BLOCKCHAIN

AND THE BUILT ENVIRONMENT

ARUP

About Digital at Arup

We are committed to shaping the digital built environment. We will embrace the opportunities that digital offers and develop new capabilities that keep us commercially and creatively relevant. A digital Arup will continue to raise the standard for world-class built environment expertise using new tools and technologies. We will focus on providing better outcomes for our clients and society through improved design and insight, enabled by data. We seek collaboration with partners in our research and share our thinking to help us and others shape a better world.

About Arup Foresight, Research and Innovation

Foresight, Research and Innovation is Arup's internal think-tank and consultancy which focuses on the future of the built environment and society at large. We help organisations understand trends, explore new ideas and radically rethink the future of their businesses. Research has played a fundamental role in defining how we anticipate and leverage emerging business opportunities. To this day, research continues to underpin our ability to address client challenges across the public and private sectors. Through applied research, we are able to explore and experiment at an early stage to minimise long-term risk.

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Executive summary

Blockchain technology has not (yet) created the same transformative disruption in the built environment that it caused in the financial industry. But it is never the first generation of technology that delivers a supernova; it's the second or third generation.

Blockchain is the start of what the internet was 28 years ago. We are witnessing a punctuated equilibrium — a long period during which applications are developed and researchers look for new ways to use, build and recycle applications or certain aspects of the emerging blockchain technologies.

As the technology develops and matures, we might see step changes and emerging applications of blockchain. The disruption will happen when these step changes are realised, but it is hard to predict what these will be and when they will happen. For now, we will continue to experiment and work with other early adopters.

In this report, we explore applications of blockchain technology within five key markets of the built environment: cities, energy, property, transport and water.

We have created a blockchain technology timeline based on insights from internal and industry experts, venture capitalists, academics and enthusiasts to estimate the expected early adoption of blockchain technologies being tested within the five markets.

The research reveals a current lack of industry-wide case studies outside the financial sector, but a number of case studies are rapidly emerging in the cities, energy and transport markets with adoption estimated for 2020–25.

During the evolution of blockchain technology, we must prepare for scenarios that could reshape the built environment by building a new foundation for machines and humans to interact and transact with each other. This phenomenon could become part of a new technological backbone to combine building information modelling, platform technologies, the internet of things, and digital twins.

Foreword

Volker Buscher
Data leader
Arup

Digital technologies are transforming every aspect of the built environment. Blockchain has the potential to be part of a newer technology infrastructure to help us deliver on the United Nations' Sustainable Development Goals and transform our — and the industry's — business model in the age of data.

At Arup, we consider it essential to understand how digital technologies can transform real-world experiences and decision-making. We learn to combine intelligence, creativity and disruptive technologies in our drive to create better insights and designs for clients and society. At the core of this new paradigm is 'data'. They help us to simplify and make sense of the world in ways we could only imagine a few years ago. However, this opportunity is not risk free; with major breaches and scandals around the use of data, we are facing fundamental questions beyond improving the built environment. Our thinking must consider the digital human, security and the integrity of our systems.

Within the built environment, we create vast amounts of data every day. Every time we run our models, exchange emails with our clients, simulate the real world and create designs, we need to reflect on how technology can not only improve, but transform our industry. This research helps us collaborate, comprehend and respond to change.

Blockchain promises to be part of this technological infrastructure by reducing transaction costs, improving transparency and challenging the contractual model of our highly distributed industry. With the administration of smart contracts, blockchain could help to reduce the delay across the lifecycle of trading and exchange from days down to minutes, or even seconds, while also removing unnecessary intermediaries.

The internet transformed how we view data and create value; blockchain might transform how we exchange value and whom we trust to enable the transformation of a highly fragmented and complex industry. Our aim is for this report to contribute to that journey.

Please stay in touch with us via research@arup.com as we explore blockchain further, and perhaps help us think through our next research work around digital twins.

Introduction

Every blockchain is a form of a distributed ledger, but not every distributed ledger is a blockchain.

We are witnessing the beginning of what is expected to be the infrastructure that ties in building information modelling (BIM), cloud and platform technologies, and the internet of things (IoT) systems to provide truly smart connected cities and power the federated world of digital twins.

Within the built environment, blockchain technology is in its infancy, as is the terminology. We need a consensus on definitions now, but as the technology becomes meaningful in the industry, the terminology will mature as the technology matures.

Blockchain has been around for longer in the Fintech, banking and retail sectors, but emerging case studies in the cities, energy, property, transport and water markets indicate that meaningful applications built on blockchain may appear within three to five years.

Is blockchain here to stay?

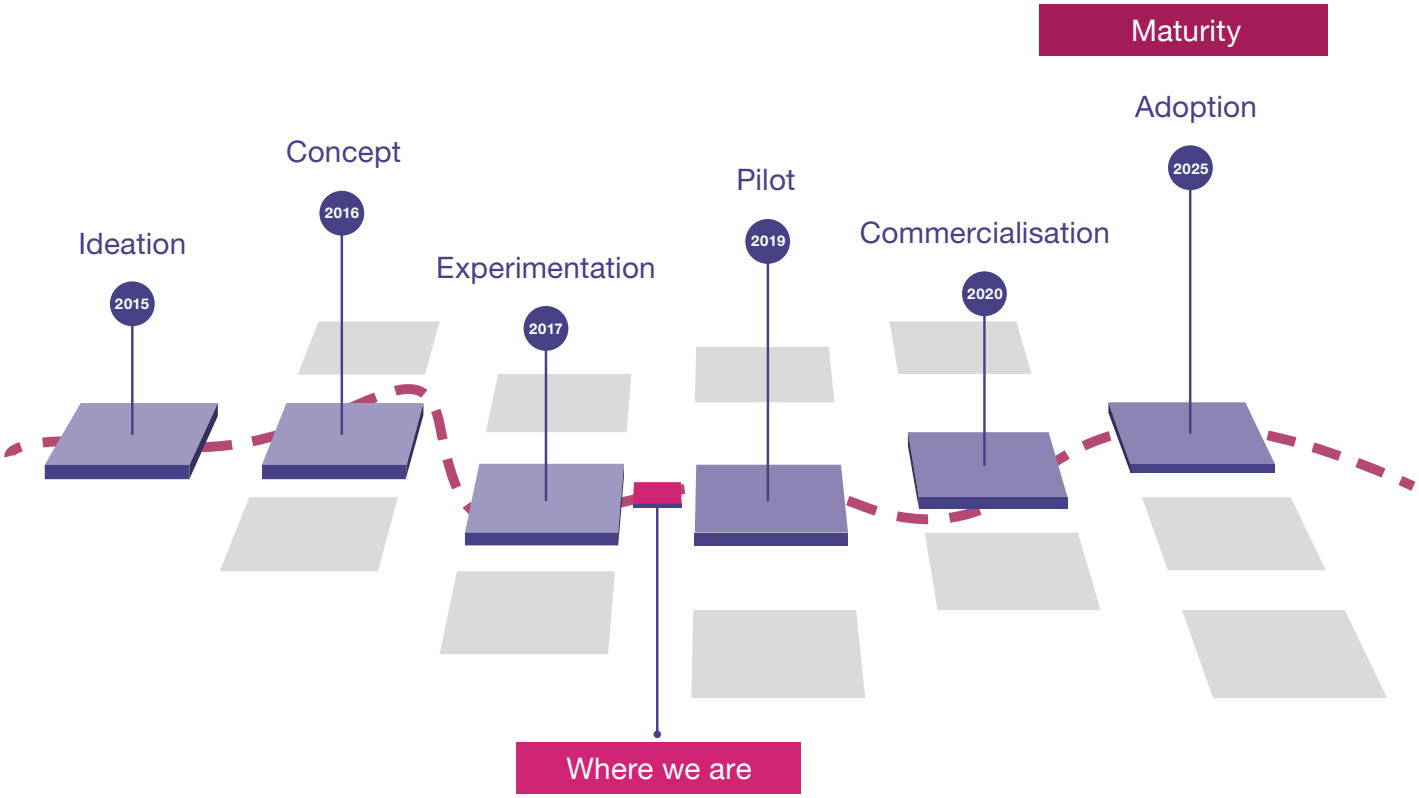
If we strip away the hype about the technology, we can define key characteristics that will help to solve many of the problems we have in the built environment. So, the answer to whether blockchain technology will persist, is yes. But how disruptive will it be? Will it be transformative? How quick will the change be? How much time do we have to react and to strategise? The answer is, it depends.

As the technology matures, there may be step changes and new applications will become available. It is these step changes that will be disruptive — and they are hard to predict. We are nowhere near the level of maturity the internet had reached in the 1990s when use of the world wide web expanded so rapidly. There are similar parallels between the mobile phone industry and the built environment. It was only from the early 1990s to the 2000s — when the technological infrastructure was available — that smart phone technology really took off.

This is Arup's second report on blockchain technology in the built environment. The first was published in October 2017 to examine how the inventions behind Bitcoin were enabling a network of trust for the built environment.[1] In this updated edition, we explore the world of blockchain again, investigating whether it is here to stay and, if it is, what it means for the built environment.

We focus on five key markets: cities, property, energy, transport and water. These markets show early adopters for blockchain opportunities. Our technology timeline helps to structure the current state of applications within the built environment. Based on a set of interviews, we have created an expected adoption timeline ranging from 2018–50. The timeline is not intended to be empirical, but demonstrates the breadth and depth of the applications happening today and how these applications may be used in each of the markets in the future.

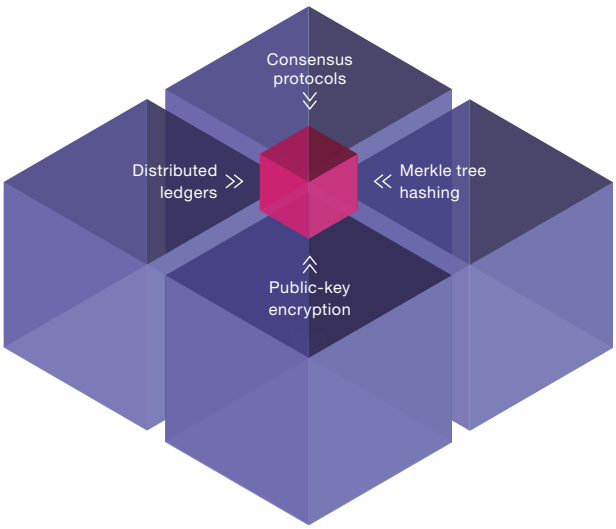
Figure 1 The current state of blockchain maturity for the built environment



History of blockchain technology

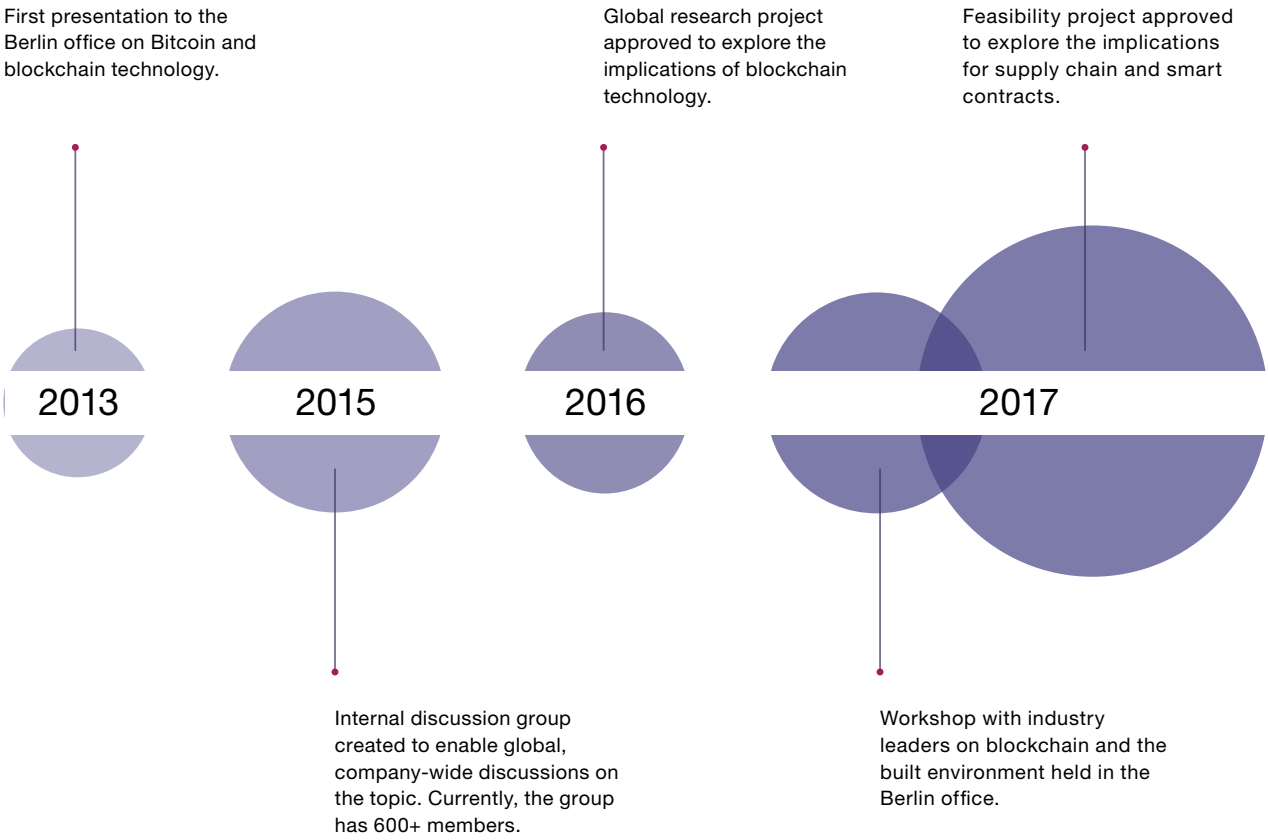
Blockchain is a combination of existing technologies: distributed ledgers, public-key encryption, Merkle tree hashing and consensus protocols.[2] Devised by Satoshi Nakamoto, blockchain is based on the proof-of-work (PoW) concept. It combines the economic incentive and cryptographic link between records and the distribution of the data on a decentralised network that is available to all participants on a node system.[3] The technology makes it more difficult — the longer the chain — to change any specific node as all participants have access to the same information. A hacker would need access to a significant amount of computational power to create real damage to the information. The technology means hackers would waste a lot of time and energy changing a single date from the past, while verified users are continually producing new data.

Figure 2 The combination of four existing technologies that make up blockchain technology



Evolution of blockchain for Arup

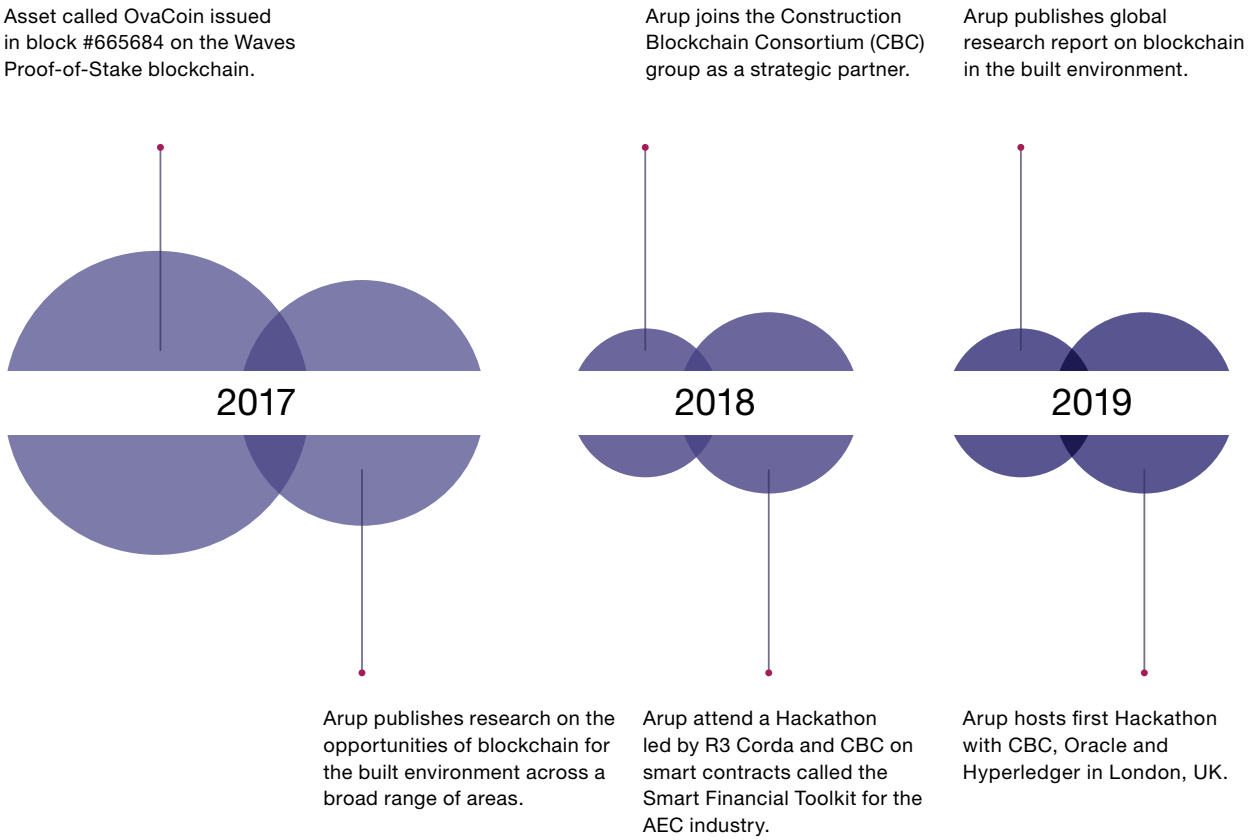
Figure 3 The blockchain journey for Arup



Arup's interest in blockchain began in early 2013 with research into Bitcoin and the potential use of the technology for the built environment. The term 'blockchain' did not exist at that time. Figure 3 shows Arup's progress to date and our exploration continues as we find more examples of blockchain use that are affecting the built environment.

As Bitcoin gained momentum, Arup established an internal platform in 2015 to enable global, company-wide discussions about the projects occurring in this field. The platform has allowed the firm to advance its understanding and establish a dialogue about emerging case studies and prototypes within the industry. In 2016, Arup invested in its first research project in collaboration with the Global Foresight, Research and Innovation team to explore the implications of blockchain technology.

In 2017, Arup took a more active role in furthering its knowledge of the technology by launching its own cryptocurrency, the OvaCoin, on the Waves Proof-of-Stake blockchain.[4] The intention was to better understand the implications, feasibility and challenges of tokenisation, initial coin offerings and the associated enterprise software platforms.



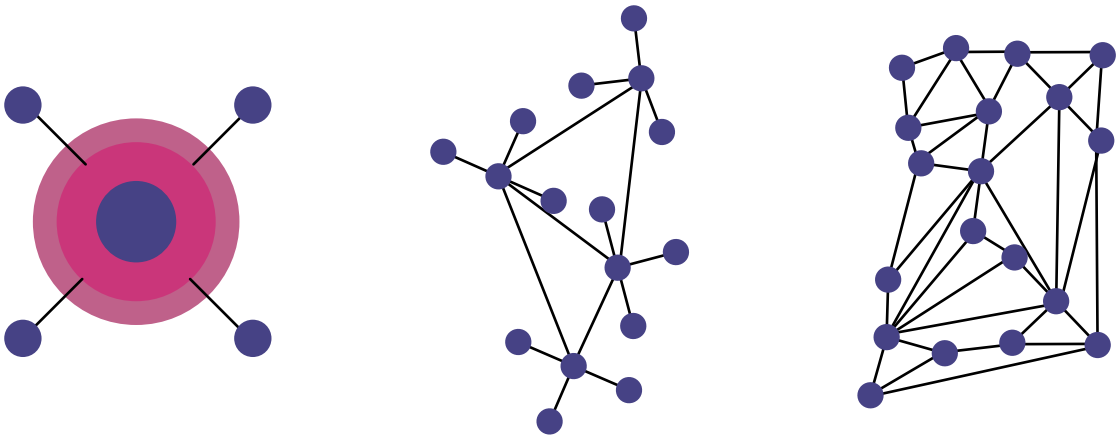
In response to interest from our clients, Arup hosted a two-day workshop in Berlin in 2017 with industry participants including Deloitte, Volkswagen, Ellen MacArthur Foundation, HM Government, PwC and Skanska. The agenda covered potential case studies and impacts on society. In October 2017, Arup launched a first-of-its-kind report, *Blockchain Technology: How the Inventions Behind Bitcoin are Enabling a Network of Trust for the Built Environment*. Upon its release, the report was recorded on to the Bitcoin blockchain as a ledger item.

In 2019, Arup's blockchain journey continues with further research into proof-of-concepts within supply chains and smart contracts. As part of its progression, Arup has joined two consortiums — the Construction Smart Contracts Committee and the Construction Blockchain Consortium — with partners such as IBM, SAP, Arcadis, Siemens and Tata Steel.[5,6]

How blockchain works and its key benefits

Blockchain has the potential to provide trust in a network and combat against corruption and disputes through consensus.

Figure 4 Types of blockchain networks



Centralised
A centralised database processes and stores information at a single location.

Decentralised
A decentralised database processes and stores information at multiple locations.

Distributed
A distributed database is located on multiple devices in the same location and spread across networks of interconnected computers.

A blockchain can be designed to be either centralised or decentralised, but it is important to not confuse decentralised with distributed. A blockchain is inherently distributed — meaning that all participants hold copies of the same ledger — but it is not inherently decentralised.[7]

Blockchains are not designed to cut computational costs, but rather to achieve a decrease in social costs; there is usually an increase in computational costs.[8] This is an important, but often misunderstood, point — blockchains are not efficient.

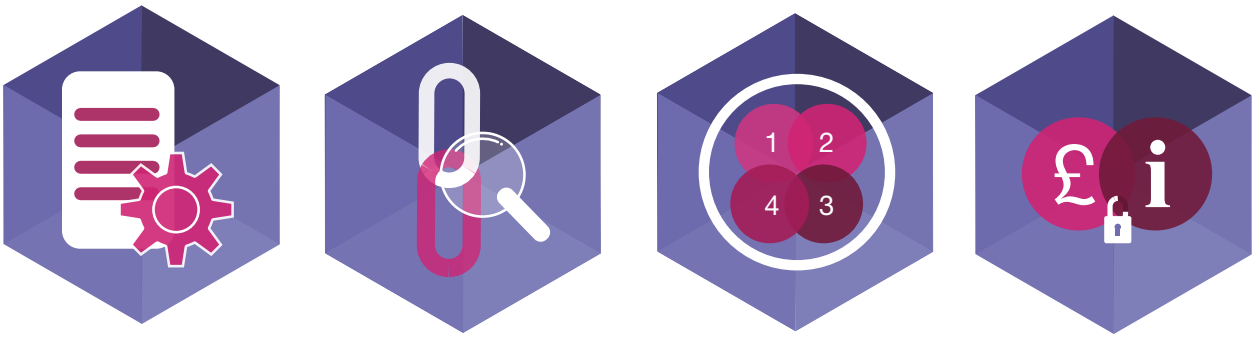
A centralised blockchain refers to the 'rights of the participants on the ledger'. In a centralised network, the identities of participants are validated, and only trusted participants are able to post to the ledger.

In a decentralised network, anyone can participate and post to the ledger. Therefore, there must be policies or protocols in place to ensure the information posted to the ledger is correct. This can be controlled through a consensus algorithm (PoA, PoS, PoW) to maintain the integrity of the ledger and prevent participants from corrupting the system.

Centralised databases are typically favoured in highly regulated industries such as water, energy and transport where compliance, regulation and legislation exists to protect consumers.

Figure 5 Key steps on how a blockchain-based application works.
These steps consist of real world and blockchain actions.
It is possible to automate 4 out of 5 of these steps through smart contracts.

Figure 6 Key benefits of blockchain for the built environment



Improving contract management

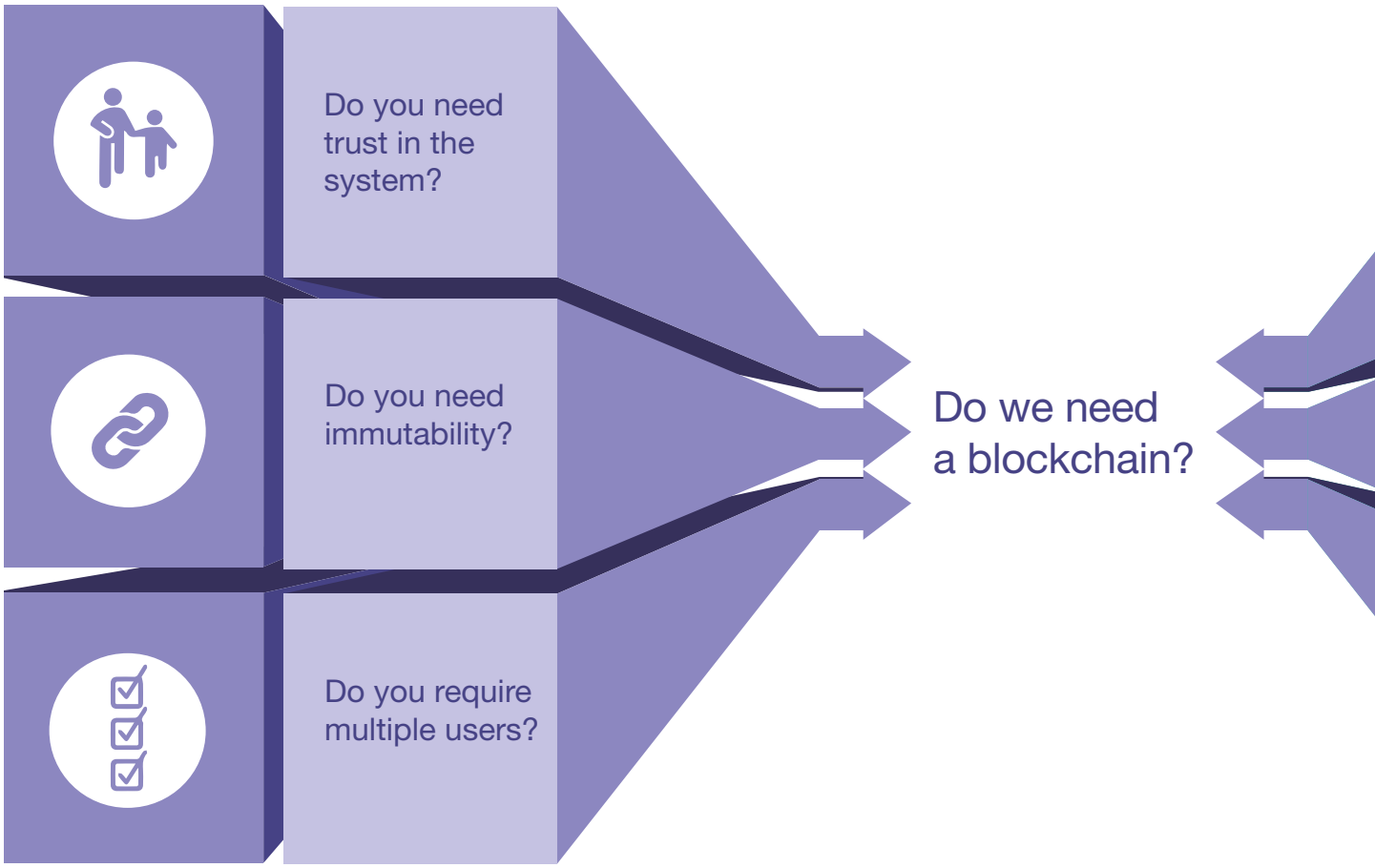
Enabling more transparency in supply chains

Enabling the infrastructure to combine circular economy, BIM and IoT

Tamper-proof exchange of value and information

Is blockchain what you need?

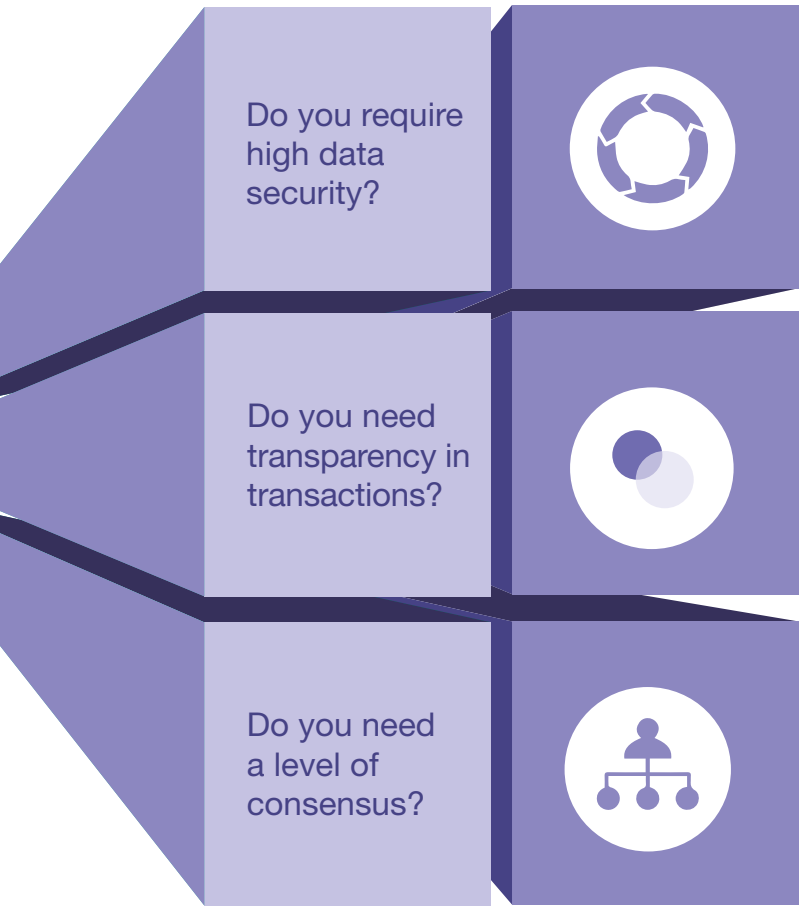
Figure 7 Eight questions to ask before you choose a blockchain solution
If you answer 'yes' to these questions, you may need a blockchain.



Current understanding of blockchain within the industry is limited and there is a risk in exploring a new technology without fully understanding which problems blockchain can solve. In addition, blockchain technologies still have some scalability issues, making them slower and more inefficient than traditional databases.

So, to determine whether blockchain is the right choice for a particular problem, we need to ask ourselves: What are the high-value and blockchain-specific applications? Can we get away with a traditional database? What problem are we trying to solve with blockchain that we couldn't solve with traditional databases?

Different case studies show distinct characteristics that will chime with different business ecosystems in terms of relevance. A good starting point is the flowchart of questions created by the World Economic Forum as an aid to making a decision about using blockchain.[9] Aspects to be considered when choosing whether a blockchain is right for your business include: permission versus permissionless; trusted



versus trustless; controlled versus decentralised; structured versus democratised, etc.

The potential switch to blockchain technology requires rethinking the entire design process and programming it to behave in a robotic and scripted way. Currently, the development of smart contracts are not built with artificial intelligence and machine learning. Smart contracts are not produced based on data.

The use of the word 'smart' is misleading. The reality is that smart contracts are programmed to execute the agreement if a set of conditions are met. But in fact, smart contracts are not that smart at all. The technology is very rule based and follows a script almost exactly. In blockchain smart contracts, there is no deviation from a script so there is no room for ambiguity. There is no feedback loop or machine intelligence — it strictly follows a set of rules. However, for our industry, the low hanging fruit are implementations in the automation of transactions and on cash flow management.

Blockchain technology can be designed to automate payments and transactions between parties and pay contractors and subcontractors for work completed. It can be designed to keep a retainer and release partial payment. The conditions of the contract and payment schedules can be designed upfront; solving this problem will provide a big step forward for the industry as many contractors are dependent on positive cash flow.

The collapse of facilities management and construction services company Carillion in 2018 has highlighted the need for blockchain technology. The characteristics of blockchain could help to solve the supply-chain problem of late payments that Carillion suffered and prevent a similar case happening in the future.[10] Companies run into cash flow problems for many reasons, but with blockchain technology, when an agreement is entered, the elected controlling body is established early to provide a fair and trusted system. All transactions are authorised by a community once work is completed; this can avoid multiple intermediaries.

On a decentralised system, the funds are held centrally and released when work is verified. This could help to prevent clients withholding funds from contractors and, consequently, contractors withholding funds from subcontractors, therefore providing better cash flow.

What does blockchain mean for our markets?

Dr Will Cavendish
Digital services leader
Arup

For the built environment sector, blockchain technologies have not yet been transformational, but early use cases are emerging and some are showing real promise.

We have yet to see many significant and successful blockchain case studies outside the financial sector. However, examples are beginning to emerge in the cities, energy and transport markets, with experts judging that early adoption may start from 2020–25.

As we move towards the digital economy in infrastructure and the built environment, there will be increasing quantities of data and digital transactions, and ever more interconnected systems. So an obvious starting point for blockchain is in eliminating the middleman. This can reduce transaction costs and facilitate greater exchange.

In the energy sector, for example, the rise of local, renewable electricity generation means that increasing numbers of households and communities can trade energy with each other on microgrids. They can also sell energy back into regional and national grids. In these situations, blockchain can reduce the costly process of tracking these transactions.

Similarly, renewables companies incur huge costs in the simple process of auditing renewable origination. Blockchain solutions are being piloted in Singapore and the UK in an effort to cut these barriers to renewable generation and increase the returns on solar and wind power.

Equally, blockchain can help in securing the trust and verification that underpin so many markets in a digital era. For example, construction supply chains are long, often costly and inefficient. For the circular economy, it will be necessary to track and verify individual resources from creation through to use, reuse, adaptation and disposal. In the smart city, it will be important to secure and assure the uses of personal data. In electric vehicles, power sharing

between vehicles could be hugely beneficial, but will need decentralised protocols to verify these exchanges.

In all these areas, organisations are experimenting with blockchain to solve the trust and verification problems they face. Not all will work — indeed, perhaps only a few will succeed — but those that do could have a profound impact.

At the same time, we need to be alert to some of the wider challenges posed by blockchain technologies and ensure they are resolved in advance. Take the well-known, voracious energy consumption of some current blockchain uses, such as Bitcoin. It is ironic that blockchain is being developed in some areas to help tackle the world's environmental challenges, while the design of other blockchain systems is making things worse.

Likewise, the digital and technology sector is rightly being taken to task about its casual attitude in the past to issues of trust and control, whether over personal data or rules under which companies work. Different blockchain technologies have very different approaches to these questions: we should set the rules for blockchain now, so that these issues are properly embedded in the design of blockchain systems, not added as an afterthought.

So we at Arup are excited about the potential of blockchain in the built environment, and are working with others to develop our own systems. However, we are determined to do it in a way that is guided by our mission to "shape a better world" and develop these technologies in a way that is compatible with our deep commitment to broader social, ethical and environmental goals.

Blockchain and built environment markets

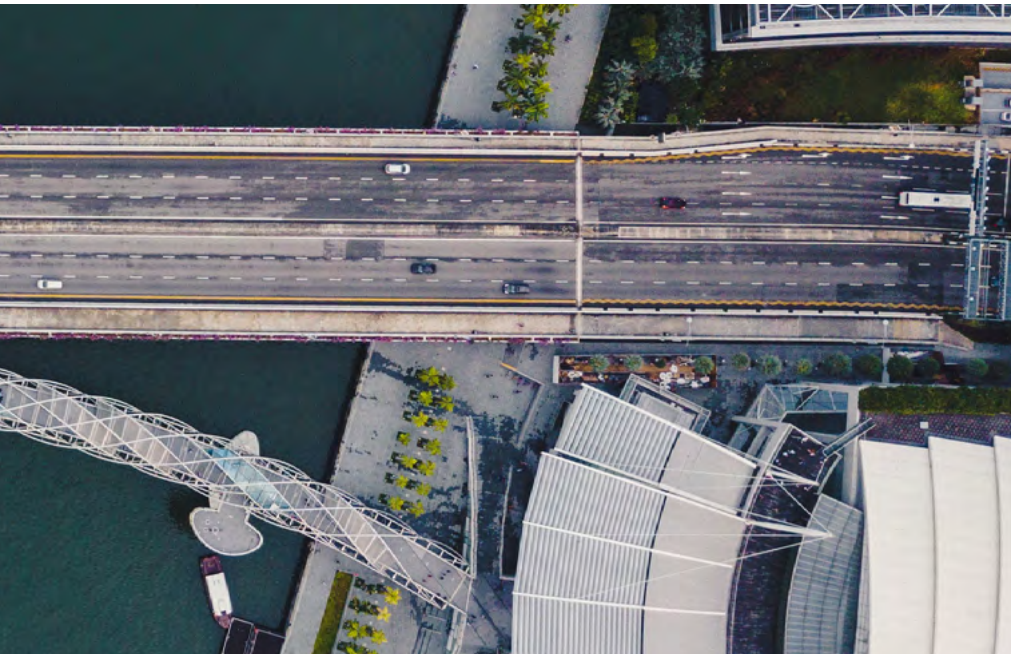
We are witnessing the natural evolution of case studies merging across the built environment within the cities, energy, property, transport and water markets.

Apart from financial services, we are seeing a real push from industry leaders in manufacturing and energy, with the US and China leading the blockchain revolution.[11]

In markets such as cities, progression is fast due to a less regulatory nature and freedom to experiment. In highly regulated markets, such as the water market, development is slower because the challenges go beyond the purely technological, as governing bodies need to comply with standards such as the US's Safe Water Drinking Act.[12]

New business models using blockchain are emerging, either replacing obsolete models or upgrading them to meet the current transactional and trading needs of peer-to-peer networks. Start-ups are challenging the Uber and Airbnb models by eliminating the need for a middleman to connect end-users with the taxi drivers and rental owners, and removing the need to pay transactional fees. Meanwhile, other start-ups are addressing the electric vehicle infrastructure problem by providing a transactional platform to allow users to travel longer distances using their electric vehicles and be confident that there will be a charging station on their journey.

On the social and environmental side, we are experiencing a smart city revolution with rapid urbanisation and stretched resources being addressed by integrating blockchain with the United Nations' Sustainable Development Goals (SDGs).[13] In a report by UN Global Compact, blockchain has been identified to advance many of the SDGs.[14] The report examines SDGs 1, 9, 10, 12, 16 and 17, ranging from no poverty to reducing inequalities, to enable new webs of value exchange between all connected IoT devices. Blockchain has the potential to advance



1 Cities

2 Energy

3 Property

4 Transport

5 Water

many of the SDGs by creating an infrastructure to build trust, reduce friction and increase transparency and efficiency across supply chains.

Blockchain is gaining a lot of attention for its role in how devices will communicate directly with each other. We believe the immediate value of blockchain is in applications that involve transactions and interactions.

The convergence of four major solutions — the circularity model, the product environment (BIM), the smart sensor (IoT) and the trust model (blockchain) — could directly communicate and form a digital twin. A digital twin is a replica of a physical asset with varying levels of intelligence. It's still early days, but some fast-moving cities and countries have already bought into the idea of using blockchain for their digital identity platforms such as visa processing and voting protocol.

Dubai is using blockchain in a bid to be the smartest (and happiest) city in the world.[15] Singapore is using blockchain to transform its former fishing village into a living Smart Nation, the hub for innovation.[16] Estonia is leading the vision to be the first 'digital' country with its first blockchain implementation in 2008.[17] And Vienna is developing the city's first digitisation initiative to validate and provide security for the city's Open Government Data platform.[18]

We are living in an exciting time as we begin to understand the value of what a data-driven society can do for its citizens; but technology cannot do it alone. The development and ambitions of these visions require cross-disciplinary cooperation and partnerships to solve much larger societal challenges beyond blockchain. But blockchain can help to address some of the grand challenges.

Blockchain technology timeline

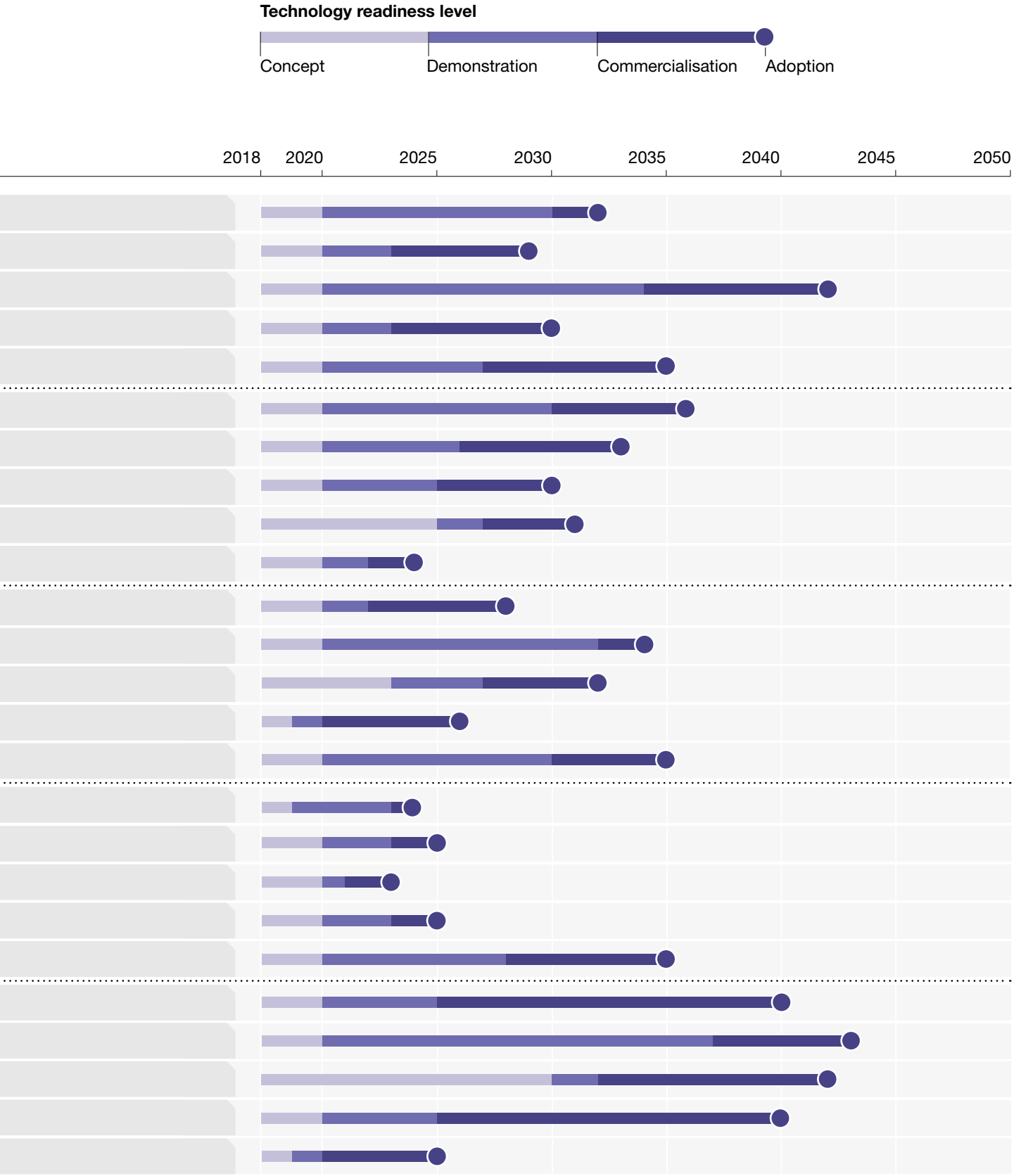
Methodology

The blockchain technology timeline was developed from interviews with experts (based on their experience and know-how), who were asked to estimate the rate of maturity of case studies based on the Technology Readiness Level framework.[19] The experts estimated the year in which a specific case study was expected to transition through the product development cycle: from idea, to concept, to demonstration, commercialisation and into early adoption. A set of 60 interviews were conducted with experts lasting between 30–90 mins. Based on the interviews, a set of data points were collected with the average early adoption represented. The interactive digital format is available on arup.com.

This timeline uses global case studies that are under development within each of the markets. It looks at where we are on the blockchain technology timeline and when we expect early adoption of these case studies to take place. This is a snapshot in time and the case studies may have changed in status since publication of this report.

The key findings are that there are no significant case studies approaching early adoption outside the financial sector, but there are several emerging rapidly in the cities, energy and transport markets with early adoption estimated for 2025 and beyond. The number of case studies in the property market is growing, and the water market is progressing as it breaks through its highly regulated market.

Market	Technology
Cities	**+ Circular economy**
	+ Cash flow construction management
	+ Procurement of supply chain
	+ IoT integrated smart city
	+ Building information modelling (BIM)
Energy	**+ Energy microgrids**
	+ Electric vehicles power sharing
	+ Smart meter billing
	+ Clean energy sources
	+ Renewable certificate tracking and trading
Property	**+ Smart contracts for real estate**
	+ Title records
	+ Lease agreements and automated payments
	+ Sale and asset transactions
	+ Property data management (MLS)
Transport	**+ Freight tracking and logistics**
	+ Ride hailing
	+ Car sharing payment system
	+ Material passport
	+ Biometrics to enable gateless borders
Water	**+ Water quality**
	+ Water trading
	+ Water treatment
	+ Utility contracts and billing
	+ Access to water for developing countries


Technology readiness level
Concept
Demonstration
Commercialisation
Adoption
2018
2020
2025
2030
2035
2040
2045
2050

1

Markets: Cities

Cities are complex; as they grow, we are struggling to understand how to scale the public services and infrastructure they need — blockchain technologies offer the potential to transform them.

By 2050, more than 70% of the world's population will reside in a city.[20] With rapid urbanisation, there is an ever growing need for sustainable urbanisation and growth. 'The world has many great cities; more of us are living in them. The world has many great cities; it also has many struggling cities, and many cities that are simply doing reasonably well. They are complex and diverse, and more and more of us are living in them.

But they share a problem. Population growth, rising GDP and job creation demonstrate that our cities are thriving, but we face mounting pressures to fund and expand the public services, infrastructure and supply chains that keep them running and support the daily lives of billions.

In mature economies, an ageing population is the primary challenge: a smaller proportion of the population is in work and paying taxes to support the public services on which a larger proportion of the population depend in their retirement. Consequently, there are continual disputes over the funding of health, public safety, education, transport and other vital public services.

This will get worse in coming decades as technology automates millions of jobs, and city economies are disrupted as efforts are made to create new skills, jobs and businesses to replace them.

In contrast, in many developing economies, the primary cause is urbanisation and climate change. City populations are growing rapidly — faster than we have ever previously built infrastructure and services to support them. Urbanisation brings changes in lifestyle too; cities import their food, and as people benefit from the wealth created by city economies, they are adopting a Western-style diet, rich in meat and processed food. This diet requires about five times as much fresh water to produce compared with more traditional diets, and consequently, if we do not change the way we feed ourselves, we will run out of fresh water at some point in the next 30 years.[21]

Markets: Cities

Dr Rick Robinson
Associate director
Digital Property and Cities
Arup

As our cities expand rapidly, blockchain could enable the dynamic marketplaces to broadly transform city systems for the better.

Although the Smart Cities movement has long argued that digital technology can help to solve the challenges of ageing populations, urbanisation and climate change, some evidence suggests that, so far, it has added to them. Although the online marketplaces that offer casual employment in sectors from professional services to accommodation to transportation create flexibility for self-employed workers, compared with traditional business models, they distribute a smaller proportion of the wealth they create to the working population. They are contributing to inequality. Several businesses use these models to enable processed food to be easily ordered and delivered to the home. Are they contributing to food sustainability? Or are they exacerbating health issues such as heart disease and childhood obesity, both of which are rising?

Of course, no single technology will address all the challenges and opportunities found in our cities. But if cities are understood to be complex, emergent phenomena that arise from the interactions of millions of people, then any technology that enables new forms of cooperation could be transformative.

Jane Jacobs, an American–Canadian journalist, author and activist, famously differentiated cities from smaller forms of human habitation by defining them as solutions to the challenge of creating safety among strangers.[22] Blockchain does something similar: it enables trustable interactions between parties who don't have a prior reason to trust each other, and without requiring any single organisation to act as the arbiter of trust.

Why do we have public services and regulated industries? Because there are certain jobs that we only trust to be done under the aegis of an elected body paid for by our taxes, and because they create an environment that enables us to live, work and prosper. Today, that trust is shown in our laws, policies, regulations and contracts. But these all take time to negotiate and time to change. It is a crude simplification, but as well as protecting the qualities of our cities, they create a barrier to innovation and therefore a barrier to improvement.

What if we had a more flexible way to ensure that public resources were used to create the outcomes that matter to us, such as economic growth, opportunities for everyone, happiness and well-being, and a sustainable environment? Could we create an environment in which different approaches could compete safely, dynamically and fairly to find the best answer? And what if entrepreneurs, social enterprises, citizens, businesses and communities of every sort could play a part in that process of innovation and discovery? What if doing so is part of the creation of a wider transformation of society and the economy based on trust, collaboration, experience and interaction?

Blockchain cannot address all these questions; it doesn't provide a framework for measuring social or environmental value, for example. And no technology is more than a tool that we individually or collectively use to accomplish what we think to be right.

But transaction networks enabled by blockchain technologies have many benefits. They are transparent, auditable, can be made open to new participants without significant barriers to entry, and can add layers of validation, accountability and governance to the dynamic marketplaces that have enabled private sector services such as ride-sharing to flourish. What if they could transform how urban services more broadly are delivered?

We know that the demand and the capacity exist. For example, some local authorities have stopped cutting the grass on highway verges to save money. But in some places, local residents have coordinated themselves through social media to cut the grass, as a temporary measure, to maintain clear lines of sight along their roads. However, as highways are potentially dangerous public assets, maintenance activity requires workers to be trained and/or the use of traffic calming measures, which requires permits. Blockchain could help to provide those requirements for validity, accountability and transparency.

Although there is a global wave of hype surrounding blockchain, its technologies deliver genuinely new capabilities and they have real relevance to the challenges faced by cities. They will give rise to innovations that will reshape our cities — some of which will go wildly beyond anything we have yet to imagine.

Circular economy

Definition

The structure of resource consumption in the built environment is shifting. Where once consumption took a linear form, from sourcing to use to disposal — sometimes termed the take-make-use-dispose model — we now find ourselves on the cusp of a radically different ethos. The circular economy in the built environment is an increasing priority for developers looking to curb the consumption of natural resources, obviate waste and increase efficiency through the reuse, recycling and responsible sourcing of building resources.[23] This new model will save on negative externalities such as carbon emission, increased pressures on landfill, unsustainable levels of water extraction and widespread ecosystem pollution. In addition, it will create numerous opportunities for the industry across the entire supply chain.

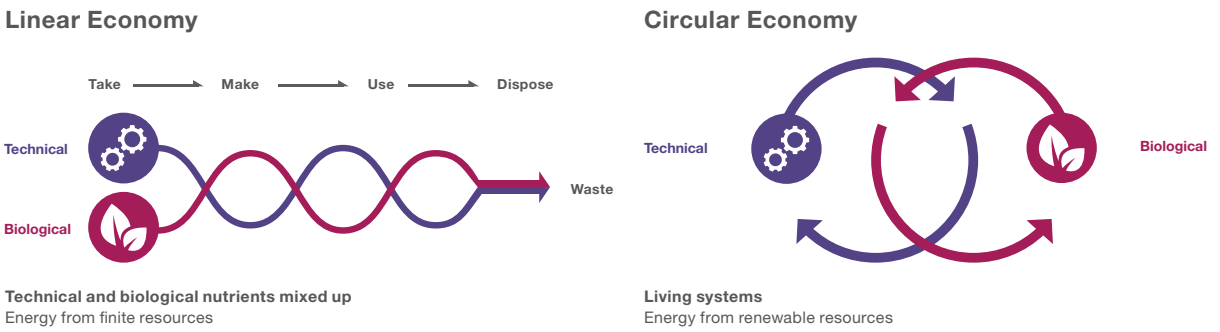
Relevance

The relationship between blockchain and the circular economy should not be understated. Blockchain will allow the effective and reliable tracking of materials, components and whole products throughout the supply and reuse chain. This has the potential to continue in perpetuity as units and elements, as well as whole products, could be reused again and again. The manufacturer, recycler and consumer can consistently and confidently assess the circularity of their products.

Case study

The theory has already found rudimentary application through Circularise, which has created an open-source distributed communications protocol for a circular economy.[24] Circularise is an open and distributed communications protocol for the circular economy. The platform allows information to be exchanged throughout the value chain, creating transparency around product histories and destinations of materials.

Figure 8 The Linear and Circular Economy models



> *"Fragmentation, opaque transactions and Victorian practices are all characteristics of the construction sector that could be swept away by the adoption of blockchain."*

Dr Mark Bew
Chairman
PCSG

> *There is a clear fit between the benefits of blockchain and specific challenges facing the construction industry, such as low trust, low productivity and high fragmentation. This linkage needs to be explored."*

Jens Hunhevicz
PhD candidate
Innovation and Industrial Construction
ETH Zurich

Cash flow construction management

Definition

Construction is a complex, costly and inefficient process that is typically over budget and over schedule. The process is fragmented and coordination between the various stakeholders is often mismanaged resulting in lost productivity, rework, delayed progress and increased fees. Construction management is required to supervise every aspect of the project, from managing communication to inspecting onsite quality and safety compliance.

Relevance

Blockchain technology can be designed to be applied throughout the lifecycle of an asset, from design to delivery to operation. The technology can act as a bridge between all stakeholders, allowing each party to track progress with the option to set up automatic payments for work completed. This technology can help to better manage the construction progress monitoring stage, as well as solve the cash flow problem often experienced by companies.

Case study

SiteSense® — a cloud-based project site field tool — addresses these issues by creating a blockchain technology to monitor, categorise and maintain relevant resources and documentation.[25] A comprehensive list of transactions is stored in a secure, private blockchain and can be accessed by any number of stakeholders. The product is in its early stages but has the potential to change the structure of commissioning, contracting and delivery of projects at every scale, with the aim of automating and simplifying the payment process.

Procurement of supply chain

Definition

Procurement is the acquisition of goods, services or products from external sources. Optimally, a robust procurement procedure will gain the most competitive price, alongside other benefits in terms of quality, quantity, time and location. But it is time-consuming as it is exposed to the obstacles of multiple intermediaries and there is the risk of fraudulent transactions. Ideally, procurement processes should minimise risk.

Relevance

Blockchain can improve the procurement process by facilitating the automation of trust. The parties involved can have certainty regarding identity, reputability and a price guarantee, as well as a record that cannot be changed. It can also replace invoicing. This will help companies to avoid administrative bottlenecks, such as the standard 30-day settlement term, which in turn will reduce cash flow challenges.

Case study

Retail corporation Walmart has been testing blockchain technology for use in procurement management in conjunction with IBM and Tsinghua University in Beijing.[26] In principle, the technology will allow farmers and fieldworkers to input data directly into the blockchain using mobile phones and innovative data entry tools. This will make the data available to retailers in minutes rather than days, improving the efficiency of the supply chain.

> ***"Applying blockchain technology to the built environment will change the way people interact and how the projects are procured and delivered."***

Dr Joan Zhong-Brisbois
Project manager
WSP USA

IoT integrated smart city

Definition

The IoT refers to the network of physical objects, devices, appliances, etc. equipped with the ability to collect, connect and exchange data. As the IoT becomes increasingly ubiquitous with the proliferation of smart objects — from phones to cars to lights — the networks of information and functionality will extend. This will increase the potential for smart cities through the development of smaller, faster and more efficient processors.

Relevance

Once the IoT has gathered and compiled the data, blockchain is the mechanism that governs how it is distributed. Combined with an immutable ledger of transactions, there is great potential to manage infrastructure and other systems efficiently. As the systems around us — transportation, infrastructure, energy, waste and water — become more connected, a trusted system such as blockchain can potentially offer a greater value yield. The technology can manage infrastructure nodes and energy more efficiently on a secure ledger of the blockchain.

Case study

Telecommunications company Nokia is offering a blockchain-powered IoT sensing service for smart cities.[27] It aims to employ the technology, utilising data analytics and blockchain, for the economic and environmental upkeep of our cities. The technology can be applied to detect environmental behaviours such as illegal construction, rubbish burning or unusual particles in the atmosphere. Nokia also sees possible applications in unifying the management systems in a smart city, and improving the roll-out of new services, for example by a city council.

Building information modelling (BIM)

Definition

BIM brings together architecture, engineering and construction professionals under a single digital tool and process, enabling the coherent, cooperative and integrated design of buildings and infrastructure. It allows the construction of a 3D model for the generation and management of digital assets.

Relevance

In BIM, blockchain technology can facilitate security, liability, transferability and live data collection. A digital immutable ledger allows the project to be mapped and tracked at every stage. During the design phase, this is useful for establishing ownership of models and tracking incremental improvements and changes. Once operational, a BIM blockchain-aided virtualisation can be linked with its physical manifestation, with changes recorded internally. The data can be controlled and relied upon, both internally and externally, increasing transparency and trust. This will benefit stakeholders by reducing the opportunity for corruption, inefficiencies and contractual disputes.

Case study

In France, bridges are being designed using BIM and blockchain by tech start-up, bimchain.io.[28] Its service offers the potential to revolutionise BIM into a collaborative and legally binding tool. The benefits are in the output of a quality and accountable BIM product. Smart contracts can be drawn up and payments automated to ensure that stakeholders are committed to achieving their stated outcomes. It is also possible that insurers might reduce premiums, given the additional financial security built into projects. A market-ready product is expected in 2019.

2

Markets: Energy

Blockchain technology could complement a shift of dynamics within the energy system. The technology could play a role in facilitating new business models and the new transactional requirements in this future energy market.

Will deregulated market-trading platforms using blockchain or distributed ledger technology have a role to play in future energy markets? The answer is most probably yes. Here we explore the challenges facing deregulated energy markets and ask whether blockchain could improve competition, while also giving access to distributed energy generation in a way that improves network resilience.

Deregulation of our central utilities systems (electricity, gas, water) has been in progress in most developed countries since the 1990s, and much has been achieved in the past 20 years. The power generation market has been opened up to accommodate owners of both legacy and new plants bidding for the right to generate and supply power with differing inherent characteristics to an electricity grid that is exposed to increasing levels of renewable and stored energy. There are many technical challenges for the network operators, transmission system operators and distribution system operators in improving system resilience while developing a competitive market with more players in the generation (wholesale) and supply (retail) markets. The evolution of small-scale distributed energy production (mainly photovoltaic) by consumers has led to the evolution of the 'prosumer'.

The roll-out of electric vehicle technology will bring a new distributed power storage resource as vehicle batteries can draw from and supply to the grid to take advantage of troughs and peaks in demand. Smart energy metering systems will be developed to enable the distribution system operators to control the ebbs and flows of demand and power in a network that has fast-reacting storage and low-carbon power generation plant to provide the necessary system inertia to 'keep the lights on'.

Markets: Energy

John Burgess
Global energy skills leader
Arup

The shift towards renewable energy dominance and decarbonisation will also mean the energy system will transition from the current centralised model to a decentralised model — consumers will become prosumers (producing consumers).

Our publication, *Energy systems: A view from 2035*, examines new trends in the global energy markets.[29] There will be changes to the energy system as society adapts to the decarbonisation imperative driven by commitments to address climate change. Renewable energy sources such as solar and wind energy, combined with energy storage capabilities, will allow energy consumers to be their own energy producers and increasingly independent from national energy grids. Industrial parks, universities, airports and new towns will develop micro-grids, reducing the reliance on a national grid. There will be a diverse range of energy sources with significantly lower emissions. Heat pumps and electric vehicles will use electricity as their primary energy source. Smart meters will allow households and businesses to be actively engaged in their energy management.

Smart meter technology will lead to more direct energy trading and balancing between consumers and local prosumers. This will enable consumers to participate in demand-side energy management as well as providing micro-grid balancing and ancillary services via virtual power plants and aggregators.

However, certain aspects of the energy supply networks, by necessity, must remain under the control of a national regulatory body and network operator.

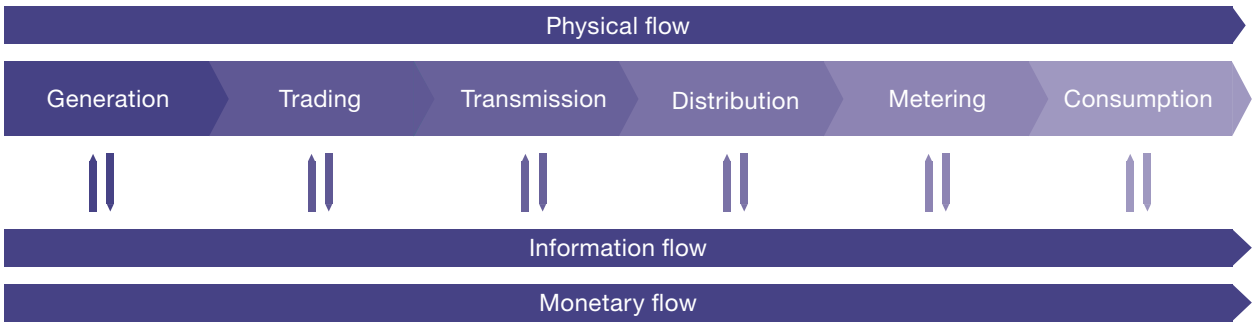
Different countries will have differing approaches to protecting their utility networks from the risks of completely open, price-driven market behaviour that ignores externalities, such as the cost of building and maintaining the network infrastructure. Resolving a fair and equitable method of recouping the network costs from energy consumers will pose one of the challenges for new trading platforms operating outside the approved retail frameworks.

With decentralisation of the energy markets, intermediaries facilitating transactions between energy generators, retailers, aggregators and energy users are looking at open-source trading platforms to reduce marginal costs and create leaner, automated business models.

Blockchain will provide tamper-proof record keeping and enable smart contracts that lead to reduced transaction costs and increased speed of transaction processing. These possibilities will affect the role of intermediaries in the energy system. It also has the potential to remove barriers to entry and allow smaller producers and prosumers to participate in the energy market.

Implementable technology for blockchain is still emerging, and at its current capacity, decentralised ledgering technologies cannot compete with more traditional forms of transaction management. Permissioned private blockchain or ledgers are catching up, but given their nature, they offer less innovation than completely open transaction and information management solutions.

Figure 9 Electricity value chain



Blockchain will be a catalyst in shifting the dynamics from a focal to a distributed energy network. Figure 9 shows the value chain for conventional electricity where power flows in one direction; future systems will be more decentralised and less linear. The technology could play a role in facilitating new trading platforms in future energy markets at a local, national and regional level. International electricity networks, such as the recently activated Integrated Single Electricity Market (I-SEM) in Europe, will see more opportunities for the adoption of blockchain that transcend national boundaries, using secure, open, fast-acting trading platforms that improve competitive pricing for energy.

Blockchain technology could be used in several trading points within the energy system:

1. Power generation markets (wholesale — year, month, day ahead trading)
2. Renewable energy generation and distribution markets
3. Demand-side management, load shedding and generation start-up — aggregation markets
4. Retail energy markets
5. Off-grid micro-grid markets

Given the transaction and intra-system balancing times required for energy systems, and the huge volumes of transactions required, a dedicated solution similar to those being considered for banking institutions would be required. It is possible that the internet infrastructure will be followed as a model here. Initially, this showed similar problems with scalability and throughput, which could be solved by some of the clever multi-layered structures in use today. The trend towards a recentralisation, currently observed on the internet, must be avoided in the area of decentralised blockchain applications, as the benefits achieved by decentralisation cannot be amplified by applying centralisation again.

Developing the ability to confirm that the necessary real-world conditions have been met in order to strike a smart contract, will be key to the implementation of blockchain solutions. The implication is that a proliferation of smart meters will be necessary, and the security of these devices will be critical. The immutability of data transferred on the blockchain is irrelevant if the data have been tampered with before they reach the blockchain. Without this ability, the immutability element of the blockchain concept cannot be upheld, which is a significant barrier to effectiveness. Although blockchain can enable a decentralised energy system, conventional databases can also record transactions and data flows, and they are readily available and already well researched and understood.

The World Energy Council outlines six conditions in which blockchain has great potential to provide better solutions than current technologies:

- Multiple parties share data — multiple participants need views of common information.
- Multiple parties update data — multiple participants take actions that need to be recorded and change the data.
- Requirement for verification — participants need to trust that the actions that are recorded are valid.
- Intermediaries add cost and complexity — the removal of ‘central authority’ record-keeper intermediaries has the potential to reduce cost (e.g. fees) and complexity (e.g. multiple reconciliations).
- Interactions are time-sensitive — reducing delay has business benefits (e.g. reduced settlement risk, enhanced liquidity).
- Transaction interaction — transactions created by different participants depend on each other.[30]

For blockchain to be implemented successfully, coordination and collaboration between regulatory bodies is essential. Blockchain offers the opportunity for greater transparency and access to information, simpler regulatory processes and reduced overhead costs. Regulators could have instant, real-time access to immutable data through blockchain.

From a more radical viewpoint, blockchain is a tool to reduce the requirement for unanimous global regulation. While there will always be a need for a regulatory framework regarding the physical (i.e. generation, transmission and distribution) side of energy networks, blockchain presents an alternative to the regulation of jurisdictionally bound energy markets (i.e. metering and trading). This could be achieved by implementing the regulatory requirements in the blockchain. This market model requires the consent and initiative of the market's participants and could work without a single global regulatory body.

There are already examples of blockchain in use for off-grid, micro-grid solutions in developing markets and its use in energy markets will evolve over the coming years. Some countries will adopt and move ahead with blockchain in many areas of our lives, not just in energy. When issues affecting the resilience of our energy networks are resolved, expect to see national regulatory bodies and energy market stakeholders participating using blockchain.

Energy microgrids

Definition

Micro-grids are localised energy grids that can be combined with or isolated from wider (e.g. national) grids and are capable of operating autonomously. They facilitate independence in energy supply with multiple benefits, including the tailoring of supply to peak times and allowing localised maintenance without widespread disruption. They are powered by autonomous sources, such as renewable energy turbines or distributed generators. Micro-grids can cut costs, provide backup to the main grid in emergencies and allow local energy independence.

Relevance

As people are increasingly installing and building with renewables, the structure of the energy industry must adapt. Through blockchain, energy consumption and supply can be used to record transactions at specific points in time. Using blockchain technology to monitor and equalise energy supply and demand can offer reliability and control on a decentralised and shared network.

Case study

LO3 Energy has built a pilot blockchain-enabled micro-grid called Brooklyn Microgrid to create a secondary market where local consumers have the opportunity to pay local producers for energy.[31]
LO3 is developing a blockchain to revolutionise how energy can be generated, stored, purchased, sold and used across all levels of the industry. Siemens has invested in the company, building its stake in the technology in anticipation of wider adoption.
LO3 Energy aims to provide a decentralised grid while providing a fairer and more consistent supply of electricity to its customers.

> ***"The energy industry is facing disruption from many directions. The question isn't whether blockchain will also be disruptive, but whether it is a tool to manage the disruption."***

Jon Ferris
Strategy director
Electron

> *Blockchain will revolutionise supply and consumption of energy. Trading renewable or stored energy with neighbours will be more efficient and cost effective compared with centrally distributed energy."*

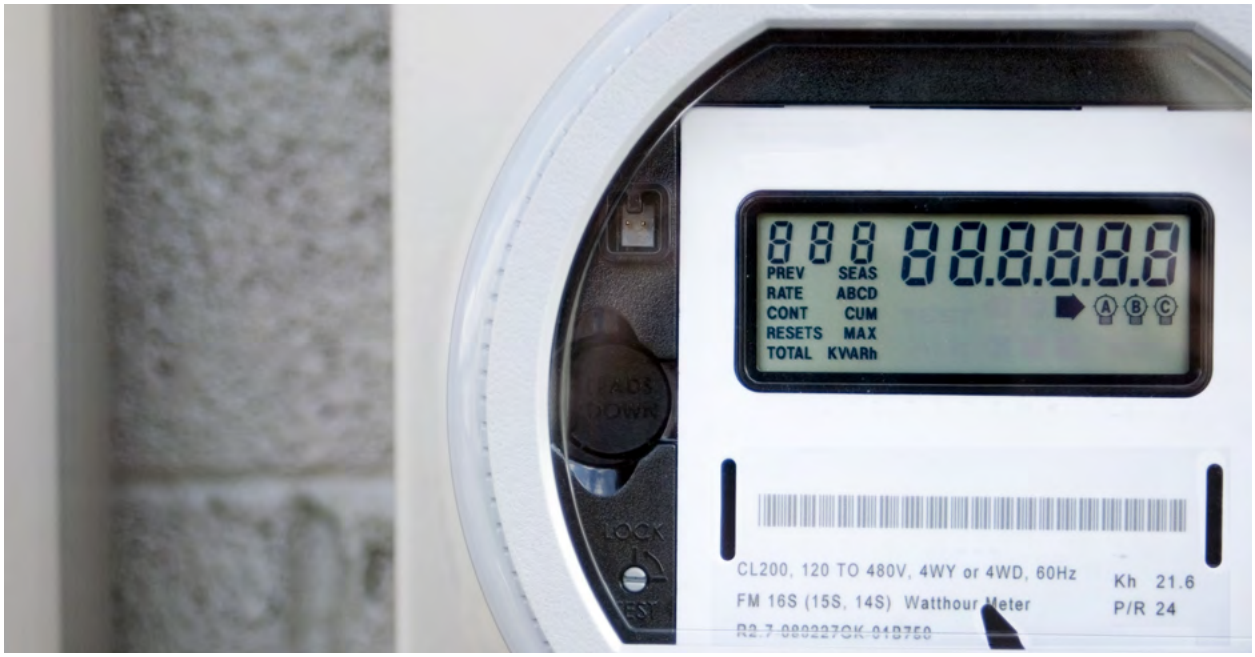
Ian Deakin
Executive consultant
Cuvia Labs

Electric vehicles power sharing

Definition
Electric vehicles are becoming more prevalent as climate concerns increase and government interventions step up to reduce the stock of petrol and diesel cars. However, a barrier to adoption is the range and the availability of charging facilities. This has limited electric car take-up for the most part to urban areas, but electric car owners are encouraged to share charging facilities to counteract the current technological deficit and reduce range anxieties.

Relevance
Blockchain can be applied to the charging of electric cars as a means of recording the energy transaction (time and energy transferred either grid-to-vehicle or vehicle-to-grid) and facilitating payment between car owners and charger owners. By increasing the ease and accessibility of charging facilities in a reliable and monitorable way, blockchain may encourage the uptake of electric cars. Sharing electrical facilities also helps to optimise the grid facilities available by making more constant use of charging units, reducing the load on the grid. The model is also useful for electric car owners, who can offset their energy costs by renting out charging units to other electric vehicle owners.

Case study
Share&Charge has produced a share and charge platform utilising blockchain technology to create a decentralised protocol for electric vehicle charging, payments and data sharing.[32] Share&Charge is developing a blockchain platform to support mobility infrastructure. It connects charging assets around Germany and is implementing a pilot in the UK. It has coupled with a variety of charging station operators, such as Volkswagen, to connect electric vehicle owners to charging points. Furthermore, it has created smartphone apps and is actively reducing the range anxiety of electric vehicle owners.



Smart meter billing

Definition

Over the next 15 years, the UK Government plans to supply smart meters for gas and electricity to every home in the country.[33] The potential benefits include reduced bills for consumers and greater autonomy over demand as consumers can be advised when it is advantageous to switch loads on or off, for example the demand-side management of electric water heating. The meters will increase flexibility in energy and gas consumption, forcing suppliers to become more competitive, and greatly enhance the resilience and reliability of the energy networks.

Relevance

Applying blockchain technology to this system will allow consumers to control their consumption, decrease the risk of security breaches and inaccurate billing, and provide a seamless transaction log. The advantage of using blockchain in this situation is that it provides the security and confidence to use smart meters and smart contracts to carry out transactions currently performed by people in billing departments and banks.

Case study

The German Energy Agency (dena) and the European School of Management and Technology (ESMT Berlin) have released a publication showing how blockchain technology could make smart meters more secure.[34] The technology can prevent security gaps by acting as a decentralised transaction log; however, there are still security vulnerabilities to solve. The level of sophistication and resilience is also contingent on the correct institutional and regulatory framework.

Clean energy sources

Definition

The future of energy is shifting away from fossil fuels. It could move towards a network of local grid-connected devices — the majority of them small, with a few larger ones — providing energy through a decentralised distributed energy resource system. This is being driven by new lower-cost technologies and consumer demand for clean energy.

Relevance

Blockchain enables the trading of energy among decentralised sources without unnecessary third parties (note that trading can occur without blockchain). As such, this will encourage more renewable energy projects, enabling producers of renewable energy to connect efficiently with investors. The future of energy looks very different with blockchain eliminating intermediates between the energy producers and the domestic and commercial consumers.

Case study

Electron, a UK start-up, is using blockchain technology to create efficient and scalable systems for energy trading and grid-balancing solutions.[35] Electron aims to support the transition to smart grid infrastructure in this way, enhancing decentralisation, decarbonisation, digitisation and democratisation. The start-up has established a blockchain energy consortium with EDF Energy and Shell (and other big players) as part of a group to address key challenges in ensuring cheap, clean and reliable energy.

"Blockchain is part of the platform revolution, and tokenised platforms have tremendous potential to increase our talent liquidity, productivity, ability to win work, and margins."

Thomas Wendling
Blockchain community of practice lead
Jacobs Engineering

3

Markets: Property

Blockchain technology has the potential to transform the property market to provide a trusted, open-value platform where users and machines can trade value to generate a new range of services.

Property design, delivery and operations are the last stronghold of traditional analogue methods, characterised by multiple stakeholders, complex procurement routes, low margins and unpredictable performance. The sector is confined by outdated data-processing methods and exchange flows for a large proportion of business information. For example, designs and plans are exchanged on paper and shape behaviours and outcomes. We need digital solutions that will provide openness, transparency, honesty and immutability throughout the built environment lifecycle — this is the role of blockchain.

The built environment poses many complex challenges, from early decisions in the planning phase through to composite coordinated design and construction choices to ongoing commissioned systems during operation and maintenance. To provide a seamless journey through these established gateways, blockchain offers the potential to create immutability and trust between all parties, leading to faster, secure and honourable dealings.

Although still largely unproven with real-life examples, blockchain technology is here to stay. It will play a fundamental role in the built environment and have a profound effect on each stakeholder within the lifecycle of a development — from architects, quantity surveyors and design teams, to tenants, visitors and guests. By creating a global network of trust, blockchain will allow people and machines to transact with each other without the need for intermediation.

Markets: Property

Matt Proctor
Associate, Digital
Arup

With the rapid advancement of digital technologies, coupled with the consumerisation of IT, the boundaries between work and personal life are becoming ever more blurred and complex within the property sector.

Blockchain technologies provide an opportunity to harness new and secure ways of trusted interactions between users and machines. An area where blockchain can add value to the property sector is in building information modelling (BIM). Currently, most construction projects work towards BIM Level 2, in which data is attached to disparate 3D models in multiple locations. Blockchain could accelerate the advancement towards BIM Level 3 — where all parties work together on a single, collaborative, shared model — by permitting increased levels of security, reliability and live data collection within an open, trusted environment. Blockchain could provide an immutable record of changes, proving ownership of a model or digital component and decentralised common data environments.

With the resurgence of the digital twin, blockchain can link digital components to their physical counterparts, creating an entirely new paradigm for building data and derived insight. A real-time digital twin of a property portfolio could provide datasets to an estates director or facilities manager, creating an advantage when buying, selling or leasing property to clients.

As IoT devices permeate every aspect of the design, construction and development lifecycle of a building, there will be a requirement for a trusted system able to process transactions between autonomously provided IoT services and information sources.

Increasingly, buildings are fitted with sensors that monitor and record their state, using the internet for the transference of data to derive value. For example, a maintenance company tracking how frequently soap dispensers are used and identifying where and when refills are required, as well as when to replenish stock. Building owners can see a real-time audit of where maintenance occurs.

Billing could be provided at a local level, with tenants given a breakdown of which systems and devices are contributing to the overall costs, offering incentives and cash back for reducing usage at certain times of the day.

This is where the security of blockchain comes into play, allowing the secure transmission of data using a distributed ledger. However, offering scalable IoT solutions currently provides only information, not value. IoT networks are a plethora of ecosystems and protocols developed by different organisations and manufacturers resulting in a lack of interoperability. Blockchain technology can provide a trusted, open-value platform where users and machines can trade value to generate a new range of services.

Assuming IoT devices will soon be able to communicate over non-proprietary open standards, blockchain would add the benefit of enabling value to be conducted over a network, raising the possibility of a value-transfer system where people and machines can exploit a sensor's data stream.

Blockchain technology has the potential to transform the built environment by building a new foundation for machines to interact and transact with each other. The implementation of a trust network can underpin huge operational improvements, particularly for contracts, which are prone to corruption or disputes. Blockchain could help to improve contract management, enabling more transparency in supply chains, and provide the technological backbone needed to combine aspects of the circular economy, BIM, IoT systems and smart sensors.

Smart contracts for real estate

Definition

In the sale or lease of property, there is a long paper trail of contracts with multiple stipulations that need to be signed and verified by several parties. This process is time-consuming and mainly executed through paper-based signatures. Additionally, in executing contracts for real estate, there is a lengthy due diligence and identity verification process.

Relevance

Executing smart contracts on a blockchain will automate the transactions of the real estate process. Smart contracts have the ability to execute monetary transfers based on contingencies, as well as enable follow-on transactions such as utility accounts and payments. The blockchain technology enables a trusted verification of all parties involved in the contract and creates a seamless and direct process.

Case study

StreetWire, a real estate blockchain services company, is working to innovate and streamline the process and management of transactions.[36] It aims to deliver value to users through data management and smart contracts. Using a blockchain model, StreetWire delivers an encrypted ledger covering all aspects of real estate creating a shared truth between property owners and renters, agents, investors, lenders, borrowers and recorders. Due to the verified nature of the system, StreetWire can develop faster and more secure transaction solutions for the real

> ***"Blockchain fundamentally changes how we all exchange value and interact with data. It offers the construction sector a powerful new way to collaborate in a more manageable, secure and transparent way, creating trust and enabling a more complete and realistic digital transformation of the built environment."***

Dr Abel Maciel
Principal
Design Computation Ltd

> *Unlike centralised or consortium databases, I believe a decentralised, open blockchain with proper incentivisation and scaling solutions will become the transactional infrastructure that powers and secures other major technologies such as the internet of things and digital twins.”*

Christopher Kinnaird
CAD technician
Arup

Title records

Definition
Title records include various methods of recording information based on the conveyance of property and land ownership. Title records are accessed and used by governments, insurance agencies, real estate brokers, buyers and sellers. In a real estate transaction, there is often a transfer of ownership of a title, and there is a lengthy verification of identity and due diligence process.

Relevance
Using blockchain technology for land title management will consolidate the previously siloed and mostly paper process into an easily accessible and trustworthy resource. With blockchain, the parties involved in the title recording can both input and gather information about properties on one common reliable platform. A blockchain for title management will also provide a more secure platform for information storage and ownership transfer, thus reducing the potential for real estate fraud.

Case study
Velox.RE, a legal deed software company, has launched a pilot programme in Chicago in which it aims to make real estate peer-to-peer and transparent.[37] In the programme, velox.RE transferred ownership of real estate through blockchain and recorded the conveyance on the public record. The system works by digitising the real estate asset through the creation of a Bitcoin token, or coloured coin, to represent the asset. The asset is then transferred through the Bitcoin blockchain and the coloured coin functions as a digital deed.

Lease agreements and automated payments

Definition

The process of executing a property lease can be time-consuming and uncertain. A property owner must perform extensive due diligence and background checks on the tenant. Other stakeholders are often involved, such as lawyers, banks and property managers. Executing the lease agreement requires paperwork transfer and signatures by stakeholders. After the execution of the lease agreement, transfer of funds including a damage deposit and rental payment occurs between the renter and owner.

Relevance

Blockchain technology can streamline the property lease process, create comprehensive records and permit a trusted and direct transactional process between owner and renter. Using blockchain technology, payments can be made between owners and renters through an authenticated secure payment system. Renters can log maintenance requests directly to the owners, which are enabled to quickly respond and have a complete record of the property maintenance and damage. Additionally, blockchain can reduce inefficiencies and increase transparency by enabling the lease agreement, including damage deposit and contingencies, to be automatically processed through a smart contract. Finally, the blockchain will aid a more trusted transaction between renters and owners through the verification process, thus minimising the effort needed in the due diligence process.

Case study

Real estate company Midasium has created software for independent landlords and property managers to manage the cash flow of their property portfolios.[38] The software uses a system of smart contracts to automate the cash flow of a property and allows full transparency of properties. The technology delivers three key features: security of bond deposit, reconciliation of tenancy ledger, and expense management. The contract is digitally signed by both parties at the outset of the tenancy agreement and the contract is programmed for the tenant's payments, and creates a tenancy ledger for the owner.

> ***"The promise of blockchain is that 'what I see is what you see'. It can massively reduce the risk and cost that comes with trading. We are now seeing technologies applied in the construction, architecture and engineering sectors, where the same problem is emerging."***

Joel Dudley
Co-maintainer and knowledge transfer
R3 Corda

Sale and asset transactions

Definition

The sale of property is a lengthy process beginning with a search for a buyer or seller and ending with an executed and recorded sale. Many parties are involved, including a buyer, a seller, real estate agents, lawyers and notaries. The service of the agents, lawyers and notaries can be expensive and time-consuming. The closing of a property can be an intimidating process for buyers.

Relevance

Blockchain technology can enable the sale of property directly between buyer and seller, cutting out the middlemen and benefiting both parties financially. Additionally, the immutable ledger created by blockchain will securely and reliably track titles and ownership of the transaction process. Using smart contracts, the sale can be executed automatically based on contingencies of the sale process. Blockchain sales can enable an efficient and secure process of selling peer-to-peer.

Case study

Sweden's land registry authority, Lantmäteriet, and partners are piloting a blockchain-based process for real estate sale transactions and mortgage deeds.[39] The process connects the seller with a real estate agent and buyer and integrates the land registry and bank information. Recent demonstrations of the technology include an identification verification process, approval and execution of digital agreements, and an export of finalised legal contracts. The blockchain transaction takes the duration of the process of signing a purchase agreement through registration of the sale from four to six months down to a matter of days or even hours.

Property data management (MLS)

Definition

The National Association of Realtors defines Multiple Listing Services (MLS) as private offers of cooperation and compensation by listing brokers to other real estate brokers.[40] MLS are databases where real estate brokers share information on properties they have listed and create partnerships with other brokers working with buyers to help sell their listings. However, today, there are more than 800 of these broker-to-broker databases that real estate professionals pay to access. Additionally, there is not a standard format for sharing property information, and the formats and information contained in the various MLS are inconsistent.

Relevance

By taking MLS information to a blockchain, the property data are decentralised from fee-charging institutions. This reduces barriers for both buyers and sellers. The aggregation of multiple sources of information will give buyers' and sellers' agents direct access to each other. Further, a blockchain will standardise the property information distributed and increase the validity and trust of the quality of information provided.

Case study

The company Imbrex is building a global real estate data exchange that is accessible to both buyers and sellers.[41] The platform has replaced the traditional MLS server and database scheme with open technologies. The structure aims to minimise fees and maximise exposure of real estate listings through a blockchain. Additionally, Imbrex's platform allows agents, firms and brokers to easily migrate information between systems and improve the quality of listing information available to buyers.

4

Markets: Transport

The global rise in passenger numbers and increased demand on transportation systems will create a greater need for the eradication of paper-based approaches to operating and managing assets. Blockchain provides the trust, transparency and security to transform the sector.

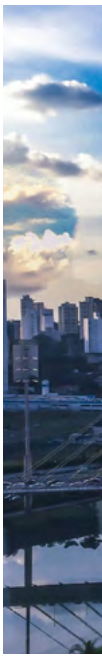
Revenue from the global transportation and logistics industry is predicted to experience a compound annual growth rate of 7.5% from 2015 to 2024.[42] This expansion will require new mega transportation terminals that will process both passengers and cargo.

Over the last seven decades, global transportation has been an area of significant evolution, especially in the aviation sector. Since the mid-20th century, the number of people taking flights has increased exponentially, to an ever-increasing range of destinations. Airlines collectively handled more than 4.1 billion passengers in 2017, with the International Air Transport Association forecasting that the market will reach 7.8 billion passengers by 2036.[43]

Such large numbers of passengers require infrastructure that can serve them quickly and efficiently in the form of mega hubs to centralise and coordinate services. Areas in which blockchain could be applied in the transportation sector include: smart contracts, automated payments, capacity monitoring, tracking and interventions in logistics, identity checks and vehicle lifecycle management.

Markets: Transport

Kevin O'Grady
Associate director
Aviation Development
Arup



Blockchain presents many opportunities to challenge outdated practices at a time when accelerating growth in global populations requires cities and connecting infrastructure to become smarter. Greater use of emerging digital technologies will improve transportation infrastructure, both economically and socially.

Blockchain could present new opportunities for optimisation, coordination and automation across the fundamentals of the transport and logistics industry. A smart contract would be able to self-execute coded tasks using the distributed ledger, completing processes automatically when preordained conditions are met. For example, in a supply chain, payment could be released upon receipt of an item, negating the need for the administration involved in invoicing. Similarly, in a large construction project, a smart contract linked to activities and attributes in a 3D model that releases payment once activities are verified on the distributed ledger will give reassurance on the flow of payments between a client and contractors, and provide equity in the development of transportation infrastructure facilities.

Blockchain, with the help of innovations in the internet of things (IoT), can be particularly useful for capacity monitoring. Arup is part of a study into the application of IoT sensors in an airport terminal, collaborating with leading industries, legal firms, universities and blockchain experts. Circular economy benefits can also be realised when assets are assigned digital passports that contain data such as service histories recorded on an immutable distributed ledger.

Efficiencies in logistics could be achieved by using blockchain technology to track shipments in trucks, shipping vessels and air cargo. A distributed ledger secured through blockchain technology on shipments would bring time and administration benefits, especially since goods often travel via multiple modes of transport and are passed between many logistics providers.

Travel technology providers are using blockchain technology to store and authorise biometric details when creating a single token on a mobile device — otherwise known as a digital passport — which can then be used by passengers to travel through security at borders, seaports and airports.

Arup is exploring the potential whole lifecycle of a motor vehicle to increase transparency and trust concerning its status and value. This process can begin before an asset is operational: from design to the build phase, using components supplied by independent manufacturers, and continuing throughout the operational life of the vehicle, to destruction. The blockchain can be used to record import and registration in local markets, ownership changes, service records and component replacement. If the vehicle has an accident history, those details can also be added. Finally, at the end of the asset's life, the ledger can be used to aid recycling and reuse of the product, feeding the circular economy with reliable parts and materials, and extracting the highest value from the asset, even upon decommissioning.

By using IoT sensors in trucks and shipping vessels, transportation companies know the amount of space taken up in a shipment and can determine cost accordingly, transmitting this information to the blockchain.

The security of the ledger is especially important if there are multiple stakeholders and the cargo changes hands many times before reaching its destination.

Freight tracking and logistics

Definition

Freight shipping demand is increasing, with global freight rates 37% higher in the first five months of 2017 than in the same period of 2016.[44] In a recent survey, 42% of people said they spent more than two hours on paperwork to arrange a shipment, while 83% said they struggle to track shipments across the globe.[45] This is due to the fragmented nature of tracking and logistics, which ultimately leads to low standardisation and transparency, combined with quantities of data and various levels of technology adoption.

Relevance

Using blockchain, we are able to transform global supply chains by tracking, verifying and coordinating freight autonomously. A key bottleneck for logistics is the manual data entry and paper-based documentation for customs processes. Blockchain can overcome this barrier, raising efficiency, transparency and access along the supply chain. Costs can also be saved through automated systems that are error-free, raising the predictability of logistics, minimising counterfeiting, and tracking at scale.

Case study

Shipping company Maersk and IBM created a blockchain venture to digitise trading workflows and end-to-end shipment tracking.[46] The system allows each stakeholder to track the progress of items throughout the supply chain and see the status of customs documents, bills of lading and other freight data. The role of blockchain is to ensure a secure, well-documented exchange of data and transparent repository. The aim of the venture is to track tens of millions of shipping containers each year while reducing the cost of tedious manual paperwork.

Ride hailing

Definition

Ride-hailing services have grown in popularity, with growing public acceptance of services such as Uber, Lyft and Chariot. The ride-hailing concept promises lower prices for short trips, clean vehicles with amenities, congenial service and a user-friendly smartphone app. The apps remove uncertainty, enabling users to know exactly when they will be picked up, by whom, how long the journey is expected to take and what it will cost. The platform operator ensures that drivers get paid, minus a transaction fee, offering transparency for the customer from start to finish.

Relevance

Blockchain can enable a seamless, integrated system between the driver and the customer. Drivers will be able to receive the total journey cost without paying a fee to the middleman (such as an Uber/Lyft platform operator). This decentralised platform will create a new way of working and fair working conditions; the incentive may lead to an increase in economic growth and decrease in unemployment. The technology relies on a consensus agreement to verify the driver's identity, credentials, past records and history to provide a safe and secure environment for consumers.

Case study

TADA, a new ride-hailing app launched in Singapore by Mass Vehicle Ledger, is using blockchain to provide customers with promises of free cancellation and lower cost zero commission for drivers.[47] Pricing will be either point-to-point or metered. Security is also enhanced with blockchain, eliminating the need for a middleman. The firm has recruited 2,000 private-car drivers and aims to create a licensed community where the drivers and consumers are treated with fairness.

Car sharing payment system

Definition

Traditional models of ownership are changing, and platform-based, peer-to-peer services are disrupting a growing number of industry sectors worldwide. The younger generation are increasingly choosing not to own cars. Car use in London peaked in 1990 at 50% of trips and has since declined to 37%; by 2050 it is projected to fall to 27%.[48] Similar trends are evident in Birmingham and Manchester. The global car-sharing market is expected to grow by 35% between now and 2025.[49]

Relevance

Blockchain technology has many of the features required for a car-sharing framework, including the ability to enable secure data transfer, efficient vehicle recording and a peer-to-peer integrated trading platform. The technology has the ability for various users to gain authorisation, and to provide a database of journeys in real-time with updated traffic conditions. Blockchain could provide users with predictive and dynamic pricing.

Case study

Car manufacturer Porsche, in collaboration with software corporation XAIN, is trialling a new business model using blockchain technology in its cars for access purposes.[50] The platform is testing transactional and processing speeds, including locking, unlocking and temporary-access authorisations if the owner is locked out of their car. This innovation will enable a diversity of users to access the car, for varying amounts of time, all tracked and logged securely.

> *Blockchain, if implemented correctly, is the ideal solution for significantly increasing transparency in design and construction processes and contracts, which could help to reduce corruption."*

Matthias Geipel
Consultant
Arup

Material passports

Definition

As industries add new models and expand their output, opportunities increase for supply chain investment. For example, in the automotive industry, the interaction between the manufacturers, suppliers and government has led to new supply chain investments requiring new technological advances to enhance connectivity and improve tracking of materials. Material passports are digital representations of physical assets. Through mass integration of sensors on both materials and vehicles, and innovations such as material passports, materials can be tracked from design, to installation, operation and end-of-life. This supports the principles of a circular economy where maximum value is extracted from products before they enter the waste stream.

Relevance

Blockchain can enable companies to track materials using a material passport. This tracking can follow a consistent documentation of the material, including its product structure or construction. The material passport provides information on past, current and future performance, and the data can be linked to the digital asset to keep the information up to date.

Case study

Car manufacturer Renault is prototyping a digital car maintenance book by using blockchain to enable a single source of truth for each vehicle's performance and subsequent maintenance needs.[51] The collaboration with Microsoft and information systems specialist VISEO explores the technology to ensure that the car passport data are stored securely and transparently. The digital car maintenance book stores a log of all the activity concerning the vehicle in one location. For example, if the owner puts the vehicle up for sale, special permission can be granted to the potential buyer to have access to historical information, creating trust between the parties.

Biometrics gateless border

Definition

Biometric data, such as fingerprint and facial data, are increasingly incorporated into technological innovation. For borders, such data have enabled the creation of gateless borders whereby no face-to-face contact is necessary to verify a person's identity. Therefore, passengers can expect a quicker, more stress-free journey.

Relevance

The combination of biometric data and blockchain technology can enable gateless borders that are secure and efficient. They can help to reduce the bottlenecks in border control areas by providing secure checkpoints and allowing passengers to be processed more quickly. The future of biometrics may involve the logging and tracing of all movements of passengers and staff on to one localised system.

Case study

Dubai's government is exploring the use of gateless borders using biometric data and blockchain technology.[52] This combination offers seamless entry for residents and tourists at the airport, verifying their stay. The technology enables a digital biometric passport for passengers allowing them to register in the country without human screening.
The identity trust security measure can be built into the blockchain technology allowing passengers to be screened using the verification capabilities.

> ***"Blockchain has challenges, but its potential to solve the longstanding accountability and efficiency issues in our industry is too great an opportunity to miss out."***

Balint Penzes
Consultant Engineer
COWI UK

5

Markets: Water

Blockchain and the water sector are well suited to come together for the benefit of all, enabling fast, efficient, transparent deployment of the right quality of water for the right use and the right user.

Understanding the availability of water in our catchments, particularly where there are competing interests for its use, requires significant resources and management. Water abstraction is increasingly affected by climate change, and there is great concern over the future availability of water for the environment, communities, agriculture, industry and other stakeholders.

Water regulation has a strong focus on ensuring that water takes are accounted for and verified. Primarily, this is about quantity, but quality will play an increasing role as specific end-uses require particular water qualities that need to be guaranteed as fit for purpose.

Water and environment regulators seek to understand why or where water is accounted and unaccounted. A key benefit of a decentralised water trading system over a centralised system is that it encourages 'buy in' from all users. In order for users to take part in the system, they need to abide by system protocols and, in return, gain access to the water trading platform. This encourages greater accountability and transparency across the network. Blockchain is the technology solution for this.

Water trading is a complex market where water brokers complete water trades in a highly non-regulated environment with little transparency. Trades occur between farmers, irrigators, towns and government to meet the diverse needs for allocation.

Markets: Water

Dr Therese Flapper
Associate principal
Infrastructure and Water
Arup

Blockchain is an ideal technology to track water transactions and water compliance activities. Regulators, water users and stakeholders have the same copy of water trading and compliance information across a water network with no discrepancies.

Blockchain is currently being tested and deployed across the water sector. It is receiving significant attention in the international community. For some, the technology represents a radical shift away from the centralised systems held and managed by government agencies.

The fundamental advantages of blockchain for the water sector include:

- Increased transparency with the complete history of each transaction available immediately to all users in the network.
- Increased level of stakeholder engagement and responsibility as each stakeholder owns a part of the chain.
- Increased efficiency and timely transactions that can meet the fast-changing needs for water in a given part of the catchment.
- Increased cyber security as blockchain networks make use of proof-of-stake (PoS) or proof-of-work (PoW) algorithms which make network tampering near impossible.

More fundamentally, the environment can be identified as a user in the system and all users can gain access to allocated flows. This can assist the various participants that compete for water allocation in a system, such as the complex negotiations of the Murray-Darling Basin in south-east Australia. The Murray-Darling Basin Authority aims to achieve a healthy working basin for the benefit of the Australian community. The Basin Plan ensures that in times of drought, water is prioritised for critical human needs; so water is provided to communities for drinking and household water, before being allocated for any other use.

Blockchain in the water sector provides transparency and efficiency, which is cost effective and timely. It operates in real time and is responsive to changing water needs.

This balance is hard to achieve and is under increasing pressure to be clearly demonstrated and transparently reported. Blockchain technology can support water resource plans, manage and adjust sustainable diversion limits, report river data and allocate water to the various users. The efficiency and ability of government and the private sector to transact allocations across the environment and communities is improved with the use of blockchain. The predictive analytics of transactions can assist policymakers and regulatory agencies to administer allocations to benefit everyone.

Blockchain technology may change the role of water brokers so that water trades are made directly by users. Fewer intermediaries and the accessible ledger mean that blockchain is already providing other industries with reduced transaction costs and improved transparency.

Blockchain provides the water sector with a clear audit trail and is verified. As the ledger is distributed and copies are made on numerous devices, any unauthorised changes are picked up and replaced by verified copies immediately.

As blockchain is deployed across the whole water sector — from catchment to tap — management of this resource will become more effective as pressures upon it increase. Blockchain will be able to underpin water resilience for cities, communities and industries. Areas for deployment can be:

- Water trading — quality and quantity — inter-agency, inter-catchment, inter-government, B2B, P2P.
- Capital investment through cryptocurrency links.
- Smart contracts and transactions for fast and transparent responses — procurement, delivery, billing.

Blockchain is a new age tool, applied in other sectors, that will support and enable the water sector to meet humanity's needs into the future. Within the very near future, we would expect blockchain to ameliorate the demands of the water, energy and food nexus.

Water quality

Definition

Water quality means the suitability of water for a purpose or process. Categories include potable water, grey water, reclaimed water, recycled water, freshwater and more. Water quality may depend on a wide range of human and natural factors that affect or limit its use. Water can be taken untreated or treated using a variety of methods depending on the concentration and state of matter in it: dissolved or particulate, organic or inorganic matter. Certain physical characteristics of the water also affect the state of the matter.

Relevance

Blockchain technology can improve trust and verification of environmental impact monitoring. Combined with smart sensor devices, blockchain will enable real-time access to environmental statistics, such as water quality measures, and allow live monitoring of environmental conditions. The system can provide access to historical water quality data on a tamper-proof blockchain ledger and give confidence in environmental quality data.

Case study

The Genesis Research and Technology Group in the US has developed a system to monitor fracking and groundwater quality.[53] The process uses temperature, conductivity, turbidity, dissolved oxygen and pH sensors to analyse water quality during the fracking process. These records are stored on the Ethereum platform, making it possible to track and verify water quality results. This significantly increases transparency, efficiency and accountability of the environmental impact of the fracking process. The future of fracking could be positive for the water industry.

> ***"The synergies between BIM and blockchain have the potential to unleash culture change in the design and construction industry. BIM and blockchain combined can provide a "scaffold of trust" for true collaboration."***

Malachy Mathews
Senior lecturer
Dublin Institute of Technology

> *Blockchain applications in engineering will allow for the direct conversion of the intangible value of human ingenuity into tangible assets on a balance sheet. This changes everything we know about finance."*

Daniel R. Robles
Founder and CEO
Integrated Engineering Blockchain Consortium

Water trading

Definition

Water trading allows water users to buy and sell water resources to respond to supply and demand. It involves buying and selling water access entitlements, often referred to as water rights. Water trading is typically a complicated and opaque process governed and managed by the cooperation of various government agencies, each with its own processes and rules for allocating water. This can increase barriers to trade, create an unclear pricing structure and cause restrictions within the trading market.

Relevance

Blockchain technology can streamline processes in the water trading industry by improving current practices in record management, identity management and transaction processing. A blockchain-enabled system could allow real-time monitoring and auditing of water trading activity, and improve security and efficiency in regulatory compliance requirements. Regulators would then be able to respond quickly to activities in the water trading market and automate transactions through smart contracts to reduce the time required to settle transactions.

Case study

Civic Ledger, an Australian civic blockchain start-up, has developed a peer-to-peer platform that uses the technology to monitor trading and update state registries.[54] Currently, water trading is the shared responsibility of five state governments. The start-up is working with agencies to track the transactions between parties. The government clients are: Queensland Government, Federal Department of Agriculture and Water Resources and IP Australia. This platform removes the need for intermediaries and reduces the potential for fraud.

Access to water for developing countries

Definition

Globally, 663 million people live without easy access to clean water and 2.4 billion people lack access to improved sanitation facilities.[55] Access to clean water, good sanitation and hygiene can transform lives. It is estimated that 3.36 million children (the majority of whom are girls) and 13.54 million adult women were responsible for water collection in households with collection times greater than 30 minutes.[56] One of the United Nations' Sustainable Development Goals (goal 6) is to ensure the availability and sustainable management of water and sanitation for all.
The targets are set for 2030 to achieve universal and equitable access to safe and affordable drinking water.

Relevance

NGOs can apply blockchain technology to create a robust and comprehensive decentralised platform that restores transparency and ensures judicious use of charitable project funds. A blockchain-based token can allow people from all over the world to donate money in support of clean water initiatives across the globe. The utility token can be used within the clean water initiative ecosystem to show where the charitable contributions are invested and towards which project.

Case study

Fintech company BANKEX has established a WaterCoin pilot project in Kenya, which provides clean and potable water to families from donations around the world.[57] The project provides 10,000 litres of clean drinking water per month to more than 1,000 people in the area. Using blockchain technology, BANKEX has eliminated the middlemen ensuring that relief efforts are felt directly by those in need. The project was launched in June 2018 to test the WaterCoin ecosystem. People anywhere in the world can donate by purchasing WaterCoins with the option to specify how they want their donations allocated.

> ***"Blockchain is more about enabling new business patterns than technology; patterns that enable networks of actors to transact with low friction and high confidence."***

Erwin Frank-Schultz
Technical leader
UK&I for Infrastructure Industries
IBM UK Ltd

Water treatment

Definition

Water treatment improves the quality of water for its intended use. Uses include: domestic (drinking and cooking), agricultural (farming and fisheries), industrial (manufacturing), recreational (swimming and sailing) and hydropower generation. As an example, wastewater is treated in a wastewater treatment plant by removing and breaking down the pollutants in the water to produce a quality of water that can be safely returned to the water cycle with minimal impact on the environment.

Relevance

Blockchain technology can be used to garner funds to develop and deploy water treatment. It could be used for tracking water source and water end-use/water users, and for fundraising initiatives for capital deployments, procurement and contracts.

Case study

OriginClear, a water treatment technology provider, is creating a blockchain protocol called WaterChain to address the water crisis.[58] The aim is to create a platform to improve water quality worldwide and reduce the number of deaths caused by unsanitary water conditions. The platform allows investors to take a stake by buying tokens to fund water recycling projects and receive a return. WaterChain is an attempt to create new funding opportunities for water treatment facilities.

Utility contracts and billing

Definition

The water utilities industry is quickly evolving to meet the demands of a dynamic, highly deregulated and competitive market. As more and more customers have smart meters, the demand for transparency increases because customers want to know exactly what they are paying for and how they can make smarter decisions to reduce their costs. Customers want to understand how charges are broken down in terms of distribution system maintenance, cost of delivery, cost of usage and cost of commodity.

Relevance

Blockchain can improve auditability and traceability in the water market through smart contracts and billing reconciliation. Blockchain algorithms and structures — initially developed for the financial services sector — are increasingly used in applications for the water industry. The technology can connect all industry parties to share a public view of a register suitable for recording transactions and automating payments and processes through blockchain.

Case study

Product maker Treon has launched an Ethereum platform aimed at the utility market for the payment of utility bills through a mobile app and digital wallet set-up.[59] The platform enables consumers to settle their utility bills using a token through a one-click experience, making it faster to pay bills. The customer will get loyalty points in return as a reward and can redeem them towards favourable or preferred consumption rates.

Conclusions

Blockchain has the potential to transform the built environment by building a new foundation for machines and humans to interact and transact with each other.

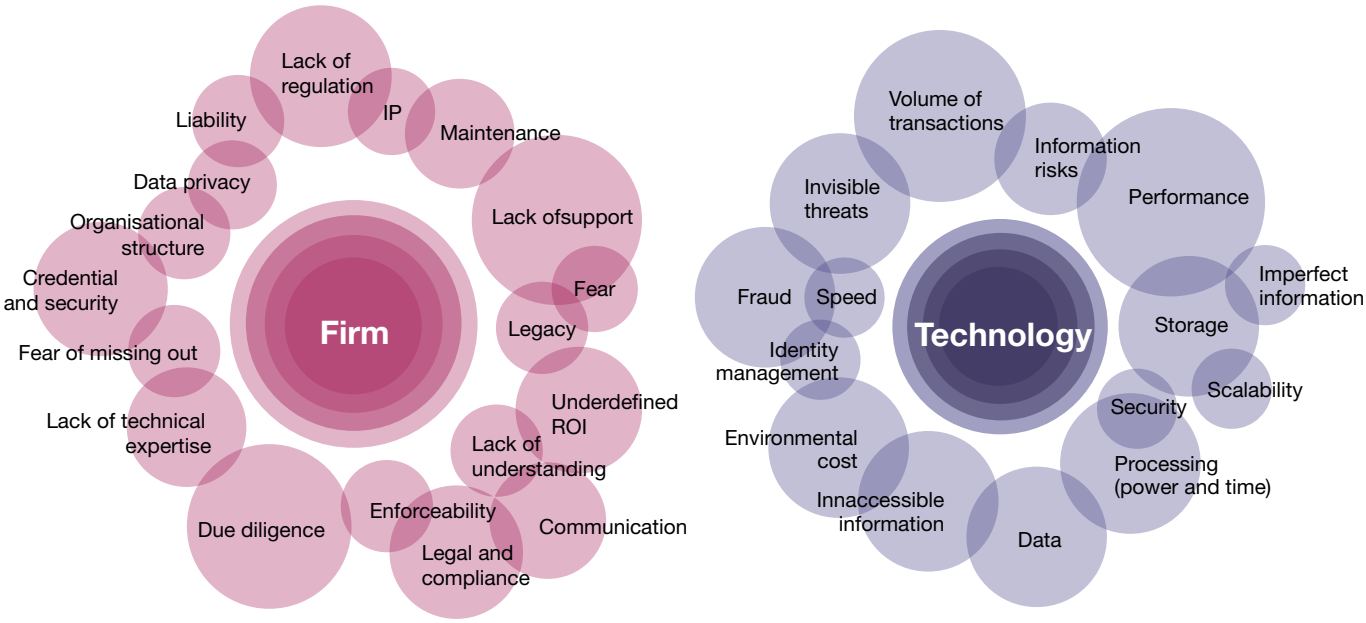
For the built environment sector, blockchain technologies have not yet been transformational, but early use cases are showing real potential. The report highlights that the first phase of blockchain implementation has focused on the automation of payments and transactions. The second and third phase will be more complex with improvements to transactional efficiency and fidelity, governance and data management. Across the built environment sector, blockchain could help to increase transparency in supply chains and provide the technological backbone needed to combine aspects of the circular economy, BIM, IoT systems and smart sensors.

As our cities expand rapidly, blockchain technology could help to solve the challenges of ageing populations, urbanisation and climate change. Blockchain technology enables new forms of cooperation and interactions between millions of people, which could have a real relevance to the challenges faced by cities. Further, blockchain technology could give rise to innovations across parallel emerging technologies, such as digital twins, smart buildings, autonomous robotics and intelligent mobility. This could fundamentally reshape our cities beyond anything we have yet to imagine.

Risks and challenges

At this stage in our industry's blockchain trajectory, the potential risk of blockchain is significant. Blockchain technology presents new challenges, with increased security vulnerabilities and a bigger network economy than we have ever had before. Blockchain thrives in an open world. Therefore, we must be careful with the data we add to a

Figure 10 The risks and challenges from the firm versus technology point of view



blockchain, so that sensitive information is not leaked and we reduce our vulnerability to attacks. New vulnerabilities could be created if valuable data on the blockchain is given an economic value. As users, we must be vigilant to potential scams, such as insincere initial coin offerings and potential hackers.[60] The trust system of blockchain is built on the assumption that private keys cannot be hacked or stolen. Yet this has become an incentive to hackers to crack codes in ever more ingenious ways.

The decentralised autonomous organisation (DAO) was an early blockchain prototype that can teach us many lessons. The DAO was a smart contract built on top of Ethereum, yet the prototype was hacked using a code exploit just three weeks after its launch in June 2016.[61] Rigid security protocols must be implemented on blockchains to ensure code integrity.

Blockchain technology has the potential to change the way we design and engineer the built environment. As we explore the opportunities created by blockchain, our collaboration with stakeholders through co-innovation and co-investment will help build a new open and accessible digital infrastructure. We are looking for research partners and collaborators to develop the technology and support our deep commitment to shape a better world.

Appendix: Features of blockchain

Deciding which blockchain to use can be just as challenging as understanding how one works. Here are eight key features to get you started thinking about blockchain and the unique features the technology could enable. This table can be used as a checklist to aid the decision process. A list of potential solutions can be found on Pages 66 and 67 to show what the available market solutions could look like.

Table 1 An overview of the eight key features of blockchain and the underlying architecture

1 *Consensus*	2 *Digital currency (cryptocurrency, crypto-token)*	3 *Transactions*	4 *Identity*
A mechanism that ensures the network agrees on the current status of the database	A digital token native to each blockchain acting as an incentive for honest network participants	An atomic — 'smallest possible' — digital event on the blockchain. Each block is a collection of transactions	The layer of the system that controls the access and permissions for all participants
Network typology Decentralised Hierarchical Distributed	*Asset* Own the currency Convertible multiple asset None	*Data Structure* Merkle tree Tangle	*Access and control* Public Permissioned public Permissioned private
Immuatability PoW PoS PoA Hybrid	*Supply management* Limited Unlimited Predictable Unpredictable	*Transactional mode* Traditional ledger	*Identity* Anonymous Limited Open/transparent Pseudonymous
	Tokenisation None Third party	*Server storage* Full nodes Thin nodes	
		Scalability Number of users Number of nodes Number of transactions Confirmation time	

5 *Security and privacy*	6 *Codebase*	7 *Rewarding and charging system*	8 *Extensibility*
The component of the system that secures and protects data and the sharing of information	The component of the system that looks at the underlying IT architecture	The mechanism to compensate active members and fees required to participate	A systemic measure that takes into consideration the future growth of the system
Data encryption SHA-2 ZK-SNARKS	*Languages* Single Multiple	*Reward system* Lump sum Block — security	*Interoperability* Implicit Explicit None
Data privacy Built-in Add-on	*License* Open source Closed source	*Fee system* Mandatory fees No fees Optional fees	*Governance* Open source Technical Alliance
	Software Architecture Monolithic Polylithic	*Fee structure* Variable fees Fixed fees	*Script language* Turing complete Generic

Appendix: Snapshot of potential blockchain solutions in time

Table 2 summarises potential blockchain solutions to inform your understanding of the underlying features and architecture. The solutions and features are a snapshot in time and so information may be out of date.

Table 2 An overview of the possible blockchain solutions

Platform	Types	Smart contract	Internet of Things (IoT)	Currency	Accessibility	Operation
Bitcoin	Blockchain	Limited	Yes	Bitcoin (BTC)	Public	Permissionless
Ethereum	Blockchain	Yes	Yes	Ether (ETH), tokens possible	Private or public	Permissionless
EOS	Blockchain	Yes	Yes	EOS (EOS)	Private or public	Permissioned
IOTA	Distributed ledger	No	Yes	Iota	Public	Permissionless
Hyperledger Fabric	Ledger	Yes	Yes	None, tokens possible	Private	Permissioned
Corda (R3)	Decentralised ledger	No	Not suitable	None	Private	Permissioned

**current state as of October 2018. While blockchains have low transaction throughput, scalability solutions are becoming available to increase throughput significantly.*

Decentralisation	Immutability	Consensus	Energy consumption	Scalability*	Launched
Yes	High	PoW	High	<10 transactions per second	Jan 2009
Yes	High	Ethash (PoW) Casper (PoS)	Medium	30 transactions per second	ICO, Jul 2015
Partially	Low	Delegated PoS	Low	up to 6,000 transactions per second	ICO, Jun 2017
Partially	High	PoW (DAG)	Low	up to 1500 transactions per second	ICO, Nov 2015
Partially	Low	Pluggable, PBFT	Low	3,500 transactions per second	Dec 2015
Partially	High	Pluggable,	Low	up to 1700 transactions per second	Mar 2016

Blockchain terminology

This is a degree of blockchain terminology. As the technology matures, so will the terminology.

Blockchain is a digital, replicated ledger of transactions that are secured against alterations once the peer-to-peer network has validated and added the transaction to all instances of the ledger.

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

Decentralisation is the core aspect of blockchain systems and describes the distribution of control and points-of-failure across many physical and organisational instances with the aim of higher security at the expense of efficiency.

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 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 the network.

Public (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.

References

1. C Kinnaird, M Geipel (2017). Blockchain Technology. Source: https://www.arup.com/-/media/arup/files/publications/b/arup--blockchain-technology-report.pdf. Date accessed: 11/01/2019
2. P Tasca, C Tessone (2018). Taxonomy of Blockchain Technologies. Principles of Identification and Classification. Source: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2977811
3. S Nakamoto (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. Source: https://bitcoin.org/bitcoin.pdf. Date accessed: 11/01/2019
4. Waves Platform (2018). Source: https://wavesplatform.com/mining. Date accessed: 11/01/2019
5. Helium Blockchain Alliance (2018). Source: http://cobieblockchain.com. Date accessed: 11/01/2019
6. Construction Blockchain Consortium (2018). Source: https://www.constructionblockchain.org/. Date accessed: 11/01/2019
7. E Rutland (2018). Blockchain Byte R3 Research. Source: https://www.finra.org/sites/default/files/2017_BC_Byte.pdf
8. Twitter (2018). User @VitalikButerin, Vitalik Non-giver of Ether. Source: https://twitter.com/VitalikButerin/status/1072162427045736449. Date accessed: 28/01/2019
9. World Economic Forum (2018). Blockchain Beyond the Hype. Source: https://www.weforum.org/whitepapers/blockchain-beyond-the-hype. Date accessed: 28/01/2019
10. F Mor et al. (2018). The collapse of Carillion. Source: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-8206. Date accessed: 20/01/2019
11. PwC (2018). Blockchain is here. What's your next move?. Source: https://www.pwc.com/gx/en/issues/blockchain/blockchain-in-business.html. Date accessed: 27/01/2019
12. US Environmental Protection Agency (2018). Safe Drinking Water Act (SDWA). Source: https://www.epa.gov/sdwa. Date accessed: 011/01/2019. Date accessed: 11/01/2019
13. United Nations (2018). Sustainable Development Goals. Source: https://sustainabledevelopment.un.org/?menu=1300. Date accessed: 11/01/2019
14. United Nations Global Compact (2018). Project Breakthrough Blockchain. Source: http://breakthrough.unglobalcompact.org/site/assets/files/1667/hhw-16-0019-d_k_blockchain.pdf. Date accessed: 28/01/2019
15. Smart Dubai Office (2019). Smart Dubai 2021. Source: https://2021.smartdubai.ae/. Date accessed: 26/01/2019
16. Token Economy Association (2018). Singapore comes in top in blockchain cities ranking. Source: http://teasingapore.org/singapore-comes-in-top-in-blockchain-cities-ranking/. Date accessed: 20/01/2019
17. e-estonia (2018). Source: https://e-estonia.com/. Date accessed: 20/01/2019
18. SmartCitiesWorld (2018). Vienna progresses blockchain strategy. Source: https://www.smartcitiesworld.net/news/news/vienna-progresses-blockchain-strategy-3198. Date accessed: 28/01/2019
19. NASA (2012). Technology Readiness Level. Source: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html. Date accessed: 15/11/2018
20. M Stevenson, B Gleeson (2019). Complex Urban Systems: Compact Cities, Transport and Health. In: Nieuwenhuijsen M., Khreis H. (eds) Integrating Human Health into Urban and Transport Planning. Springer, Cham
21. BBC (2018). How can our blue planet be running out of fresh water?. Source: https://bam.files.bbci.co.uk/bam/live/content/zc8887h/transcript. Date accessed: 29/01/2019
22. J Jacobs. (1961). The death and life of great American cities. New York: Random House.
23. Arup (2016). The Circular Economy in the Built Environment. Source: https://www.arup.com/-/media/arup/files/publications/c/arup_circulareconomy_builtenvironment.pdf. Date accessed: 29/01/2019
24. Circularise (2018). Source: https://www.circularise.com/. Date accessed: 28/01/2019
25. Intelliwave Technologies (2018). SiteSense® ROVER – Mobile RFID Infrastructure for Construction Sites. Source: https://www.intelliwavetechnologies.com/sitesense-rover-mobile-rfid-infrastructure-for-construction-sites/. Date accessed: 28/01/2019
26. E Yoo (2017). Walmart, JD, IBM and Tsinghua University launch a blockchain food safety alliance in China. Source: https://technode.com/2017/12/14/walmart-jd-com-ibm-tsinghua-university-launch-blockchain-food-safety-alliance-china/. Date accessed: 28/01/2019
27. BTC Inc. (2019). Nokia Launches Blockchain-Powered IoT Sensing as a Service for Smart Cities. Source: https://bitcoinmagazine.com/articles/nokia-launches-blockchain-powered-iot-sensing-service-smart-cities/. Date accessed: 28/01/2019
28. Lutecium SAS (2018). Source: https://bimchain.io/. Date accessed: 04/01/2019
29. Arup (2018). Energy systems: A view from 2035. Source: https://www.arup.com/perspectives/publications/research/section/energy-systems-a-view-from-2035. Date accessed: 15/01/2019
30. World Energy Council (2018). The Developing Role of Blockchain. Source: https://www.worldenergy.org/wp-content/uploads/2017/11/WP_Blockchain_Exec-Summary_final.pdf. Date accessed: 28/01/2019
31. L03 Energy (2018). Source: https://lo3energy.com/. Date accessed: 28/01/2019
32. MotionWerk GmbH (2018). Source: https://motionwerk.com/. Date accessed: 28/01/2019
33. The Guardian (2009). Smart energy meters in every UK home by 2020. Source: https://www.theguardian.com/environment/2009/may/11/smart-meters-energy-efficiency. Date accessed: 28/01/2019
34. Deutsche Energie-Agentur (2018). dena launches study on blockchain in the energy transition. Source: https://www.dena.de/en/newsroom/meldungen/dena-launches-study-on-blockchain-in-the-energy-transition/. Date accessed: 28/01/2019
35. Electron (2018). Source: http://www.electron.org.uk/. Date accessed: 28/01/2019
36. Streetwire (2018). Source: http://www.streetwire.net/. Date accessed: 28/01/2019
37. Velox RE Tech, Inc (2018). Source: https://www.velox.re/. Date accessed: 28/01/2019
38. Midasium (2018). The Blockchain of Real Estate. Source: http://midasium.herokuapp.com/. Date accessed: 28/01/2019
39. Cointelegraph (2018). Swedish Government Land Registry Soon To Conduct First Blockchain Property Transaction. Source: https://cointelegraph.com/news/swedish-government-land-registry-soon-to-conduct-first-blockchain-property-transaction. Date accessed: 28/01/2019
40. Multiple Listing Network Ltd. (2019). Source: http://www.mls.com/. Date accessed: 28/01/2019
41. CryptoSlate (2018). Imbrex REX. Source: https://cryptoslate.com/coins/imbrex/. Date accessed: 28/01/2019
42. GlobeNewswire (2018). Global Transportation Management Systems Market Will Reach USD 24.1 Billion By 2024: Zion Market Research. Source: https://globenewswire.com/news-release/2018/10/08/1617753/0/en/Global-Transportation-Management-Systems-Market-Will-Reach-USD-24-1-Billion-By-2024-Zion-Market-Research.html. Date accessed: 28/01/2019
43. International Air Transport Association (IATA) (2018). 2036 Forecast Reveals Air Passengers Will Nearly Double to 7.8 billion. Source: https://www.iata.org/pressroom/pr/Pages/2017-10-24-01.aspx. Date accessed: 28/01/2019

44. T Loadstar (2017). Container Lines Praised for Capacity Management Skills. Source: https://gcaptain.com/container-lines-praised-capacity-management-skills/. Date accessed: 28/01/2019
45. The Economist (2019). The global logistics business is going to be transformed by digitisation. Source: https://www.economist.com/briefing/2018/04/26/the-global-logistics-business-is-going-to-be-transformed-by-digitisation. Date accessed: 28/01/2019
46. IBM (2018). Maersk and IBM Form Joint Venture Applying Blockchain to Improve Global Trade and Digitize Supply Chains. Source: https://www.ibm.com/think/fintech/maersk-and-ibm-form-joint-venture-applying-blockchain-to-improve-global-trade-and-digitize-supply-chains/. Date accessed: 28/01/2019
47. T S Kit (2018). TADA: New ride-hailing app, driven by blockchain, launches in Singapore. Source: https://www.channelnewsasia.com/news/singapore/tada-new-ride-hailing-app-drivers-zero-commission-10564068. Date accessed: 28/01/2019
48. The Conversation Trust (UK) (2015). 'Peak car' means we might get much closer to our carbon targets than we realised. Source: http://theconversation.com/peak-car-means-we-might-get-much-closer-to-our-carbon-targets-than-we-realised-44398. Date accessed: 28/01/2019
49. Insider Inc. and finanzen.net GmbH (2017). Carsharing Market to witness a massive 34%+ growth over 2016-2024. Source: https://markets.businessinsider.com/news/stocks/carsharing-market-to-witness-a-massive-34-growth-over-2016-2024-1002207831. Date accessed: 28/01/2019
50. XAIN (2018). Source: https://xain.io/. Date accessed: 28/01/2019
51. Renault (2018). Groupe Renault teams with Microsoft and VISEO to create the first-ever digital car maintenance book prototype. Source: https://media.group.renault.com/global/en-gb/media/pressreleases/94238/groupe-renault-microsoft-et-viseo-sassocient-pour-creer-le-premier-prototype-de-carnet-dentretien-nu1. Date accessed: 28/01/2019
52. Future Travel Experience (2018). Biometrics and blockchain technology to bring 'gate-less border' to Dubai Airport. Source: https://www.futuretravelexperience.com/2017/06/biometrics-and-blockchain-technology-to-bring-gate-less-border-to-dubai-airport/. Date accessed: 28/01/2019
53. PR Newswire Association LLC (2017). Genesis Research & Technology Group Cleans the World With the WaterToken. Source: https://www.prnewswire.com/news-releases/genesis-research--technology-group-cleans-the-world-with-the-watertoken-300540884.html. Date accessed: 28/01/2019
54. Civic Ledger Pty Ltd (2018). Source: https://www.civicledger.com/. Date accessed: 28/01/2019
55. Unicef (2019). Water, Sanitation and Hygiene. Source: https://www.unicef.org/wash/. Date accessed: 28/01/2019
56. Unicef (2019. UNICEF: Collecting water is often a colossal waste of time for women and girls. Source: https://www.unicef.org/press-releases/unicef-collecting-water-often-colossal-waste-time-women-and-girls. Date accessed: 28/01/2019
57. Bitcoinist.com (2018). BANKEX unveils first blockchain-based public access clean water system in Kenya. Source: https://bitcoinist.com/bankex-unveils-first-blockchain-based-public-access-clean-water-system-kenya/. Date accessed: 28/01/2019
58. WaterChain, Inc (2018). Source: https://www.waterchain.io/. Date accessed: 28/01/2019
59. Treon (2018). Source: https://www.treon.io/. Date accessed: 28/01/2019
60. Futurism (2016). The Failure of The DAO: Should We Regulate Cryptocurrency? Source: https://futurism.com/the-failure-of-the-dao-should-we-regulate-cryptocurrency. Date accessed: 28/01/2019
61. Ethereum Foundation (2018). Source: https://www.ethereum.org/. Date accessed: 28/01/2019

Figure 8
Ellen MacArthur Foundation (2015). Growth Within: A Circular Economy Vision for a Competitive Europe. Source: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf. Date accessed: 31/01/2019
Figure 9
T Fens et al. (2005) Trends in energy 2005 Utility value chain optimisation. Netherlands: Cap Gemini Ernst and Young.
Table 1
X Xu et al. (2017). A Taxonomy of Blockchain-Based Systems for Architecture Design. Source: https://ieeexplore.ieee.org/document/7930224
Labazova et al. (2018). From Hype to Reality: A Taxonomy of Blockchain Applications. Source: https://www.researchgate.net/profile/Tobias_Dehling/publication/327690411_From_Hype_to_Reality_A_Taxonomy_of_Blockchain_Applications/links/5b9f6cf6299bf13e603809b7/From-Hype-to-Reality-A-Taxonomy-of-Blockchain-Applications.pdf
Table 2
M Salimitari, M Chatterjee (2018). An Overview of Blockchain and Consensus Protocols for IoT Networks. Source: https://arxiv.org/abs/1809.05613
Bitcoin Project (2018). Source: https://bitcoin.org/en/. Date accessed: 28/01/2019
Ethereum Foundation (2018). Source: https://www.ethereum.org/. Date accessed: 28/01/2019
Block.one (2018). Source: https://eos.io/. Date accessed: 28/01/2019
IOTA Foundation (2018). Source: https://www.iota.org/. Date accessed: 28/01/2019
The Linux Foundation (2018). Source: https://www.hyperledger.org/projects/fabric. Date accessed: 28/01/2019
R3 (2018). Source: https://www.r3.com/. Date accessed: 28/01/2019

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Blockchain Technology (2017)

What opportunities will blockchain technology bring to the built environment? The report considers the potential application of blockchain across a broad range of areas, including smart city programmes, supply chain management, the circular economy, and sectors, such as property and transport. Blockchain provides a new layer of infrastructure for the secure exchange of value and information.

Reimagining Property in a Digital World (2017)

Digital technology continues to disrupt and remake our world, and the property sector is beginning to experience the transformation. In this report we look at how digital technology and big data is changing the way leading property managers are making key decisions and improving the value of their portfolios. Every business will need its own digital strategy if it wants to achieve improved operational performance, a better end user experience, and consequently, higher long-term valuations.

Smart City Strategies (2017)

The persuasive nature of digital technology means that cities are constantly evolving to meet the changing needs of everyday life. This report, produced by Futures Cities Catapult and Arup, explores the landscape of smart city strategies and aims to provide insight into how cities around the world are approaching the smart city agenda. The review enables us to build a richer knowledge base for cities and shed light on the principles and patterns seen in smart city strategies across the world.

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About Arup

Arup is the creative force at the heart of many of the world's most prominent projects in the built environment and across industry. We offer a broad range of professional services that combine to make a real difference to our clients and the communities in which we work.

We are truly global. From 80 offices in 35 countries our 14,000 planners, designers, engineers and consultants deliver innovative projects across the world with creativity and passion.

Founded in 1946 with an enduring set of values, our unique trust ownership fosters a distinctive culture and an intellectual independence that encourages collaborative working. This is reflected in everything we do, allowing us to develop meaningful ideas, help shape agendas and deliver results that frequently surpass the expectations of our clients.

The people at Arup are driven to find a better way and to deliver better solutions for our clients.

We shape a better world.

Blockchain has the potential to transform the built environment by building a new foundation for machines and humans to interact and transact with each other. For the built environment sector, blockchain technologies have not yet been transformational, but early use cases are showing real potential.

Blockchain technology enables new forms of cooperation and interactions between millions of people. As our cities expand rapidly, blockchain technology could help to solve the challenges of ageing populations, urbanisation and climate change.

This report examines applications of blockchain technology within five key markets of the built environment: cities, energy, property, transport and water. It provides a review of the opportunities, challenges and emerging case studies of blockchain technology, informed by conversations with experts across industry and academia.

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