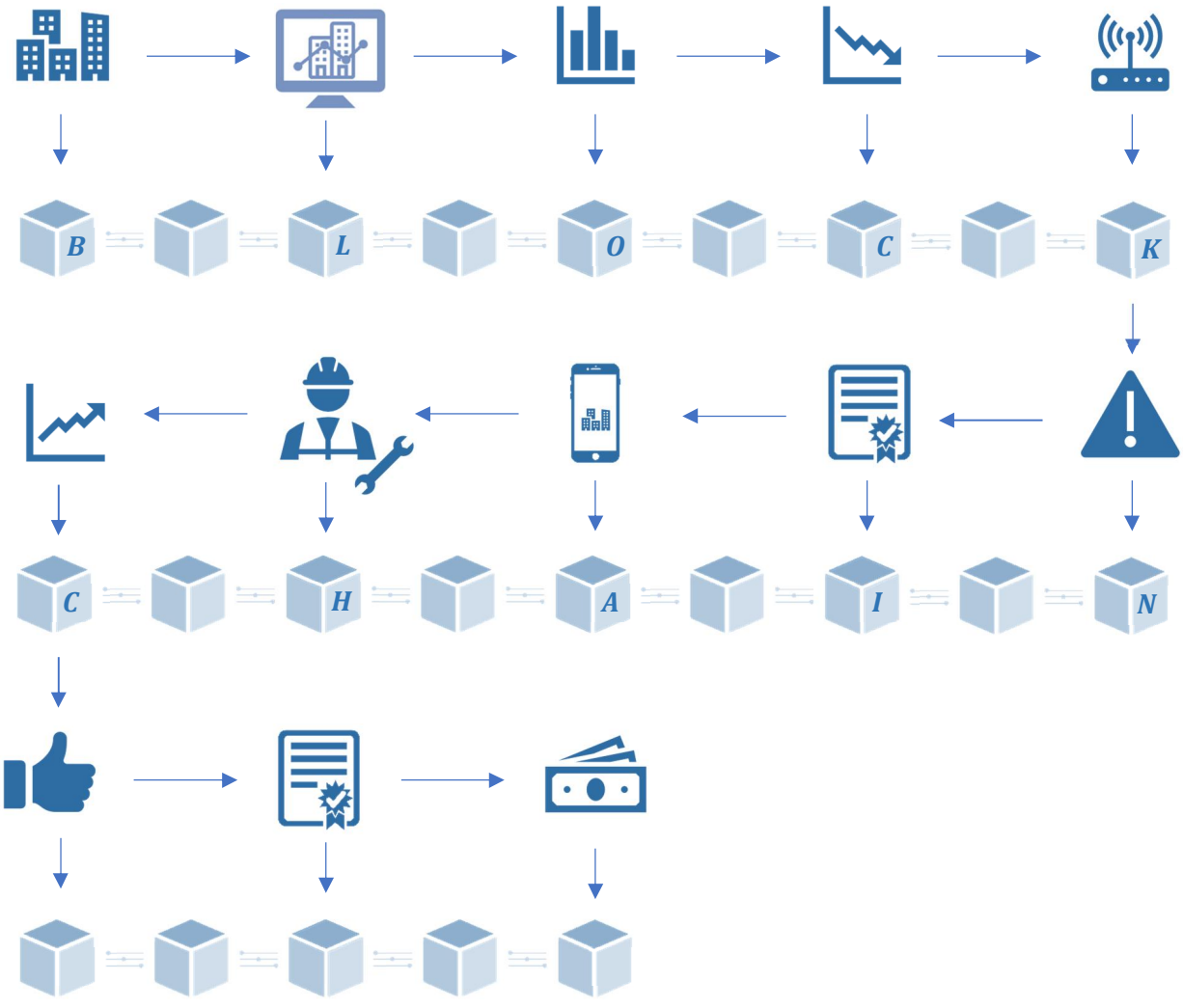


Figure 21: Structural Health Monitoring. Source: Author

#3

Goods Delivery and Construction Site Management

Goods delivery could be traced and compared against a schedule allowing consequently payments, applying penalties in case of late arrival on site. Structural engineers mark the Reinforcement ready to be produced directly on the BIM Model. A smart contract, after the approval, would order the reinforcing bars and start a contract between two parties. The rebar will then be produced, shipped and traced until the arrive on site. A QR code or a sensor could proof their location, declare the mechanical properties and all the relevant information; a comparison with what present in the model would close the process and allow the payment to the manufacturer. All traced and recorded on an immutable database like blockchain. Method and timeline of micropayments will be happening like defined on the smart contracts. The construction phase is automatically documented without paper documents.

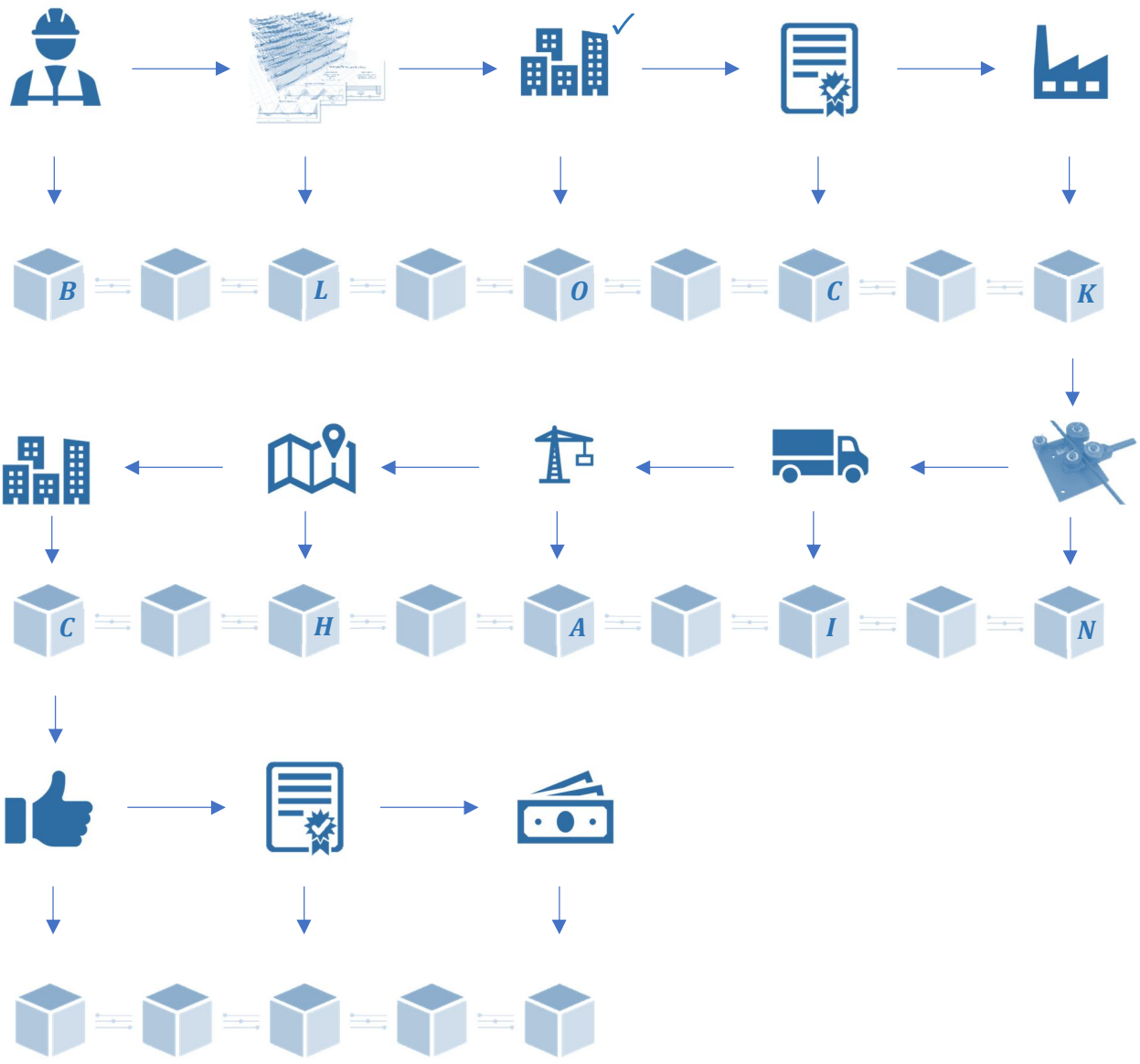


Figure 22:Goods Delivery and Construction Site Management. Source: Author

#4

Tendering

Another example where blockchain, smart contract and BIM could revolutionise the construction industry, is its application in the tendering process. The idea that Design professionals could benefit, at the end of planning phase, submitting a BIM model for planning assessment is already not so unrealistic. All the relevant information contribute to create a digital asset to be deliver at the end of the planning.

A process of automatic Code checking, which is a grey area of the planning process, could be enforced with the use of code checking applications that run through the digital models and report on compliance.

The BIM model submitted can be ascribed on to the Government Planning Blockchain with a digital marker. When planning is granted a smart contract is then activated with the planning permission certificate and conditions. The planning file is cryptographically secured and open to public scrutiny. The result is a speedier, more realistic, cost effective and transparent planning system.

The BIM Modell is then issued for tendering. A structured scheme of all information will allow several contractors to be able to make an automatic a quicker offer. An application on the blockchain would validate the offers filtering and selecting with several criteria. At this point a smart contract between the winning contractor and the client could automatically take place.

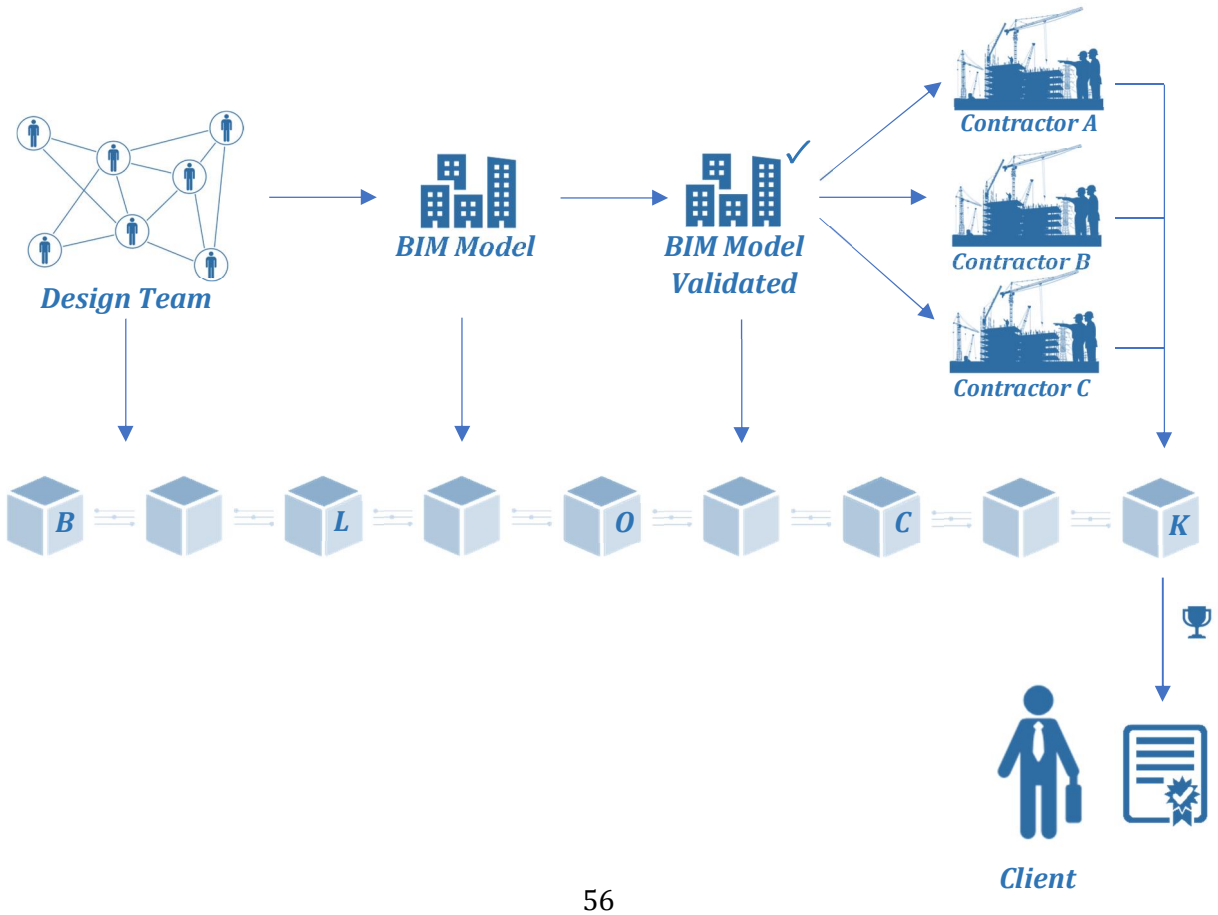


Figure 23: Tendering. Source: Author

#5

Prefabricated columns: from design to construction

A column design process usually starts from an architect's idea and a structural engineer gives his input for the required geometry in relation to the loads that it has to carry. The column is first part of the architectural model. The same column, it is in most of the current design cases in the structural model as well. A federated model will then be used for the coordination between the disciplines. As we have seen in one of the previous use cases, the whole process until this stage can also be recorded in a blockchain with its advantages. In this use case we will be focusing on the relation designers-manufacturer. Once the BIM Model is validated can then be shared on a blockchain. The information about the column is than accessible to several manufacturer that could make and offer through a smart contract application. Following the criteria on the smart contract a manufacturer is chosen and will receive a contract to produce the column. Also, in this case the total fee is divided in small ones to incentivise the manufacturer to enter the data on the blockchain. The column will be produced and digitally saved on the blockchain platform for the validation with the design component. Once arrived on site it is put in place, validated and insert in the As-build BIM Model.

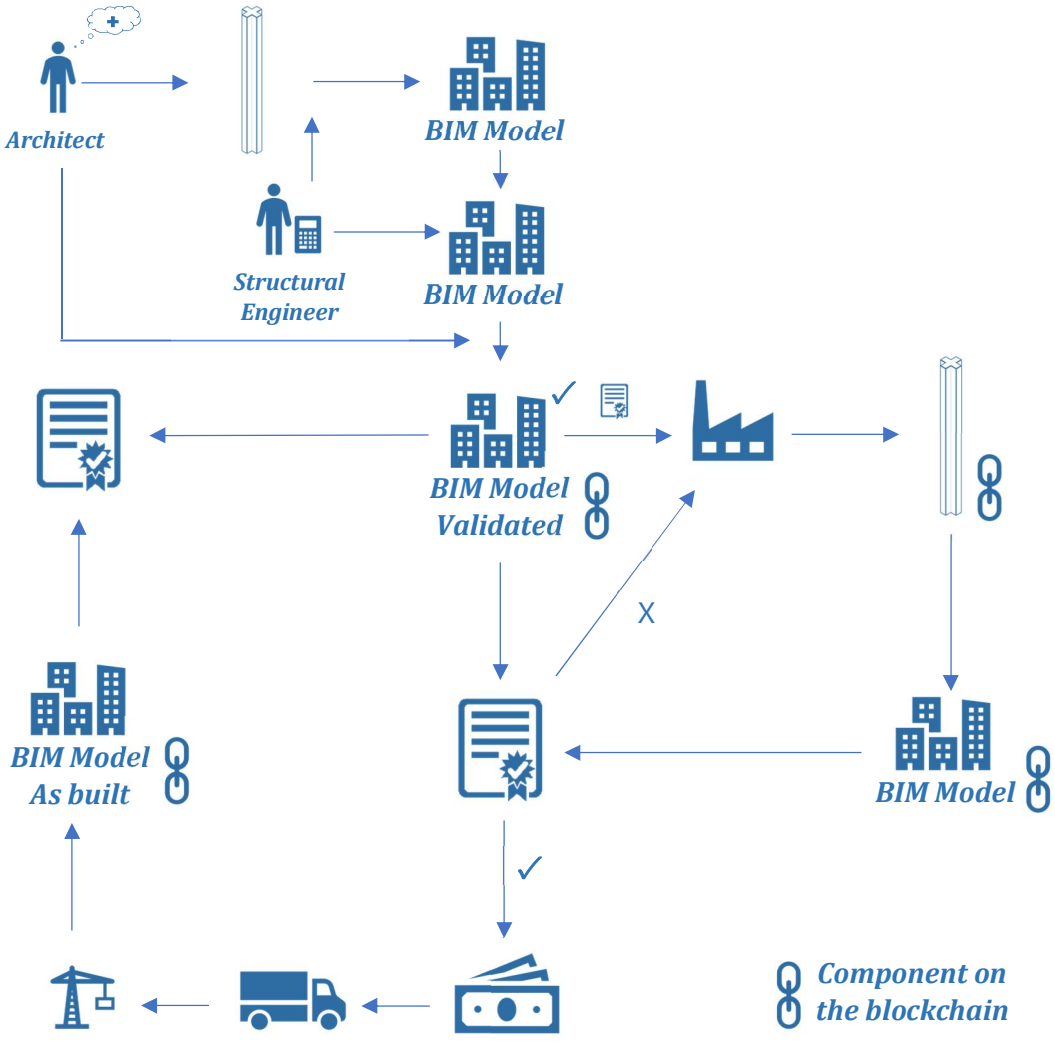


Figure 24:Prefabricated columns: from design to construction. Source: Author

#6

Professional blockchain: A New Business Model

New business model could be introduced in the construction industry thanks to the blockchain technology characteristics. A network of professional able to collaborate to several projects offering and sharing their knowledge to the community. A team of expertise able to contribute to different projects being reward and payed for their work. As example, Quant is a cryptocurrency that is currently being developed in the USA by a group of engineers with the purpose to enable a global network of professionals and enhancing collaboration. This could be the case when a project requires a specialist that is not available within the company or a technical solution to a problem saved on a blockchain solved by engineers and approved by a dedicated experts blockchain.

#7

The Vision: Level 3 BIM. A decentralised technology for a centralised design process.

Level 3 has not yet been fully defined, however the vision for this is outlined in the UK Government's Level 3 Strategic Plan. Within this plan, they set out the following 'key measures'[24] to be secured with further funding:

- The creation of a set of new, international 'Open Data' standards which would pave the way for easy sharing of data across the entire market
- The establishment of a new contractual framework for projects which have been procured with BIM to ensure consistency, avoid confusion and encourage, open, collaborative working.
- The creation of a cultural environment which is co-operative, seeks to learn and share
- Training the public sector client in the use of BIM techniques such as, data requirements, operational methods and contractual processes
- Driving domestic and international growth and jobs in technology and construction.

In the Level 3 collaboration is no longer limited to primary consultants but includes most of the project team across all project lifecycle. At this level, the project model is saved into a single data sharing environment, the BIM Platform, in which each professional can create, consult and correctly manage the BIM model for each discipline and during the building's entire lifecycle: from planning to implementation through to maintenance or dismantling. The principal aspects of the Task Group's business plan for BIM Level 3 include increased focus on lifecycle management and the use of real time cost and carbon data. It also seeks more service and performance-based approaches, and the connection of built assets into the wider Internet of Things and smart cities. It this scenario the amount of big data generate will be enormous and its control will assume an important aspect. The blockchain technology could, together with the smart contract, be the key to realise the Level 3 BIM vision. In the figure below are summarised the milestones for a building Lifecycle process. The whole process saved on a blockchain will deliver more trust, transparency, traceability, collaboration, efficiency and address the intellectual property issues. The BIM Level 3 benefits are realised throughout the building Lifecycle. A digital twin together with an immutable database will add value to all the process. The stakeholders will be incentivised, through micropayment automatically generated by smart contract to feed the blockchain and a rewording scheme for future projects. Code checking by local authorities and control offices will be automated and the approval automatically granted through smart contracts. Issues relating to trust and ownership would be lowered with the blockchain technology's properties. A Building Passport would be certifying the building identity. Sensors would help building an As Built Digital Twin Model to be used as basis for the facility management. Preventive maintenance and monitoring processing automatic could record the operation on a blockchain. Machines could themselves organising call for their maintenance. Analysis and simulations would speed up processes and help to better understand to building behaviour and performances. Building documentation stored on a blockchain will be an immutable asset that will create added value concentred in a single entity: SSOT.

[24] Source: NBS

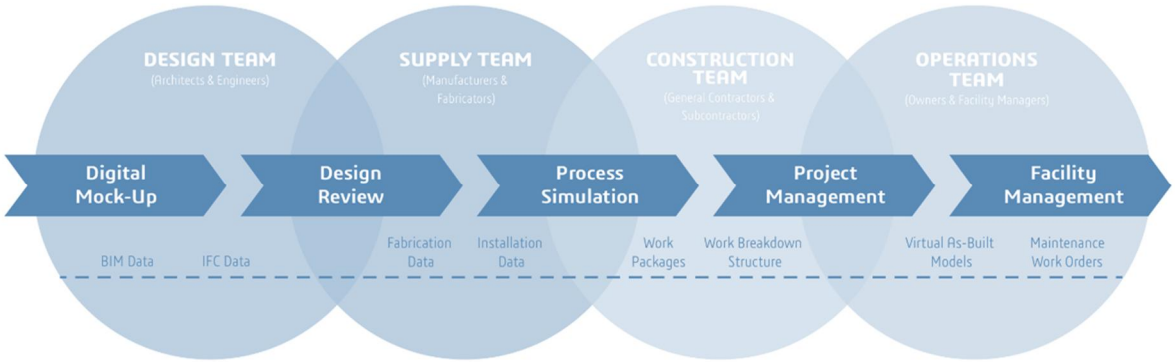


Figure 25: Extended Collaboration Model for Design, Construction & Operation. Source: Dassault System

buildingSMART chapter Switzerland

On 12th January 2016, a new chapter was launched in Switzerland. buildingSMART Switzerland is the leader in the digital transformation of the Swiss construction and real estate industry and includes institutions, associations and companies along the entire value chain. The aim is to enable digitization and thus end-to-end cooperation of all stakeholders throughout the life cycle of a property. buildingSMART Switzerland develops practicable instruments that can be used by all in the construction and real estate industry and, using best practices, demonstrates concretely the benefits of digital transformation. The national cooperation with organizations with similar concerns takes place within the framework of netzwerk-digital and Bauen Digital Schweiz.[25]

Building Room - Blockchain Group

On 19th July 2018 the "Building Room", a buildingSMART Chapter Switzerland initiative, was lunched with the aim to investigate, through use cases, themes BIM-related following buildingSMART philosophy. The workgroup *Blockchain*, among other six, was founded and it is actively working on the possible blockchain applications in the construction sector. I am currently part of this workgroup, the aim is to define use cases, build them on a blockchain and soon publish a report.

[25] Source: buildingSMART international.

Conclusion

Blockchain is still in its early development and a lot of development work is still to be done. However, decentralised applications that are run by smart contracts, without the need for a centralised governing power that generally takes a large commission or time, offer tremendous advantages in the construction industry. By removing intermediaries, a client has more control and transparency of cost, time and scope on their project. The adoption makes possible to introduce new and revolutionary business models able to change the whole supply chain and possibly being the key to the Level 3 BIM vision. Data set will have a central position in the entire building lifecycle and a SSOT approach will be achieved.

Undoubtedly, new technologies have in their adoption, advantages and disadvantages. The advantages are directly linked to the blockchain and smart contracts properties earlier introduced and already analysed; the database immutability could be seen as being the most important. Looking instead at the complexity of its adoption, as first point, a standardisation process is required. It barely thinkable to adopt new technologies and new business models without defining rules and standards. We have already witnessed how difficult it is to introduce standards in a BIM process, well blockchain and smart contracts are not any simpler. Smart contracts require programme coding, hence, people with programming skills and bugs are a big threat. A smart contract simple executes itself when a condition is verified. What about if the generated transaction has a programming error? Smart contracts are written in computer languages and it is also difficult to read their real content. The short smart contract contained in this paper shows already how difficult this task could be. As powerful as this new technology can be, we may still be several years away from implementing it across the construction industry. There are several reasons for this. For one thing, smart contracts can get extremely complicated. Smart contracts require more than one smart contract to complete tasks. A multitude of smart contracts linked together is often needed to cover all the scenarios that may occur.

Legal aspects are also so far not so clear and defined, will a smart contract have a legal value? Introducing a new organization to prove the legal value will again introduce an intermediary. A Decentralised Autonomous Organisation DAO is thought to address those issues, but right now it is a bit too early to affirm if this model would its validity. The consensus mechanism, well defined for blockchain and bitcoins, could be more complex in a blockchain where technical knowledge need to verify the transactions content. A blockchain made by experts could address this aspect. One important aspect is that Blockchain and its adoption require an incentive, something that will push stakeholders to contribute to build the information asset, this could be a token or cryptocurrency and on a non-economical level a rewarding system. Together with blockchain it is likely that micropayments and tokenisation will be taking the scene in the following years. — The mining reward process remains anyway a separated topic. The question can be then, would a planner accept to work on a project where the cryptocurrency value is volatile, not secure and has limited adoption?

Looking at the forecast, a gradual introduction will be possible in the next two to three years. Is a decentralised technology the solution for a centralised design process? Can blockchain, together with smart contracts, redefine the construction industry business? It is a radical change but potentially, it could happen for real. The technology will improve and offer smart solutions, but the answers are also linked to the economic aspect. The major benefits are clearly on the client side. A more profitable investment in data acquirement for building management use and a complete immutable information asset, using the new technology, will be the key to make this happen.

"Just talking about blockchain or writing reports on it really does not get us any closer to where we need to go. We need to start building blockchain enabled solutions to fix real world problems."

—Bart Suichies

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Glossary[26]

BIM Capability

BIM Capability represents the minimum abilities of an organization or team to deliver measurable BIM outcomes. BIM Capability is the second phase of BIM Implementation and covers many technology, process and policy topics. BIM Capability is achieved/measured through well-defined revolutionary BIM Stages separated by numerous evolutionary BIM Steps.

BIM Implementation

BIM implementation refers to the set of activities undertaken by an organizational unit to prepare for, deploy or improve its BIM deliverables (products) and their related workflows (processes). BIM implementation is made of three phases: BIM Readiness, BIM Capability, and BIM Maturity.

BIM Maturity

BIM Maturity is the gradual and continual improvement in Quality, repeatability and predictability within available BIM Capability. BIM Maturity is the third phase of BIM Implementation and is expressed as BIM Maturity Levels (or performance improvement milestones) that organizations, teams and whole markets aspire to
Also refer to the BIM Maturity Index.

BIM Readiness

BIM Readiness is the first phase of BIM Implementation preceding the Point of Adoption. BIM Readiness represents the preparedness of an organization or organisational unit to adopt BIM tools, workflows and protocols.

BIM Wash

The act of promoting an inaccurate view of one's BIM ability or credentials. BIM Wash applies to all types of BIM Players and can be measured using a 5-level scale: [0] No BIM Wash or no BIM Claim, [1] Confusion or unintentional BIM Wash, [2] Inexperience or mild BIM Wash, [3] Exaggeration or considerable BIM Wash, and [4] Illusion or severe BIM Wash

Blockchain

A blockchain is a data structure that makes it possible to create a digital ledger of transactions and share it among a distributed network of computers. It uses cryptography to allow each participant on the network to manipulate the ledger in a secure way without the need for a central authority [WSJ]. Blockchain can be used to manage and authenticate exchanges of, and changes within BIM Models as these changes and exchanges can be considered digital transactions.

Common Data Environment (CDE)

A single source of information which collects, manages and disseminates relevant, approved project documents for multidisciplinary teams in a managed process. A Common Data Environment (CDE) is typically served by a Document Management System that facilitates the sharing of data/information among Project Participants. Information within a CDE need to carry one of four labels (or reside within one of four areas): Work In Progress Area, Shared Area, Published Area, and Archive Area.

Digital Twin

A set of digital assets – models, documents and data sets - that mirror a physical Asset for part/whole of the Asset Life Cycle. In the Construction Industry, a Digital Twin typically refers to a data-rich 3D model – of a building for example - that represents, reacts to, and can cause changes in the Physical Twin, the actual building. Through Asset Coupling, the connection between the two twins can be either (i) one-way or (ii) two-way, (a) synchronous or (b) asynchronous, depending on their Coupling Level. Higher coupling – through two-way connectedness of BIModels with live sensors, cameras, scanners and Building Management Systems - allows a twin to adjust itself according to the information received from the other. As a simple example, opening a door in one, will open the door in the other. More useful examples include (1) the ability to utilise the Digital Twin to monitor and control the mechanical and environmental

[26] *Source: BIM Dictionary: https://bimdictionary.com*

performance of its Physical Twin; and (2) the real-time synchronisation of digital assets to match any changes in corresponding physical assets

Federated Model

A BIModel which links (does not merge) several Mono-Discipline Models together. As opposed to Integrated Models, Federated Models do not merge the properties of individual models into a single database

Integrated Model

A BIModel which aggregates several Mono-Discipline Models into one. As opposed to Federated Model, an Integrated Model merges all properties of individual models into a single database. Integrated Models are many types including: Design Models (DModels), Construction Models (CModels), Operation Models (OModels) or a full Project Lifecycle Models (DCOModels)

Level 3 BIM

The highest of the UK BIM Levels. Level 3 BIM refers to 'fully open' process and data integration enabled by web services; compliant with the emerging Industry Foundation Classes (IFC) and buildingSMART Data Dictionary (bsDD) (previously IFD) standards; and managed by a collaborative Model Server. This level is also referred to as iBIM (integrated BIM) and may potentially employ concurrent engineering processes

openBIM

The term generically refers to the process of exchanging non-proprietary BIModels and other data. As a trademark, Open BIM is a "universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows. Open BIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model

Supply Chain

An interconnected system of organizations and individuals involved in transforming natural/knowledge resources into a finished product/service delivered to an end user. Supply Chain activities involve the exchange of materials, components and/or information.