Blockchains for use in construction and engineering projects

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ABSTRACT

This chapter describes the technologies that underpin blockchains and illustrates this explanation using the results of a prototype project for an industrial application for a construction project. The chapter describes the application and how modular software components can be used to assemble a blockchain solution. The chapter concludes with a design of the system architecture. The background to blockchain technology includes a description of the evolving nature due to communal, open software consortia and an accelerated prototyping of systems. Four recommendations are made in the chapter. These include: the need to form consortia for prototyping applications, encouraging government involvement, the need for engagement with the open software development community and the suggestion that systems should be designed to support Lean production. A final section offers a range of discussion topics on the current state of the technology and where to expect area of increased interest. These are summarized in three (3) areas: Lean management, Industry 4.0 and Smart Cities, and topics around privacy and security.

Keywords: Automation, Trust Networks, Permissioned Blockchain Infrastructure, Internet of Things, Digital Ledger Technology, Industry 4.0 and Smart Cities.

INTRODUCTION

Perspectives of The Research and a Summary Of The Contents Of The Chapter

This chapter is about private permissioned blockchain networks (Androulaki, et al., 2018; Vukolić, M. 2017) with a general perspective on an emerging suite of interrelated modular technologies that can be used to configured systems for use in construction and engineering (C&E) projects (Zheng, et al., 2018). These so-called industrial blockchains use the same engineering principles as the versions used for cryptocurrencies such as Bitcoin (Nakamoto, 2008). Simply put, both public and private blockchains record transaction data on immutable ledgers (Berg, et al., 2018) that reside on a distributed network of computers.

Understanding how blockchains work and what they can do can be confusing because there is nothing quite like it that can be used for comparison. Broady speaking, applications by blockchains can be devided into two broad categories: blockchains for holding secure documentation such as certificates and authorisations and blockchains optimised for managing transactions. In both sets of these application, the ultimate utility of the blockchain is as a mechanism that institutionalizes trust (Anon.,2015b, Berg, et al., 2017; Werbach, 2018; Weber, et al., 2016).

What sets private blockchains apart and makes them suitable for industrial applications is the modular approach to design and the flexibility of creating applications. This includes the addition of features such as smart contracts, adaptable consensus and ordering algorithm, enhanced security and privacy measures.

Blockchains Used for Secure Recording

The secure handling is data is one of the most important functions of any IT system (see Yue, et al., 2016, for an example in healthcare). What makes storing information on the blockchain different from hosting it on secure database is that its storage and retrieval are controllable, but not dependent on a central authority. Most importantly, those accessing data can not alter it. This immutability is a powerful and very useful feature.

The most obvious application of this type in the Built Environment is for the hosting of building certification. This is particularly important in the construction industry due to the inherent risks to the public from dangerous buildings. A good example of this is the heightened concerns about the safety of buildings due to the risk of fire (see Brokenshire, 2018 or Hackitt, 2018). Updated legislation requires testing and approval across several areas including, but not limited to:

- Building regulations completion certificate,
- Certificate of occupancy,
- Defects certificate,
- Energy performance certificate,
- Established use certificate,
- Planning permission,
- Practical completion certificate and so forth.

Indeed, the final output of most industrial processes requires certification of some form or another before products can be sold to customers. Obtaining these approvals represent some of the most time consuming and bureaucratic aspects of commercial life. Indeed, this and other types of non-productive work are noted in most Government industrial strategy documents for the sector (see Cable et al., 2013 for one example). Several case studies of prototype systems have been published, for instance, for digital diplomas and educational qualifications (Jirgensons & Kapenieks, 2018). Other process, such as the registering the qualifications of staff, or preserving warranty contracts, might also benefit from an application of DLT (Cheng et al., 2018).

Note: The official certification as described in this section should not be confused with the Certificate Authority (CA), which is required by the cryptographic protocol to manage access to secure computer networks.

Blockchains Used for Managing Transactions

Blockchains can be also be used to record transaction details (see Chapron, 2017). These can be very useful, for example, for those managing complex supply chains with multiple layers of suppliers and customers (Hultgren and Pajala, 2018; Turk and Klinc, 2017, Penzes 2018). In these situations, and by recording the full chain of transactions, the blockchain is capable of providing a rich data-stream and the ultimate digital paper trail. With further enhancement, the system could also be made to administer automation, such as with secure payments (Wang et al., 2018a). These payments could be made independently of any central authority, a feature particularly useful when trading partners are not entirely trusting of each other and when delays in payment introduces additional financial strain (Tapscott and Tapscott, 2017; Carroll and Bellotti, 2015). Indeed, further automation of a range of assembly and administration processes could provide broad benefits across the construction industry and to help improve issues of low productivity and profitability (Heiskanen, 2017; Barbosa et al., 2017).

But there are more significant trends that are shaping how communication and IT are being applied and where blockchain could play a significant role, notably, the Internet of Things (IoT) (Delgado-Mohatar, et al., 2020; Panarello, et al., 2018) and Industry 4.0 (Lee, et al., 2019). These concepts, which are closely related, are based upon technology already in use in consumer as well as industrial settings, such as big-data analytics, artificial intelligence embedded systems, wireless sensors, control systems and automation. The key aspect of both established and emerging technology is that they based on machine to machine communications (Afanasev, et al., 2018) and therefore need a secure data-layer, which is the role that the blockchain can provide.

In order to clarify this role in this new technological environment, consider for a moment the example of an autonomous vehicle moving across a conurbation caring paying passengers and cargo and passing through several municipalities on its way. As it traverses the city, it uses a combination of public and private toll roads along which it picks up and discharges passengers and cargo. Near the end of the trip, the autonomous vehicle, which is battery powered, sells its excess power at a favorable rate. What characterizes this imaginary journey is a series of transactions. These transactions come in many forms as shown in Table 1. In this figure, the type of asset is listed along with the transactor (seller) and custodian (buyer). These transactions are recorded on different blockchains depending on the type of asset.

Table 1 contains a list of transactions performed between an autonomous vehicle (numbered 1 in this example) and several clients and customers represented on the blockchain as transactor and custodian of an asset.

Transaction	**Asset:**	**Transactor of asset:**	**Custodian of asset:**
Vehicle 1 picks up a passenger	Unit human transport	Passengers 1	Vehicle 1
Vehicle picks up cargo	Unit cargo transport	Customer 1	Vehicle 1
Vehicle pays toll on Road 1	Unit use of road	Vehicle 1	Municipality 1
Vehicle 1 picks up a passenger	Unit human transport	Passengers 2	Vehicle 1
Vehicle pays toll on Road 2	Unit use of road	Vehicle 1	Municipality 2
Vehicle discharges excess energy	Unit of electrical energy	Vehicle 1	Local energy collective

This example shows how blockchains form an essential component of semi-automated systems as they can be configured as trusty recording devices for interconnected and distributed services fundamental for the Internet of Things (Christidis and Devetsikiotis, 2016). Effectively, blockchains can add a layer of reliable data on transactions within a trading network that can be used by multiple entities.

Automation in this area is needed as IBM, Cisco and IDC, amongst others, have estimated the number of (partially) connected devices already in use to be in the billions (International Data Corporation. 2020) and that numbers are likely to double within a decade. These devices are expected to interact with each other though the exchange of data and to relay, often with some analysis included, the information elsewhere.

As a rule, assets can be any tradable entity, such as units of transport, or energy or a measure of work performed. If it can be represented in digital form, then the trade in an entity can be recorded in a blockchain. In practice, private permissioned blockchains record *state changes* to assets. In blockchain terminology, the transactions would all possess a *state*. Examples of this would be *issued, assigned, sold, rejected* or some other qualification that describes the asset.

This section provides a glimpse into some of the potential applications of blockchain technology. But to be useful, the blockchain must also be capable of integrating with other systems, such as databases, messaging systems and websites. These additional elements make up a complete system (Xu et al., 2019) that is collectively referred to as Digital Ledger

Technology (DLT). The terms blockchain and DLT are used interchangeably throughout this chapter.

Who is This Chapter for and How Will the Contents Assist in Technology Implementation and Adoption?

This chapter is intended for practitioners who are required to monitor the timing, quantities, quality and other measurable factors within a complex trading network and who want to make use of DLT to provide monitoring and other useful services. Amongst these are managers who have an interest in automating certain aspects of their administrative, assembly or manufacturing processes and want to be able to integrate these process with other entities, such as their suppliers, customers, banks, insurance companies and government regulators.

Users of the chapter are likely to be those who want to engage with the technology-rich, data-driven and interconnected ecosystem exemplified by the internet. It is with some optimism that blockchain technology is described in this chapter as there is often reluctance by the industry to seek out and use new technology (Waterhouse et al., 2019) or for engaging in collaborative relations with suppliers and clients (Akintoye and Main, 2007). However, new paradigms such as Modern Methods of Construction (MMC) (Raynsford et al., 2016; Pasquire & Connolly, 2002), smart cities and the Internet of Things are compelling change.

Aims and Objectives of The Chapter And A Summary Of The Contents

The long-term aim of the research group is to design, test and implement applications of novel technology into the constructing and engineering industries. A big part of this is to understand the system requirements, scope of the managerial task and the skill levels required to effectively design and deploy the technology.

The short-term objectives of this chapter are as follows:

Objective 1: To explain private permissioned blockchains and the extended version, digital ledger technology (DLT).

Objective 2: To explain the modular components of DLT.

Objective 3: To illustrate the design principles and implementation process for a DLT using an prototype example done using business process modelling.

Objective 4: To show, by example, how DLT can be applied to facilitate services in construction and engineering projects.

Objective 5: To propose a system architecture for a DLT solution that can support C&E projects.

Objective 6: To provide a set of recommendations for those with an interest in seeing blockchains develop further.

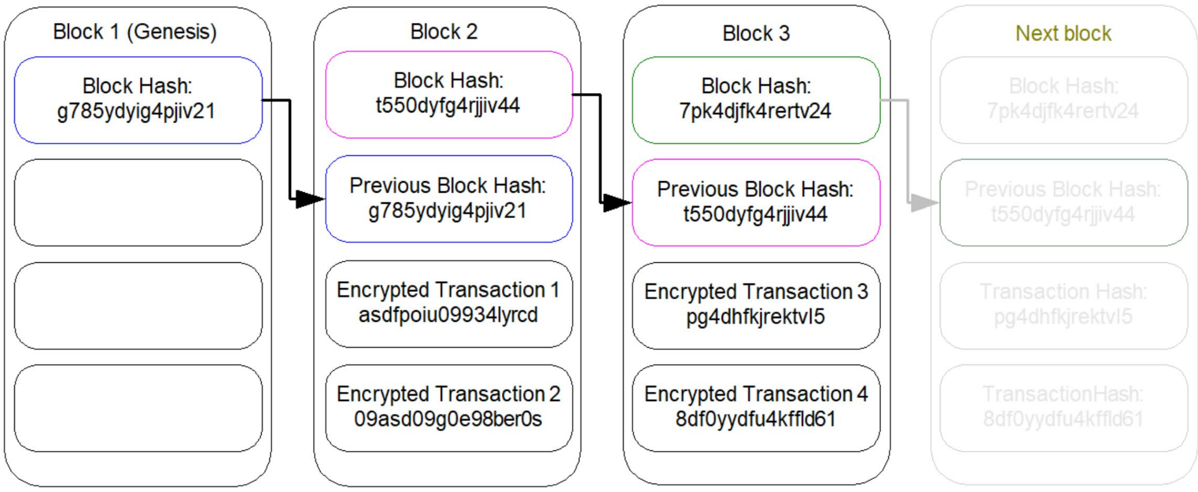
Objective 7: To introduce a set of discussion topics on the future technical development and expanded applications.

BACKGROUND

Basic Description of A Blockchain

In its most basic form, a private permissioned blockchain is a computer file that resides on nodes of a computer network and is used as a ledger to record transactions between users. An example of a fragment of a blockchain file is shown in Figure 1.

Figure 1 contains a schematic diagram of a typical blockchain file. In this example, 3 completed blocks of data are ordered sequentially, with the leftmost (the so-called Genesis block) being the oldest. A fourth block (shown as rightmost rectangle that is shaded out) will be completed once the information has been authorised through the consensus algorithm.



In this diagram, the three large vertical rectangles represent the *blocks* from which the blockchain derives its name. These contain several separate elements that include *hashes* (a form of encryption) and encrypted (i.e. *a cipher of*) transaction records. Each block also contains a hash of the previous block, creating the *chain* part of the blockchain. The design of the blockchain is based around three technologies. These are: cryptography, distributed systems on networks and consensus algorithms (Wang et al., 2018b). Since cryptography is used throughout the DLT, it will be described first.

Blockchains achieve immutability by the clever use of the cryptographic hash function (CHF), public key cryptography (PKC) and a consensus and ordering algorithm. The CHF is a mathematical function that is very useful as it converts data of an arbitrary size (for example, a message or a password) to a string (or *hash*) of a fixed size. There are no passwords involved and it is nearly impossible to decrypt them once they have been hashed. Hashes have some very useful properties, for example, miniscule difference in the original text makes for large difference in the hashed versions. This feature makes the CHF useful for common tasks such as comparing files. In a similar manner, CHF is also good for identity management as a hashed password allows comparison with a stored copy without having to reveal the original text. Finally, the CHF is the key technology in the blockchain that is used to ensure that the chain of records contained in a blockchain cannot be altered as it would interfere with the propagation of hashes that are used to link one block to the next.

An example of this is shown in the sixteen-digit hexadecimal hash (representing 64-bit encryption) shown in Figure 1. A crucial stage when building the blockchain comes when the multiple copies of the blockchain held by the peers are compared. The CHF makes it easy to spot the altered or false files and renders the blockchain immutable (Finck, 2018). Cryptographic algorithms, used in this and other areas of the DLT, ensure a level of security (Banerjee, et al., 2018; Szabo, 1997) that protects against hostile attempts to alter the details of the transactions and is consistent in ensuring the existing standards for computer security in the Built Environment (PAS 1192-5., 2015).

Private key cryptography (also called *asymmetrical key*) or PKC, is another mathematical curiosity (see Singh, 2000). In PKC, users are issued with a unique pair of numbers by a trusted certificate authority (CA). One – the private key – is kept secret, while the other, the so-called public key, is visible to all. The public key of the pair is used to encode a message that can only be decoded with the private key (Rivest, et al., 1978), thus ensuring secret communication.

Indeed, the technology is so powerful that it has been automated and used extensively throughout the internet to protect websites and their client. This application of the technology known as private key infrastructure (PKI). PKI makes use of a Transport Layer Security (TLS) Certificate Authority, which analogous to the CA, issues key pairs. TLS protected communication creates secure sites that are identified by the lock icon on the browser address pane. It is also used for email, instant messaging, *WhatsApp* and voice over IP (VoIP) services.

A simple analogy to these two related technologies can be envisioned by considering historic secret messaging. Before modern methods evolved, classical ciphers were used extensively for secret communication. In most cases, the message written in code and the envelope that carried it was sealed with an elaborate wax imprint that ensured it would remain closed until it reached the intended recipient. Even the messenger could not open it during delivery. The message in this case is analogous to the PKC with the key pair issued by a CA. While the sealed envelope is analogous to the security provided by the TLS certificate.

PKC and PKI are used extensively in DLTs for maintaining private data, securing immutability and for ensuring the legitimacy of users. Figure 1 and Figure 2 are useful for understanding this multi-layer of cryptography. Figure 1 shows how the blocks contain an encrypted version of the transaction records tied together using CHF with the message itself encrypted with PKC. Figure 2 contains the decrypted version of this record and demonstrates information useful for project management such as transaction number, time of transaction, component number and so forth.

Figure 2 shows a typical record contained as an encrypted hash within a blockchain. These data are normally encrypted and incorporated into the chain of information that makes up a blockchain. This transaction record was written went the Clerk of Works assigns the component to the installer. Further details of this example are provided in this and following sections.

Unique transaction number:	223
Component number:	25
Time of transaction:	14:52:23
Date of transaction:	June 6, 2020
State of asset:	Installed
Location:	A46P
Drawing number:	BGH58091
Transactor of asset:	Clerk of Works
Custodian of asset:	Installer

← Transaction `asdfpou09934yrcd` decoded with key

<u>From A Basic Blockchain To A Modular Digital Ledger</u>

This section describes how the consensus and ordering algorithm along with the distributed network, ensure that the information held in the blockchain is immutable and available to those with the correct permission (Cachin and Vukolić, 2017; Swanson, 2015). In these, cryptography is used extensively.

At the top level, the use of digital signatures allows only legitimate transactions to be submitted to the blockchain. Further steps are taken to permit transaction records to be added as they must fulfil the requirements of the consensus and ordering algorithm. For cryptocurrencies, like bitcoin, the most common form of consensus algorithm is proof-of-work (Anon., 2015a), a time and energy intensive operation where banks of computers crunch through the algorithm in order to confirm the authenticity and order of the transactions. In these blockchains, there can be thousands of nodes with multiple copies of the blockchain held and reaching consensus can be a time and energy consuming activity.

This is not the case for private permissioned blockchains, which may host only a handful of traders and the consensus policy is therefore relatively straightforward and used mainly to facilitate the codification of basic trading rules between members. If properly configured, consensus makes it difficult for fake, falsify or enter the same transaction more than once. In real trading environments, double entry is of concern as they are common and can be costly. Additionally, fake ledger entries of this sort are hallmarks of organized crime (Beare 2007, p43). In this way, a private permissioned blockchain consensus algorithm provides project governance.

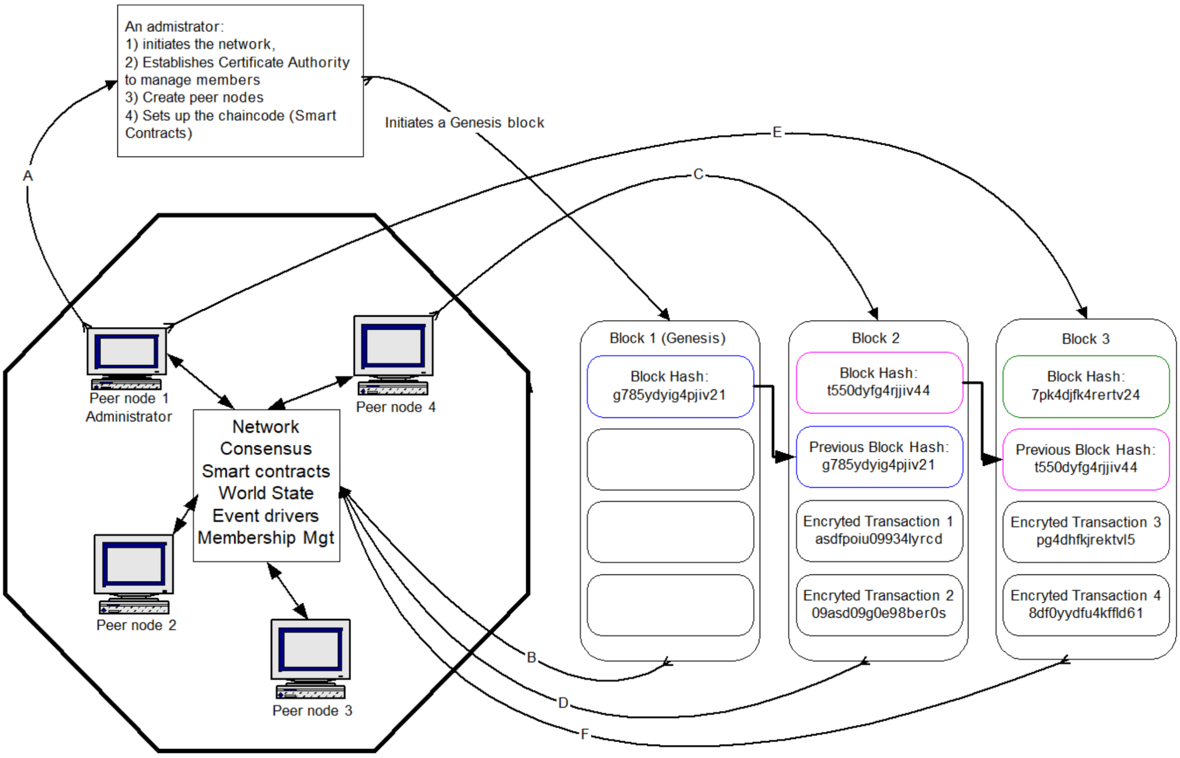
Hyperledger Fabric (HLF), a framework implementation for a public permissioned has been developed specifically for industrial applications (Hyperledger Foundation, 2017; Dhillon, et al., 2017; Vukolić, 2016). It has a consensus and ordering algorithm where members submit proposals for transactions that route through a series of checks and confirmation, differentiating the roles of ordering and ordinary peers. This routing allows the application of a multiple level security setup that ensures transactions are legitimate and ordered correctly.

Distributed systems are the other technology that make the blockchain feasible. Blockchains exist only because they can be shared by nodes across a network. Key to these working is, of course, the internet, which provides the language and physical systems that permit communication and coordination with securing messaging. Secure messaging has become so commonplace that we take it for granted. For example, when we do a web search to find the website of a retailer. Peer-to-peer applications play the largest role in the function of the blockchain. A good example of peer-to-peer systems is the popular file sharing application Napster (Steinmetz & Wehrle, 2005). Napster allowes users to connect directly to other computers (sometimes illegally) and to download files made available for the purpose of sharing. Other applications of the technology allow the computing power of multiple computers to combine to form virtual supercomputers and extended file systems.

In order to maximize the reliability of the system, HLF uses a networking protocol known as *Byzantine fault tolerance* (Lamport et al., 1982) to ensure that the data and chaincode are preserved when one or more of the nodes goes out of service or, for some reason, contains false information. In addition to BFT, the design for most industrial blockchains requires the use of a central repository. Fortunately, cloud services with blockchain platforms are available through Oracle, Amazon and IBM, to name only a few.

In order to illustrate these concepts further, consider the diagram in Figure 4. This flow chart maps the transactions of an *asset* between members of a trading network (referred to as *Nodes* in this example). The asset being traded could be any entity that is able to be represented by digital data, for example, a quantity of materials or the delivery of a building component.

Figure 3: This diagram shows a simplified schematic of how the core blockchain functions. It is a flow chart describing how transactions are recorded on a blockchain. Arrows show the direction of the records as transactions proceed and are written to the blockchain. The sequence in this flow chart follows alphabetical order starting with A and culminating with the final block being written at F.



The initiation of the network starts when Peer node 1 establishes the network and performs a series of tasks, such as setting up a certificate authority for public/private key encryption on the network. This closed, permissioned network is represented by the central octagonal box. In this scenario, the system administrator also sets up a world state database, configures the consensus algorithm and invites members to join the network. This action is represented by the arrow labelled **A** in the figure. The act of establish a network starts the process where transactions can be recorded. Trading records are sent to the Peer nodes (represented by the arrow labelled **B**) for confirmation via a network consensus and protocol to create the Genesis block. The arrow labelled **C** shows Peer Node 3 writing two separate transaction to the network. Included in this newly written Block 2 includes the hash of the previous block. Block 2 is created only after it has been confirmed and verified by the consensus algorithm. This is shown by the arrow labelled **D**. This process is repeated when Peer node 1 sends 2 transactions to peers to await the creation of Block 3 (**E**). This, in turn, includes the hash of the previous Block 2, again only after consensus confirmation has been confirmed (**F**). At each stage of this process, the nodes within the network contain identical versions of the blockchain file and will continue to do so until the next transaction is proposed.

From Module DLT To A Functioning System Suitable for Industrial Applications

The in the previous sections the basic elements that characterize Blockchains are described. In summary these are:

Item 1: A replicable ledger with the history of all transactions that are added sequentially and have an immutable past held on files that are replicated across a network.

Item 2: Business logic, in the form of embedded smart contracts, are executed along with the transactions.

Item 3: A consensus and ordering service that ensures a decentralized protocol that can be used to control inevitable disruptions and to allow the transactions to be validated.

Item 4: In all these elements, cryptography is used to ensure the integrity of the ledger, the privacy and authenticity of transactions and the identity of participants.

In this section, an example is provided of a trading network for the supply and installation of building components that will illustrate the four (4) items listed above. In this scenario, components are designed, ordered, delivered, installed, inspected, certified and paid for while recording all these transactions to a blockchain. Such a trading network would require the contribution of multiple participants, some of whom, like the shipper or installer, have only minor roles the in the process. While others may be involved with several activities of varying importance. For such a system to work, it would have to be able to record all commercial activity on a set of blockchains and to allow for the eventually of multiple pathways. This type of commercial scenario could benefit from the application of a DLT in several ways and HLF provides a good modular design platform (Syed, et al., 2019).

SYSTEM DESIGN FOR PROCESS MODELLING

Design Principles for Industrial Applications

In addition to the elements listed in the previous section, design objectives are required to implement the system and introduce automation to the process (see Li, et al., 2018). These design principle are:

Item 1: The recording of transactions between traders in an extendible network to immutable blockchain ledgers in a way that eliminates data discrepancies and allows simultaneous multi-party collaboration with data accessible to all parties in real-time.

Item 2: The ability to establish multiple trade channels or sub-networks, each with separate blockchains. Nodes have the capability to handle multiple blockchains and the freedom to trade within as many networks as feasible.

Item 3: The capability for select transactions to trigger events such as sending email messages, automatic invoice creation, payments and proof of delivery.

Item 4: Support easy deployment of smart contracts that can aid in the realistic modelling of business processes that is expandable to include multiple return loops.

Item 5: Provide a data streaming service to allow linking of the transaction records with other technology, such as IoT, artificial intelligent, business analytics and to extend the system to uses such as production and performance modelling.

Item 6: Enable a high degree of security and privacy at a level appropriate for commercial operations. This includes the adherence to General Data Protection Regulation or GDPR (Trong, et al., 2020).

Item 7: Provide membership management and a certificate authority to ensure that members and peers' identity is authentic and that they are authorized to invoke transactions within a channel in a blockchain network.

Item 8: That it provides a high degree of reliability to guarantee robust operation in industrial settings.

Business Process Modelling

Obtaining useful services from blockchain technology requires that the business process is codified in the programing language of the DLT. This mapping process uses a combination of flow and swim lane charting (Chang, et al., 2019; Auberger and Kloppmann, 2017) and done using the artifact centric business process model (Damelio, 2016; Nigam and Caswell), where multi-thread and multi-component processes are organized around service provision to online clients (Waller, 2003). Business process mapping (BPM) is seen as one of the fast-growth technology areas as it is an enabling technology underpinning the IoT (Miller, 2019) and a process for use in the automation for online commercial sites that are accessed by distributed, client-side applications (Viriyasitavat et al., 2018) with graphical and model-driven tools for the blockchain business network (Seebacher and Maleshkova, 2018).

Figure 4 is a flow chart that shows the process of installation of the component that was made off-site. Those involved in this, project manager (PM), Building Control (BC), Contract Administrator (CA), etc are listed in the membership table.

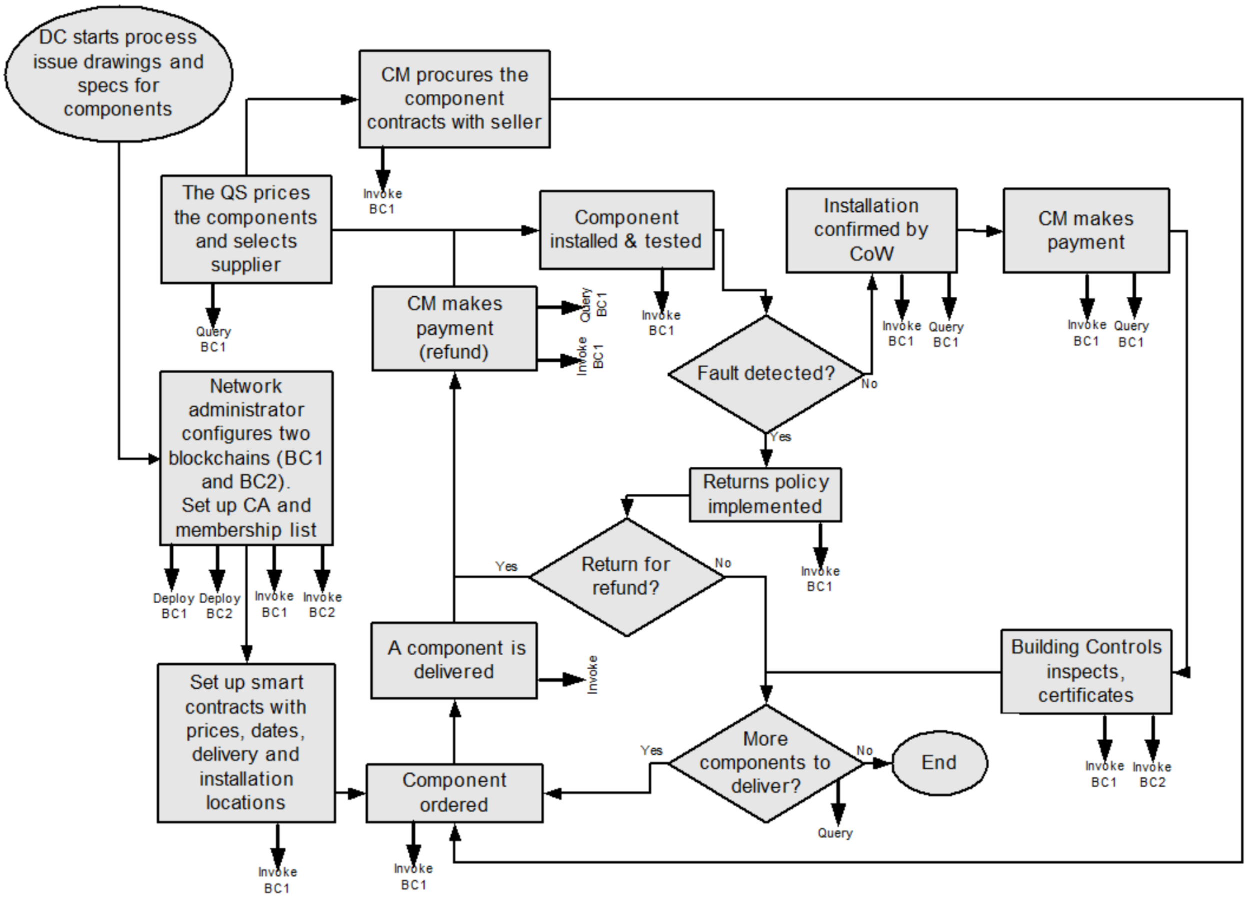


Figure 4 contains a flow chart of a business process describing a building component installation cycle. The flow chart shown here is a simplification of the typical real-life ordering, installation cycles. There are numerous branches not included, for example if the component fails during the warranty period. However, one of the main advantages of DLT is that the transaction variables (or states) can be easily added to cover all eventualities. This amounts to a democratization of the data collection process. In the simplified scenario shown in Figure 4, the *states* of transaction for blockchain 1 (BC1) are as follows:

State 1: Design approved

State 2: Price agreed

State 3: Component ordered

State 4: Component delivered

State 5: Component installed

State 6: Component inspected

State 7: Component Invoiced

State 8: Component paid for

State 9: Component rejected

For Blockchain 1 (BC2), which contains the installation certificate, there are only two states which are:

State 1: Not certified

State 2: Component certified

Other states of the BC1 transaction exist in a more completely modelled systems, for example, *component failed*, *warranty period exceeded*, *payment delayed*, *delivery delayed*, *invoice greater than quote*, for a few examples. Any of these states could trigger automatic action in invoking the blockchain. For example, if *payment delayed* is greater 5 days, then a penalty is automatically added to the invoice. It is this infinitesimally fine recording of transactions that offers the most promise for the management of C&E projects as it would provide the data required for Lean management.

For the example used in this chapter, a swim-lane chart (Damelio, 2016), shown in Figure 5, contains the chain of transactions that indicate the shifting state of the blockchain. Using this in conjunction with the flow chart allows an iterative approach to modelling to achieve an accurate representation (Garcia-Bañuelos et al., 2017) of the business process leading to the schedule for the DLT coding.

Once the blockchain has been *deployed* by the System Administrator (SA), transactions in this (simplified) example process can start. The Design Coordinator (DC) submits a set of drawings to a communal repository so that the QS can price the component and set up the terms of the contract. Once approved by the Commercial Manager (CM), this allows the CM to *Invoke* the transaction to order the component (BC1 is changed to State 3). In this swim lane chart, the process proceeds downwards with the state changing at every invocation of the blockchain until the component is invoice, then paid for. Finally, the Building Inspector (BI) provides certification, a transaction that is stored on another blockchain (BC2, in this example). The cycle then returns to the top with the delivery of another component.

Figure 5 contains a swim-lane chart for the example of a DLT in a C&E project that involve the cycle of transactions required to install a series of building components. The rightmost box on the top of the figure represents the blockchain and the arrows indicate that the members of the network, who are also identified in the boxes across the top, write to the blockchain.

	Abbr.-->	NA	DC	CM	QS	SU	SH	IN	CoW	BI	BC
Action	Blockchain	Network administrator	Design coordinator	Commercial manager	Cost consultant	The supplier	The shipper	Installer	Clerk of Works	Building inspector	**State**
Network design	Deploy BC1 Deploy BC2										BC1: 0 BC2: 0
Design approved											BC1: 1 BC2: 0
Price approved	Invoke BC1										BC1: 2 BC2: 0
Component ordered	Invoke BC1										BC1: 3 BC2: 0
Component rejected	Invoke BC1										BC1: 8 BC2: 0
Component delivered	Query BC1 Invoke BC1										BC1: 4 BC2: 0
Component installed	Invoke BC1										BC1: 5 BC2: 0
Component inspected	Query BC1 Invoke BC1				\						BC1: 6 BC2: 0
Component invoiced	Query BC1 Invoke BC1										BC1: 7 BC2: 0
Component paid for	Invoke BC1										BC1: 8 BC2: 0
Certification	Invoke BC2										BC1: 7 BC2: 1

Note that two independent blockchains are *Deployed* in this example. The first one mirrors the paper contracts between the client, shipper, and supplier. The other blockchain (BC2) is used to store official certification documentation. To add a record to this the, Building Control (BC) regulator *invokes* a transaction to the blockchain with a record that contains certification information that is required for the safe occupancy of the building. This digital certificate is repeated for each component installed done in accordance to the building code and serves as an official mark of compliance. Certificates written to the blockchain can be read by anyone with access privilege.

Some members of the network receive signals (in the form of a text message, email or other form of notification) when an event is triggered to indicate that action is required. For example, the Installer (IN) would receive notification on his mobile device when a component is ready for fixing into place. The exact location (floor and room number) for each component would also be conveyed in the DLT, so that, for example, the crane operator, plumber and other technicians can play their roles. In this section an example is provided that describes a prototype example of the DLT used in a industrial setting. In the Conclusion of this chapter, the elements that make up an industrial blockchain using modular DLT technology are explained along with the development framework that is used for testing and for prototype systems.

CONCLUSION

This section concludes the chapter with a description of a suitable development framework and architecture for the application of DLT to C&E projects. The first part of the conclusion introduces the HLF framework, describing open source development where professionals in academia, industry and the not-for-profit sector collaborate to advance this complex and novel technology. Essential aspects of the design, such as membership management and the system architecture are detailed and illustrated with the same example as in previous sections. A short sample of code written in JavaScript provides an example of how business and data models are written. The section finishes with an observation on the current state of the technology, the prospects of adoption by the construction industry and finally, a list of recommendations for readers of this chapter who would like to see the DLT advance. A brief discussion on future topics for research the chapter.

The Hyperledger Fabric Software Framework and Open Source Development Environment

The Hyperledger Fabric (HLF) is a framework implementation based on a series of projects (Androulaki et al., 2018) by the Hyperledger consortium (Hyperledger, 2017) and developed with open software principles. This development was coordinated and partially financed by the Linux Foundation, which set up the Hyperledger Project in 2015. See Söderberg (2015) for a general overview of the open source movement and Glaser (2017) for a discussion related to open source blockchains that are hosed by the not-for-profit Linux Foundation®.

Consortium members are from a wide range of organization. These include technology platform companies (such as Cisco, Hitachi and IBM), banks (ABN AMRO, BNY Mellon and others), software companies (SAP, IBM and others) and academic institutions (Columbia, UCLA and others). In open software development communities' members are often collaborating with each other at one level and then competing on another. The main advantage of open source collaboration is that it speeds up development time, spreads the risk inherent in software projects, encourages a modular approach to problem-solving and spurs innovation.

Ironically, it is the private permissioned DLT development that requires broad collaboration between industry, academic and not-for-profit organizations. Whereas, the widely used and familiar public blockchains (like *Bitcoin, Altcoin* and *Ethereum* to name only a few) are developed and maintained by small groups, working mostly with proprietary systems. The reason for this is the complexity and cost of development and the overriding requirement for broad agreement on standards and system compatibility.

Within the Hyperledger Foundation, different organization finance and champion frameworks, understandably with functions and application along the lines of the contributors. For example, the two main backers of the Fabric framework, IBM and Digital Assets Holdings (a well-financed start up based in New York that offers a turn-key cloud based DLT focusing on financial institutions that require secure and quick settlements of large transactions), have a customer base that drawn mostly from large trading and manufacturing (i.e., industrial) organizations. Other big contributors to Hyperledger are Oracle, who support frameworks associated with database use, while Intel has put effort into Hyperledger Sawtooth, which points to future growth area for that company.

The Hyperledger Consortium is overtly organized around the development of software for use in industrial settings and encourages the organization of consortia around supply chains. There is, for example, an active working group on open protocols and standards using a framework that is suitable for a range of use cases, some of which have been presented and elaborated in this chapter. The Hyperledger management has stated publicly that it would not develop application for a bitcoin-type cryptocurrency.

Since 2016, the project has been supported by a combination of large companies and well-financed startups. For example, HLF itself was created as an output of a joint project between Digital Assets, Blockstream's *libconsensus* and IBM. Digital Asset Holdings, LLC is an ambitious startup that develops and sells the high-level development language DAML, which is discussed later in this chapter.

Membership management

One of the key requirements of the DLT is the capability to provide basic membership management, to ensure that members identity is authentic and that authorization to commit transactions to the correct channels on the blockchain follows the business process modelling.

In HLF, membership profiles are initially controlled by the system administrator (López-Pintado et al., 2018) and extended to both members and consortia of members as the network develops. Operating through a software development kit (SDK), the system administrator can initiate, build and maintain the network add members and control events. In HLF the membership manager can create, stop, change the configuration or, if required, delete the peers (Dunphy and Petitcolas, 2018). Members in HLF do not need to be attached to a Peer. For example, the shipper, responsible for delivering components on site would be able to query the DLT (or be prompted by a message) for the expected time of delivery, then once one site, register the delivery with a countersign by the site foreman. This could all be done using RFID tags, digital signatures, drop down menus and tick-boxes on module devices. Indeed, much of the functionality and intelligence embedded in the system is based on the user interfaces which can limit the choices of how a member interacts with the blockchain.

To understand the basics of membership management, the example project continues with a description of its members, their roles in the project and how they interact with the blockchain. This is show in Table 2.

Table 2 showing the members in the network with their roles, activities, and transaction on the blockchain. These are associated with the mobilisation of building projects using a blockchain to record transaction and chaincode in a commercial setting.

Role	Abbr.	Task(s) in the project	Actions on the blockchain
System administrator	SA	Models business and processes, maintains membership and ensures network operates as designed.	Deploys network, creates channels & smart contracts.
Design coordinator	DC	Delivers as-built design, ensures that drawings are up to date and complete	Evokes BC1: State 1: Design and price approved.
Commercial manager	CM	Procures and orders components, delivery schedule, price, warranty period and other contract details.	Evokes BC1: State 2: Component ordered
Cost consultant	QS	Produces costs and suppliers for procurement	Confirm payment Evokes BC1: State 7: Paid for.

Supplier	SU	Produces the components in accordance with the contract and schedule as provided.	Evokes BC1: State 3: Component delivered
Shipper	SH	Delivers components in accordance to the schedule.	Queries BC1: Times for delivery.
Installer	IN	Receives the building plans from the dc and program from the PC and a signal from the SF when the component is ready for installation.	Queries BC1: to sync with the program, then evokes blockchain to confirm installation.
Clerk of Works	CoW	Confirms and inspects installation of the components.	Evokes BC1: State 5: Component inspected.
Building inspector	BI	Issues certificate of compliance for Building Control.	Deploys BC2. Evokes BC2: certification of compliance.

The members shown in Table 2 are linked to the business process as outlined in the flow chart shown in Figure 4 and the swim lane chart in Figure 5. To show this, a fragment of computer code is displayed in Table 3. This code is written in the popular *JavaScript* language and is part of a larger file that includes the smart contracts and business logic.

Table 3 contains a fragment of code used to define the business process used in this chapter. The fragment contains the object definition and one of the `CreateOrder` call. Note the same calls are used in the examples provided in the text.

```
var orderStatus = {
          Approved: {code: 1, ‘Design approved’},
          Agreed: {code:  2, ‘Price agreed’},
          CreateOrder: {code:  3, ‘Component ordered ’},
          Delivered: {code:  4, ‘Component delivered’},
          Installed: {code:  5, ‘Component installed’},
          Inspected: {code:  6, ‘Component inspected’},
          Invoiced: {code:  7, ‘Component Invoiced’},
          Paid: {code:  8, ‘Component paid for’},
          Rejected: {code:  9: ‘Component rejected’},
          Dispute: {code: 9, text: 'Order Disputed'},
          Resolve: {code: 10, text: 'Order Dispute Resolved'},
          PayRequest: {code: 11, text: 'Payment Requested'},
          Refund: {code: 12, text: 'Order Refund Requested'},
          Refunded: {code: 13, text: 'Order Refunded'},
          SuccessTestAndInstallation: {code: 14, text: 'Test and Installtion Successfully'},
          FailTestAndInstallation: {code: 15, text: 'Test and Installtion Failed'},
          ShipRequestBackOrder: {code: 16, text: 'Ship Request Back Order'},
          NotInstalled: {code: 17, text: 'Component Has not Installed'},
};
/**
 * Create Order transaction processor function.
 * @param {org.example.basic.CreateOrder} inputInfor - the order to be processed
 * @transaction
 */
async function CreateOrder(inputInfor) {
  if(inputInfor.order.status !== JSON.stringify(orderStatus.OrderCompleted)){
  inputInfor.order.commercialManager = inputInfor.commercialManager;
  inputInfor.order.supplier = inputInfor.supplier;
  inputInfor.order.createdDate = new Date().toISOString();
    inputInfor.order.status = JSON.stringify(orderStatus.Created);
    let assetRegistry = await getAssetRegistry('org.example.basic.Order');
    await assetRegistry.update(inputInfor.order);
    let factory = getFactory();
    let basicEvent = factory.newEvent('org.example.basic', 'BasicEvent');
    emit(basicEvent);
  }}
```

In the fragment contained in Table 3, the variable *`OrderStatus`* is created. This variable is used to pass information on the status of the order to all members in the network. The function *`CreateOrder`* is included in this sample to show the way that the logic around ordering a component is coded in JavaScript. The full logic of this trading network includes several hundred lines of computer code and extends to define all possible states of the component. HLF has the advantage of hosting popular computer languages so that the networks can be set up and deployed by programmers with common language skills.

Digital Ledger System Architecture

The example prototype system described in this chapter sets the requirements that dictate a system architecture that is illustrated in Figure 6. This architecture includes the following elements:

Item 1: A system administrator that can design and establish the initial configuration of the system, manage deployment of smart contracts, define and set the endorsement, consensus and ordering algorithm, invite members and ensure that the integrity of the data is maintained in a secure private server.

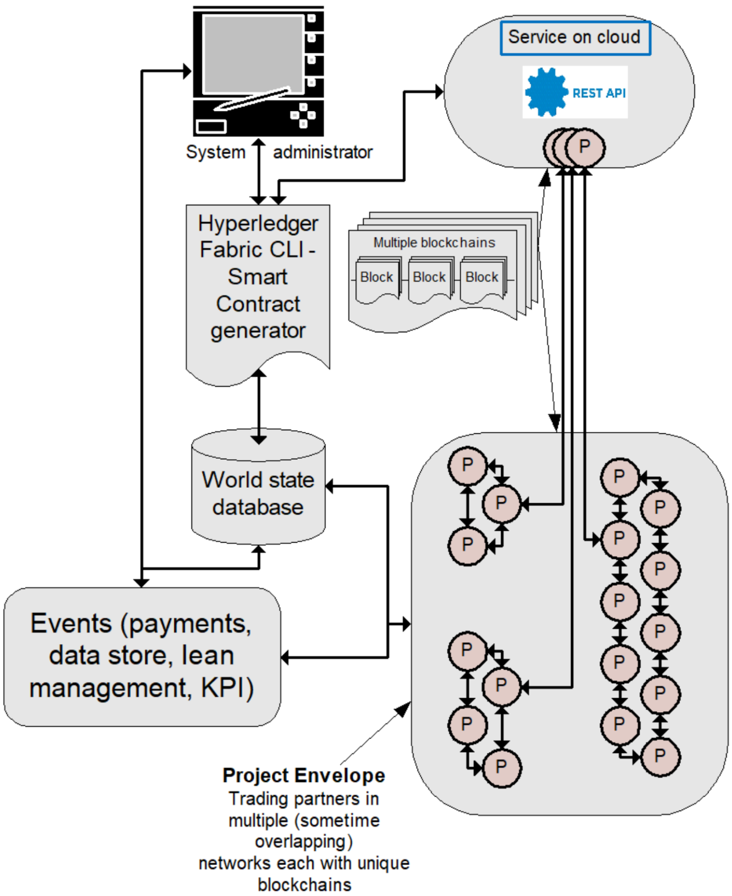
Item 2: Manage the World State in the form of a readable database that contains records of transactions and the status of the assets,

Item 3: Maintain the peer network (through membership recruitment) that contains the distributed ledgers and associated systems associated with the DLT and its applications.

Item 4: Implement and maintain an events management system as a modular component of DLT and ensure that this provides adequate communication and notification.

Item 5: Ensure that a suitable cloud service ("service on cloud") that can act as a secure data and system repository.

Figure 6 contains the basic system architecture of the DLT that includes the administrator and developer, smart contracts, world state database, peers and events based upon the HLF implementation. Peers are identified by the symbol 'P'. Other components of the system are described in the text.



The network developer and administrator, shown near the top of Figure 6 share a range of responsibilities in the deployment and administration of the DLT. Significantly, the system had the capability to manage separate sets of ledgers (i.e. blockchains) for each channel. Multiple channels are essential in that they that allow trading partners to maintain privacy. This protects confidential commercial data, but still allows mission-critical information such as the delivery date, warranty details and maintenance instructions, to be available for a wider audience.

What is not shown in Figure 6 are some of the finer features of the DLT, notably how the consensus algorithm works and the way that smart contracts are embedded into the core blockchain or how the interface uses pull-down menus, check boxes and other forms of browser-based information exchange to interact with the DLT.

Summary of the Objectives of the Chapter

This conclusion fulfils the objectives set out at the start of the chapter. By first describing the three technologies underlying an industrial blockchain and then providing a realistic use case for a prototype system, a system architecture is described. The rational for using a private permissioned blockchains, with a limited form of centralized control, is demonstrated as necessary in complex, supply-chain based trading networks. This and a set of factors on engineering requirements point to a modular architecture. Hyperledger Fabric provides a good framework for this, but it is the introduction of high-level language implementation, such as DAML, which will make programing of DLTs easier.

Whatever the software chosen, business process modelling is needed based on a set of design principles (see Eynon, 2013) to produce a data model and a business process (or governance) model. These tasks are exemplified by a flow chart and a swim lane graph.

To fulfil the additional objectives of the chapter, recommendations are made in the interest in progressing the technology and to ensure engagement with the data-rich and highly interconnected digital future that is predicted to revolutionize manufacturing, commerce and the built environment. Finally, to complete this chapter, a set of discussion topics on areas of active research interest is included.

Observations on the State of the Technology

At the time of writing, DLTs are still not being used on a regular basis in C&E projects. Part of the reason for this is that a full-featured, commercial system that is easy to deploy and manage, is not yet available. Numerous prototyping projects have presented their results and at least one startup has the skills to design and implement a working system. It will still take major effort to turn a prototype into a robust working computer system capable of working reliably in a commercial setting. However, there are some notable observations that can be made on the state of the technology and perhaps some idea of how long it will be before the technology has sufficiently evolved to the point where it is used in industry.

A few words about the history can help explain where we are today with respect to the technology. Blockchains were first written to host cryptocurrency, a novel form of money that can be traded without the need of a central bank or political authority. The technology was successful in this application, but this original application was very basic and did not contain the elements required for an industrial DLT. For example, to buy and sell bitcoins, it is not necessary to maintain a comprehensive membership list, to host smart contracts or model business processes. It was the work of insightful and futuristic thinkers that envisioned the broader application across industry (Al-Jaroodi & Mohamed, 2019), government and civil society (Swan, 2015).

There is an abundance of literature on the testing of prototype systems (Korpela et al., 2017), including a highly publicized joint project between IBM and Maersk (Hackius and Petersen, 2017). But there is some doubt that companies are progress their projects beyond the pilot stage (Allison, 2018; Lacity, 2018), a fact that indicates that the time require to adopt new technology, may take longer than expected. Indeed, many managers are skeptical about prospects of rapid-scale destructive innovation and the hype (Pardolesi and Davola, 2019) associated with the technology, and with cryptography (that uses the same technology) which is associated with wild speculation (Fry and Cheah, 2016), quick fortunes won and lost (Decker and Wattenhofer, 2014) and illegal activities (De, 2019; Stroukal et al., 2016; Barone and Masciandaro, 2019; Buchanan et al., 2018).

Adoption of the Technology by Industry

Ultimately, the adoption of a DLT system by an organization is a commercial decision that is likely to be influenced by the desire to maximize their return on investment on innovation (Christensen & Raynor, 2013). For example, in order to augment knowledge enhancement in order to gain competitive advantage or to improve their image as a business partner and employer. Companies might also be strategizing for brand reinforcement, an approach that could lead to a higher reputational profile. They might also experiment with DLTs in order to enter new technological ecosystems, a foray that would put them into contact with others who also want to see change. Whatever the outcome of these initiatives, the introduction of any new technology, especially one as revolutionary as DLT, is bound to lead to changes inside the organization itself.

Blockchains, despite the advantages presented here, may not be the most favored solution and managers need to weigh up the pros and cons of the various alternatives. To begin with, there are plenty of alternatives, including doing nothing at all and simply using existing accounting and administrative methods. Other software systems perform similar functions as DLTs, for example, Infrastructure as a service (IaaS), like those offered by Amazon AWS, Google, Oracle, Microsoft Access or open source systems such as MySQL) or ERM systems that can be configured to suit the company. Hand-held devices, of the sort used to tract packages (Navon and Berkovich, 2005) could also be integrated into back-office control and management systems that could keep track of supply chain materials and components.

One promising possibility is for governments to offer incentives and other forms of encouragement for firms to take up novel technology that promises to modernize industry. A good example of this is the UK government's strategic plans to implement Building Information Modelling (BIM) (Eadie, et al., 2015; Cable et al., 2013). In the same way that BIM can support design and construction consortia, DLTs could help with collaborative assembly and process improvements (Walasek & Barszcz 2017).

There are some promising government incentives in this area, for example in addressing the real problem of late payments to sub-contractors and suppliers. This problem is sufficiently serious and widespread to be considered source of poor performance of the entire industry (Barbosa et al., 2017). A variety of programs and recommendations have been made, notably the UK Government's Construction Supply Chain Payment Charter and the Swift Global Payments Innovation service. There is also the hope that traditional banks will develop commercial services that can be used for supply-chain rapid payment systems (CBA-Media, 2016).

Whatever the costs and expected benefits, any adoption must be done with a a well-thought-out business justification (Carson et al., 2018) using the standard approach as used in manufacturing industries (Warszawski, 2003). There is also the realization that although adoption might help the industry, the direct benefits to individual companies may be illusive.

But to see a technology reach fruition requires that that industry adopt it. Although there is evidence that blockchains may soon be in widespread use in the financial services industry (McWaters, et al., 2016, McKinsey & Company 2017), quite possibly for use in cross-border currency exchanges. The clearing (or reconciliation) of international transaction (Meszaros, et al., 2016; CBA-Media, 2016) is an activity likely to use DLTs. The advantages of using blockchains in this area are significant (Attaran & Gunasekaran, 2019). For example, in the age of globalization, cross-border payments total around $600 billion annually, with transaction costs somewhere between 2% to 3% percent and as high as 10% for less favored customers. McKinsey and Co. (Higginsonm, et al., 2019), estimate that if blockchains are used for the settlment of cross-border transactions, savings on transaction fees could be on the order of 30% or $4B/year. Speed is a factor as well and in 2016, the Canadian ATB Financial Bank successfully used blockchain technology to send 1000

Canadian dollars to Germany in about 20 seconds. Far quicker than the two to three working days that it normally takes to complete using standard methods. Security as well as speed are amongst the benefits of DLT for use in banking (Wüst, et al., 2019; Zhong, et al., 2019). For other sectors, progress may be slower.

For example, the construction industry, prone as it is to sudden downturns and disruptions, renders managers naturally conservative and often reluctant to contemplate introducing new technology that might disrupt operations (Waterhouse et al., 2017). Managers get fired for missing deadlines, not for missing out on the promise of a digital revolution.

But the industry could surely use the advantaged promised using DLT as it is characterized as having low levels of trust (Cerić, 2015), for being averse to change and slow to adopt innovation. It is also known for low profitability (Green, 2016; Davis et al., 2015) and as a locus of crime (Warne, 2016) and questionable business practices (Pontell and Geis, 2007). Optimistically, the industry is so large and strategically important, that it is both driven-to and receptive-for change (Egan, 1998; Latham, 1994).

Recommendations

The recommendation that are included in this section are based on experience gained in designing a prototype system based on HLF, on observations on the state of the technology and its use in other industries. These are:

Recommendation 1: DLT can be promoted by forming consortia to encourage collaboration for data integration along supply chains. These would help to develop the value of digital assets.

Recommendation 2: That efforts should be made to encourage governments to support the use of DLT, encouraging, for example, the use of technology for rapid and automatic payment systems.

Recommendation 3: Support the open source software community in building complex applications through collaborative efforts.

Recommendation 4: Encourage the use of data rich DLT environment to support Lean management. Lean requires abundant process data of the sort available in a well-monitored trading and supply-chain network.

FUTURE RESEARCH DIRECTIONS

This section provides a brief survey on novel research that is likely to lead to commercialization for industrial blockchains of the type described in this chapter and is intended to provide a basis for discussion. The following topics are summarized:

- The use of DLT for enterprise resource and Lean management.
- The role of the blockchain in the Industry 4.0, smart cities and Internet of Things paradigms.
- Issues on the privacy, security and on autonomous data control.

Enterprise Resource and Lean Management

Enterprise resource and Lean management are common organizational activities that rely on financial, sales, production and other data to help with management. The modernization of the industry calls for the adoption of new systems and methods that extend data analytics to all corners of the organization and beyond these boundaries and into the supply chain.

The adoption of Modern Methods of Construction (MMC) requires off-site component manufacture of bathroom and kitchen pods, door sets, and structural insulated panels (SIPS), precast concrete foundation, ceiling and floor slabs, having all the appearances of a controlled industrial process (Pan and Goodier, 2011; Slaughter, 1998). Data such as time and location of delivery, cost per item, warranty period, and any other piece of transactional information, are typical of back-office ERM systems or copied into a spreadsheet-based analysis and reporting tool. This, in turn, could supports a range of organizational–wide business processes, such as payroll, quarterly accounting and reporting, process and commercial analysis (Morabito, 2017). This is the sort of data-rich commercial environment that will allow Lean management to flourish.

Indeed, the phenomenal growth of companies like SAP, Europe's leading enterprise resource software house, is based on the need for enterprise-wide analytical systems. The construction industry is calling out for more modern methods that can coordinate just-in-time component delivery, pull system and visual displays, just to name a few of Lean management techniques.

Little enthusiasm has been shown by construction managers in implementing large-scale process integration software of the sort common in automotive, pharmaceutical or other manufacturing industries. The high costs associated with such systems dissuade all but the biggest construction companies. But the more pressing reason may be the risk associated with installing large enterprise-wide IT systems. One of the potential advantages of DLT is that it can be installed piecemeal, with the recording of transaction data added as implementation progresses. This makes DLT a data-led activity that could lead, in a roundabout way, to a fully integrated Lean assembly and supply chain systems (Liker and Meier, 2006; Liker, 2004) of the sort found in the automotive industry (Womack and Jones, 2003; Womack et al., 1990; Binder, 2007). The hidden promise of DLT is that it might provide the capability of a much larger systems at a lower cost.

The areas of research that are interesting are projects that can link the output of the DLT with the input to Lean manufacturing systems and for analytics to be applied and displayed effectively.

Blockchains in the Industry 4.0, smart cities and Internet of Things paradigms

Automation of construction processes is one of the visions of the Industry 4.0 paradigm (Lee, et al., 2019). This includes the integration of operational and administrative processes with wide-area data-rich networks and the coordination of quantities and fluxes represented in so-called big data. Some of these data would be supplied by IoT devices, such as sensors that read incoming RFID tags, or the output from logistics providers or even from the output of AI tools that can interpret photographic images. Embedded in this environment, DLT is the keystone technology that can provide a secure and immutable data-layer that is accessible from both inside and out of the enterprise.

It has been established that construction projects are industrial process (Koskela, 1992), with ample demonstration that automation has led to higher productivity and hence, higher profits (Enshassi et al., 2007). This makes them suitable for computer-based management.

A recent implementation of HLF for Walmart Canada (Hamilton & Srivastava, 2020) by the New York based DLT Labs is an encouraging demonstration of a commercial DLT system that can provide valuable managerial controls to complex supply chains. Another company, and original member of the Hyperledger Consortium, Digital Assets LLC, has completed similar projects using their high-level programming language known by its acronym, DAML (*Digital Asset Modeling Language*; Kfir, & Fournier, 2019). DAML promises to make programing of DLT systems easier and cheaper.

Research & Development in this area is likely to cover a broad range of topics, for example novel forms of internet-connected digital sensors, analytical engines accessible from the cloud, various forms of autonomous vehicles, better development environments and so forth.

Privacy, Security and Autonomous Data Control

Issues of privacy and security of data abound in data-rich environments such as smart cities, in IoT applications and distributed systems. Indeed, some of the most critical and fraught topics (Zyskind et al., 2015) revolve around the control of digital identity and personal data. Not only is the collection and use of private data highly politicized, it is also controlled by law.

Research on the social impacts of privacy and security of data are of great interest to developers of DLT.

One of the most interesting areas of research is the move away from the centralized control of data towards self-regulating systems. In other words, the data itself can contain the control mechanism as to who has permission to read or write to it, depending on how and when it is opened. This feature would help in several ways, for example, to preserve identity in the event of accidental (or intentional) release of private information. Blockchains have the potential, with their multi-layer encryption capability, so provide a central component in self-regulated data, a feature that would be particularly useful in the trading networks of C&E projects.

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KEY TERMS AND DEFINITIONS

Most of the terminology used when describing blockchains is derived from the mundane acts associated with trading, but as is often the case in software design, these terms can be cryptic.

Block: Is the basic unit that describes how files are organized in a blockchain. Blocks contain an ordered set of transactions that are cryptographically linked to the preceding block, and in turn it is linked to subsequent blocks. Blocks are assembled by the ordering service and then validated and committed to the blockchain by peers that reside on nodes.

Certification: is defined as secure data in the form of a signed document that is held on a blockchain. These records can have controlled access through multiple layers of cryptography.

Certificate Authority (CA): is a modular component of the DLT with the role of issuing encryption keys to network members and other users. The CA issues one root certificate to each member and one enrollment certificate to each authorized user. This should not be confused with using the blockchain to hold official certification by an authority.

Chaincode: is an alternative name for smart contracts used in the Hyperledger Fabric framework. Using modular features of HFL, smart contracts can be programmed into the system in several different ways, such as the client interface or through an associated database.

Channel: a name given to an enhanced feature of a DLT that allows a degree of privacy to exist within a subset of a larger trading network.

Consensus Algorithm: is the process by which the members of a network determine which transaction get recorded onto the blockchain.

Custodian: This is the term used to describe the holder of the asset, receiving it from the Transactor.

Distributed Ledger Technology (DLT): is the term given to the collection of services, interfaces, software and associate systems that allow blockchains to be used in industrial settings.

Endorsement: is defined as the process where specific peer nodes execute a chaincode transaction and return a proposal response to the client application. Endorsement is based on a policy that defines which peer nodes on a channel can execute transactions.

Genesis Block: is defined as the first block on a chain and represents the configuration that initializes and defines the ordering service.

Hyperledger Fabric: is primarily aimed at industrial blockchains. It is a quickly evolving framework that contains commands and modules to allow the blockchains to be developed, tested, deployed and initiated.

Invoke: is when a call is made via chaincode to alter the state (i.e. write) to the blockchain. This requires that the transaction is sent as a proposal to a Peer, which must be endorsed, ordered, and committed to become a permanent record.

Ledger: is a document that contains records of transactions held in chronological sequence. In modern terms, a digital ledger is defined as containing two distinct parts: the blockchain and the Current State database (or World State). The term Distributed Ledger Technology (DLT) describes copies held by multiple computers (or nodes) across a network.

Membership Service Provider (MSP): is a set of tasks within the system that provides credentials to clients, and peers that allow them to participate in a HLF network. HLF supports dynamic membership, where members, peers, and ordering service nodes can be added and removed without compromising the integrity of the network.

Orderer Nodes: are specific nodes on the network that are tasked with ordering the transactions. They ensure the consistency of the blockchain and deliver the endorsed transactions to the peers of the network. The orders provide the Ordering Service that sort the transactions into blocks and then distributes these blocks to peers for validation. The ordering service is independent of the peer processes and orders transactions and in HLF, it supports modular implementations so that the system can be extended and configured.

Organization: is a collective term use to describe users who are can read and write to the blockchain. They are also referred to as members and managed by the MSP, which defines how other members of the network may verify their digital signatures when transacting or reading the ledger access rights of identities within an MSP are governed by policies which are also agreed upon when the organization joins the network. There is no size limit to the organization if they have access to a Peer (the main trading point). If they exist, collections of organizations form a Consortium.

Peer: A network entity that maintains a ledger and runs chaincode containers in order to perform read/write operations to the ledger. Peers are owned and maintained by members and make up the principle nodes in a blockchain network. Peers host ledgers, chaincode and participate in consensus.

Permissioned Blockchain: infrastructure that is based on a principle of modular architecture. Permissioned describes a DLT that has a controlled and limited membership. This allowed a great deal of flexibility in designing systems as it permits the separation of roles between the nodes in the infrastructure, execution of chaincode and a configurable consensus and membership service.

Permissioned ledger: is a blockchain network where each entity or node is required to be a member of the network. Anonymous nodes are not allowed to connect.

Policies: are part of the language used for constructing the layers of encryption in the data blockchain. They are used to control access to data and other resources in a blockchain network, notably who or who cannot read and write to a channer, evoke, querry or deploy chaincode. Policies are defined in the configuration files prior to deploying the network, setting up an ordering service or creating a channel. They can also be specified with instantiating chaincode.

Privacy: is required by the chain transactors to conceal their identities on the network. While members of the network may examine the transactions, the transactions can't be linked to the transactor without special privilege. Data as well as transaction details can also be held privately.

Private Data: are confidential information stored by peers on the blockchain but kept separate from other data. Access to this data is restricted to members with permission, while unauthorized organizations will only see a hash of the private data on the channel ledger as evidence of the transaction For an additional level of privacy, these hashes of private data go through the Ordering Service, which keeps it hidden from the Orderer.

Query: is a call (or invocation) to read from the blockchain ledger. In HLF, chaincode is used to unwrap the blockchain in order to read certain keys or other data. Queries do not change the ledger state, although the client application can choose to submit a read-only transaction for ordering, validation, and commit, to provide an auditable proof that the blockchain has been read.

Quorum: is the minimum number of members of the cluster that need to affirm that a transaction is acceptable to write to the ledger. For networks with few members, the central authority may make up the majority vote for acceptance.

Software Development Kit (SDK): provides a structured environment where the System Administrator can design, deploy and manage the network. In HLF, the SDK is modular and configurable using standard software tools. Modules, such as the cryptographic algorithms, logging frameworks and others, can be switched in and out by the SA using the SDK. Through the SDK, transaction processing, membership services, node traversal and event handling are deployed. HLF currently uses both Node.js and Java, with two more: Python and Go, in development.

Transactions: are the official term used to describe the addition of a record to a blockchain. Members cannot write directly but must submit transaction proposals to the consensus and ordering algorithm.

Transactors: can be either human or a device, for example a shipper delivering a package and registering the transaction with a smart phone, that send a transaction proposal to the consensus and ordering algorithm.

Validating Peers: All transaction must be validated by a Peers. These are networked computer nodes owned either by one of the participant organization or hosted by a professional service provider. Nodes hold a copy of the blockchains and are responsible for ensuring consensus used to validate transactions. Once validation is complete when all nodes receive an updated version of the blockchain.

World State Database: (also called the *Current State*) is a data store that is permanently attached to the blockchain where the latest and most complete records of transactions are stored. It is more efficient to read and query the blockchain through the World State.

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