Blockchain: a new building block for the built environment?

Dermott McMeel[1], Alex Sims[2]
[1] School of Architecture and Planning, University of Auckland, Auckland, New Zealand
{d.mcmeel@auckland.ac.nz}
[2] Department of Commercial Law, University of Auckland, Auckland, New Zealand
a.sims@auckland.ac.nz

Abstract: This paper explores the innovations that are presented to the architecture, engineering and construction sector through blockchain. The authors consider blockchain, as a technology and methodology that allows us to rethink the fundamental building blocks and principles on which the sector is based. First, we provide some historical context, returning to and discussing the hypothesis that brought blockchain technology into being. Second, we review specific use cases that represent key differentiators between conventional approaches and the opportunities made possible through blockchain. Our analysis reveals how blockchain challenges the traditional structures of industry. It offers a new distributed methodology for replacing centralised and de-centralised structures of organisation and is disrupting notions of trust and authority that have been the default for industry—and indeed civilisation—for centuries. Finally, we report on original research where blockchain design workshops are held with industry stakeholders to map these opportunities into the architecture, engineering and construction sector.

Keywords: blockchain; distributed ledger technology; design; innovation; construction; built environment

1. Introduction

The twenty-first century has been dominated by the emergence of the platform economy or PE (Kenney and Zysman, 2016; Fabo, Karanovic and Dukova, 2017). More than online shopping websites, PE's mark a shift where the asset is the platform, not the things or services being delivered through it. The twentieth century was dominated by push economies enabled by the likes of Ford, Kellogg's and Heinz. Who made things and pushed them onto consumers; the more they could push the more profit they made. Towards the end of the 20th century concepts such as ebay and craigslist—for example—provide a platform where people would 'push' things back into the economy. People, not corporations, could profit through these platforms. Amazon, Uber and Airbnb are the most recent evolution of platform economies with several key features (1) they do not own the core assets for their core business. Uber do not own their cars and much of what is sold on Amazon, are not Amazon products. (2) The platform is the thing of value. Uber has spawned Uber Eats, Amazon's Web Services (AWS) is responsible for the most of Amazons profit – not online sales; individuals appropriate the platform to spawn micro-businesses on the platform. The twenty-first century has been defined—to date—by companies that develop powerful digital platforms, but do not own or make any of the physical products central to the economy they enable.

Blockchain is the most recent in a series of developments that constitute the evolution of the 20th century economic model to the twenty-first. A large part of which has been implementing digital technologies that have been couched as the Internet of Things, Industry 4.0, digital fabrication, digital twins and so on. This paper considers what blockchain may mean for the construction sector. There have been a number of systemic literature reviews that categorise and speculate on use cases (Turk and Klinc, 2017; Li, Greenwood and Kassem, 2019) including how blockchain might be leveraged within a BIM workflow (Erri Pradeep, Yiu and Amor, 2019). This research builds upon the earlier work and provides additional insights from social scientists, artists and designers, who look beyond the novelty of blockchain's application and towards the implication of application not only of blockchain but also more generally to unpack the broader implications of this shift to digital ledger technology (DLT) and platform economies. We look at specific examples of 'technology demonstrators' being developed or proposed by these scholars to investigate specific affordances of blockchain and DLTs. These projects were used within workshops with industry partners to produce more focused delineation of specific streams of research—albeit still speculative—for blockchain in the construction sector. This work points to a

Imaginable Futures: Design Thinking, and the Scientific Method. 54th International Conference of the Architectural Science Association 2020, Ali Ghaffarianhoseini, et al (eds), pp. 211–219. © 2020 and published by the Architectural Science Association (ANZAScA).

fundamental shift in power as DLTs begin to find their way into business practice as well as spawning a plethora of opportunities for adding value to the construction sector.

In the next section, we explore blockchain's origins, which was put proposed in 2008—in the form of Bitcoin—as it offers an alternative to centralised structures and helps us understand how and why blockchain differs from other technologies.

2. Blockchain

This section will explore the origins of blockchain before going on to explain what blockchain is offering that is fundamentally different from what went before. It will conclude with an analysis of the fundamental of blockchain and a delineation of key factors in determining areas of potential implementation.

A brief history

Perhaps the easiest way of understanding blockchain is understanding its origins. In 2008 the world experienced an unprecedented global banking collapse. This was broadly as a result of banks taking undue risk combined with limited oversights within the banking system. Centralised and decentralised systems, by their nature, have very few points within the system where an overview of that system can be seen. Consequently, there are very few opportunities to see and understand the 'big picture' within such a system. Bankers taking risks with mortgages or loans are rewarded if the risk pays off. This imbalance in risk and reward, in this context, provides few rationales not to take risks with people's money. This imbalance has been explained in greater detail by economist Yanis Varoufakis in 'Talking to my Daughter About the Economy' (Varoufakis, 2017).

Shortly after 2008, a person or persons using the alias Satoshi Nakamoto released a paper proposing a peer-to-peer digital cash system (Nakamoto, 2008). Transactions would be recorded publicly using digital ledger technology (DLT) removing the need for a third-party (a bank or bankers) to record and verify transactions. It, therefore, proposed the creation of a public banking system that did not require banks or bankers. This would facilitate significantly better oversight of the global state of transactions and remove the risk/reward imbalance by removing the need for banks and bankers acting as third-party mediators. The digital ledger technology (DLT) was blockchain and the digital cash was Bitcoin.

Implications

In its simplest terms it addresses the two fundamental problems that causes the banking crisis of 2008. First, it solves the risk/reward power asymmetry inherent in a centralised or decentralised system; no bankers mean no one person would benefit. Second, it creates a constant and updating 'world-view' of the entire ledger of transactions, enabling significantly more oversight. Indeed, computers on the Bitcoin network check for unauthorized attempts to alter transactional records. The importance cannot be over-stated, as virtually every human civilisation, every bank, council and local library is based on a centralised or decentralised organisational structure. Blockchain creates a technological platform to enable distributed organisational structure. Making it unnecessary to have a small number of people in positions of hierarchical power within the structure. The difference between centralised, decentralised and distributed is illustrated below (Figure 1).

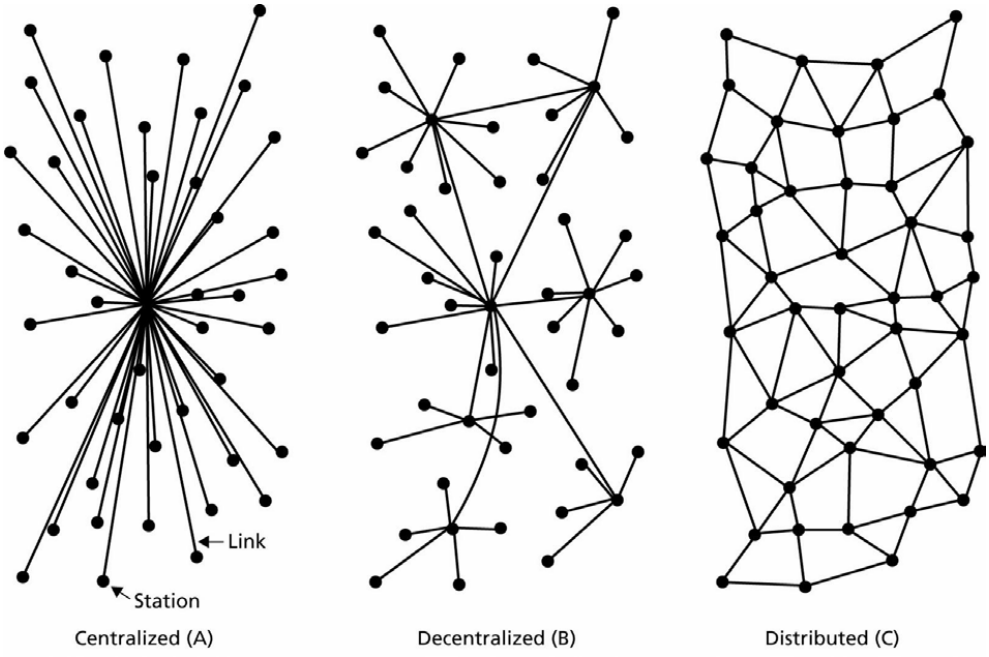

Figure 1: Centralized, decentralised and distributed networks (Source: Baran, 1964)

In both centralised and de-centralised organization systems, things flow back to a central point or points. There is a hierarchy or levels within these systems; people or groups with control and power over other people and groups. There is also a certain level of trust that what is flowing back to the central authority is accurate. In turn, when the central authority is called upon to disseminate information there is trust that it is somehow immutable and indisputable. The banking crisis of 2008 laid bare that such systems are fallible, and the proposal of Bitcoin and blockchain demonstrated an alternative system is possible.

The authors would like to suggest why blockchain remains an abstract concept and hard for many to grasp. It is because we—as a civilization—have no real point of reference for what a distributed (Figure 1: sub- image 'C') system of organization would be. Most of our history has used centralised and decentralised techniques for organisation (Figure 1: sub-image 'A' and 'B').

To summarise blockchain (1) it provides an alternative to centralised and decentralised systems of organisation required for hierarchical structures for power, control and decision-making. (2) It creates a DLT that creates trusted immutable records. (3) It distributes those records amongst the network of users increasing transparency. The questions that exist for the construction sector are: when and where would this be useful, and what new opportunities might change to a distributed system afford?

3. Case studies

In this section, we look at four case-studies or thought experiments in applications of DLT (1) the multi-national shipping conglomerate Maersk's implementation in supply-chain. (2) RADIUS a parent network using it to structure data for micro-seizure research. (3) BitBarista a bitcoin powered coffee machine developed by the Design Informatics Research Centre (DIRC) at the University of Edinburgh. (4) Caricrop a proposed 'bridge' currency to increase security within informal trading networks, also developed by DIRC. Each one of these case-studies offers insights into the application of DLT. In the following section we will analyse their affordance, before explaining how they fit into our workshop format to unpack the implications for the construction sector.

2.1. Maersk, IBM and global supply chains

Maersk is an international transport and logistics conglomerate, which was responsible—in 2018—for moving approximately 20% of the world's shipping containers (Groenfeldt, 2017). Maersk has implemented a DLT to improve the paperwork associated with shipping. A single shipment of avocados, for example, involved 30

organizations, approximately 100 people and 200 discrete transactions (Godbole, 2017). The process of shipping is already a complex distributed network of individual organizations and a variety of esoteric contracts. In 2016 Maersk partnered with IBM to prototype a system based on DLT to improve the speed and efficiency of shipping. This was implemented in the 2016 avocado case-study the following four benefits were identified:

- Simplified business processes and workflows within and between organizations.
- Immutable audit trail.
- Resilient by nature, secure by design.
- Enhanced compliance due to visibility.

In addition, the test case demonstrated significant time-saving benefits; however, the case-study noted there would be regulatory and legal barriers as well as questions surrounding the scalability of such an early stage technology.

2.2. Token economies

Second, we have two examples of the use of DLT to address short-coming in existing financial and trading structures. The first Caricrop—a proposal using DLT to reduce risk in informal agricultural trade networks (Pschetz, Dixon and Soares, 2019). Between the producer and consumer of an agricultural product, say an apple, there are many intermediaries. These intermediaries add value, for example, they package and market the product. However, payment to the producer of the product, and the intermediaries, is often dependent on that product getting to market. In some case payment is only made after the product reaches consumers and the payment trickles down through intermediaries to the producer. The process in many cases is based on informal agreements and the promise of the product making a certain price at market. This leave producers vulnerable to price fluctuations and slow to receive payment.

Caricrop proposes the creation of a 'bridge' currency, a coin (like bitcoin) based on the principle that a monetary transaction will happen in the future. When a sale of produce is agreed between a buyer and seller an equivalent amount of the bridge currency is immediately released to the producer. Within a specific network, this currency can be traded to buy goods or services amongst the intermediaries. Caricrop thus enables, rather than limits, intermediaries to trade. When the goods eventually make it to market and are sold for traditional (Fiat) currency the bridge currency is immediately converted and distributed throughout the network into real money.

The second example has been proposed by a health start-up, doc.ai. The doc.ai blockchain platform could be used by an informal distributed network of parents to collect data and finance research into a medical condition afflicting their children. This example solves two problems. Firstly, the problem, micro-seizures in children, is not big enough to attract significant research funding into the causes and cures. Second, the families only had information on one patient—their child—there was not enough data to be useful to the parents to identify seizure patterns. The second problem can be solved by creating a mobile phone app that serves as a journal for seizure information. Thus creating a structured database of seizure information. Money can be raised by charging for the app. Each purchase would buy a unique cryptocurrency, a 'neuron'. Which would be used to fund research using the data collected in the mobile phone apps (De Brouwer and Borda, 2017; Doc.ai, 2018).

2.3. Agency and automated decision making

The final example is a research project from the Design Informatics Research Centre at the University of Edinburgh. Called the BitBarista, it is a coffee machine that is controlled by a small Raspberry Pi computer (Pschetz *et al.*, 2017). The computer has a Bitcoin wallet and has been programmed to:

- Accept Bitcoin payment before making a coffee.
- Pay out Bitcoin when someone fills it or cleans it.
- Conducts a survey asking which time of coffee the user would like, best quality, lowest price, lowest environmental impact or highest social responsibility.

When BitBarista accepts a bitcoin payment, the payment goes to the coffee machine's bitcoin wallet. This contrast with typical transactions where money would be transacted between centralised back accounts. In this case the coffee machine now has money and can pay people in bitcoin for topping up its water or coffee beans or cleaning it. It now has some agency within the economy. It also purchases coffee beans online automatically based on the results of surveys it conducts on its customers. There are no people or committees intervening or mediating those decisions. In our research workshops we use these examples to seed discussion around some of the key differentiators of blockchain before beginning exploring possibilities for the construction sector.

4. Analysis

Each one of the examples outlined in the previous section exploits a specific affordance of blockchain, which we will discuss in turn beginning with Maersk. We unpack these under the themes of: supply chain; contractual relationships; and new business models.

4.1. Supply chains

As a multinational conglomerate that moves things around the world, Maersk could benefit significantly from even small improvements in efficiency. This example shows just how impactful smart contracting could be in streamlining a complex distributed supply-chain network. This case however did require an invested high-level agency (Maersk) to bring the network together. Two of the main barriers Maersk identified was legal acceptance of such a new system and the recognition that it is an early-stage technology and scalability and interoperability could be problematic.

RADIUS is an example of a situation where not enough reward or incentive exists for a central authority and hierarchical structure to be established to invest in that specific things—in this case, research into micro- seizures. The group would be able to accumulate capital in a bridge cryptocurrency in parallel by using an App to generate structured data from participants. It would enable a small group to set up a cost-effective scheme that was able to organically scale. Research usually relies on large official funding organisations and authorities that are expecting financial or societal gains. RADIUS demonstrates the potential to cut out the 'trusted third party' and connect the researchers and the parents. Or, in more general terms, groups willing to pay for a service (parents with sick children) and groups willing to provide the service (researchers).

While the first example required a high-level agency to galvanise implementation the second one did not. The first was driven from the top down the second from the bottom up. Both were driven by the party which saw value from the opportunity. However, the second example would have been much more problematic, if not economically impossible because of its scale, if traditional techniques have been used.

4.2. Contractual relationships

Our second category uses blockchain to create a more complex Token Economy (TE) than RADUIS. Caricrop changes the relationship with third-parties or intermediaries from informal to contractual—via a smart contract. This case, however, recognises that the intermediary services add value and creates a digital application that enables a clear financial mapping of trades. The purpose here is not to de-intermediate, which is often associated with digital innovation—cutting out the middlemen. When 'real' money enters the system, everyone is paid pro-rata rather than the typical 'trickle-down'. This distributes price fluctuations across the network reducing risk and incentivise efficiency. It also has secondary benefits in that what is traditionally an opaque trust-based network of trades can now be more clearly seen and audited. Organisations and people that perform well, or poorly, on the network can be clearly identified.

4.3. New business models

BitBarista also addresses the relationship to central authority. Specifically, in the case of coffee, it devolves decision-making to the individuals who use the coffee machine, the network. It removes the power asymmetry that exists between a coffee company, who profit from cheap coffee, and coffee consumers who want that coffee to reflect their values, or just taste better. The few making the decision in traditional hierarchical systems profit from and make financial gains from decisions that do not necessarily reflect the interests of the wider network of users and consumers.

Having mined into specific examples in this section, in the following section we will explain how these fit into our research workshops and what these workshops revealed about possibilities for blockchain in the construction sector. The results of the case study analysis are summarised in the table below.

Table 1: Summary of case study analysis – benefits of blockchain technology

	Simpilified Process	Audit Trail	Increased Visibility	Decentralised Governance
Supply Chains	•	•	•	
Contractual Relationships		•	•	
New Business Models	•	•	•	•

5. Construction

In this section, we ask what does blockchain mean for construction? We report on our ongoing research seeking to deepen our understanding of blockchain on the construction sector—this includes associated disciplines such as engineering and architecture. The research project 'Chip of the New Block' runs from October 2018 to October 2020. The first phase of the project, which comprised industry workshops, is complete and we here report on our findings thus far. During 2019 the research team conducted a series of workshop with industry participants to deepen their understanding of blockchain and assist speculation on how it might reshape aspects of the sector.

The workshops are based on the format developed by the Design Informatics Research Centre at the University of Edinburgh. They are comprised of three parts (1) an introductory overview of blockchain and how it fundamentally differs from other systems. In this part of the workshop, we introduce the case-studies from the previous section. Presenting tangible examples of some of the possibilities. (2) A 'trading' card game where participants trade and record their trades on a blockchain made from Lego. This phase helps with a tangible understanding of digital ledger technology. (3) An ideation and brainstorming session where participants propose new forms of business potentially enabled through blockchain.

The workshops delivered a number of possible outcomes, from community cryptocurrency to support communities, smart contracts for disaster response funding and giving beehives crypto-wallets to pay people for the upkeep of flowers in the area. The themes and situations we explore in this section are directly drawn from those workshops and are limited to the construction sector. The subjects are unpacked and developed by experts in the industry, and with the help of the facilitators they have sketched out possible futures. We will delineate these findings under the themes: *supply chain; smart contracts* and *new business models.*

5.1. Supply chains

It is perhaps overstating the obvious to say construction involves a plethora of supply chains. Take an aluminium window, for example, from material extraction and processing through manufacturing to delivery and installation in a building involves hundreds of people and dozens of individual companies. It is a complex—if not always integrated—process.

Many parallels can be drawn between the supply chains in construction and the supply chains outlined in the Maersk case-study. They are comprised mainly of small to medium businesses (SMEs). Each business on the supply chain is typically only contractually bound to—and cognizant of—their immediate buyers and suppliers within the overall supply chain. Obtaining an overview of the overall supply chain is difficult. There is little originality in stating here that supply chain is an issue requiring attention in construction and others have suggested blockchain as a technology that might offer an opportunity to improve it. However, where we do make an original contribution is unpacking the Maersk case-study where we draw specific attention to overall organizational and industry differences that present challenges to implementation.

Interoperability is a well-known problem in digital systems in general. At the early stages of a new technology, there are often competing approaches before one wins out. Albeit this paper does not dwell purely on the technical issues, we are interested here in the organizational and cultural factors of implementation. These have been proven to be as impactful on successful uptake—if not more so—than technical issues (Kling, 1996).

Maersk is a global conglomerate, moving approximately 20% of shipping containers globally. The cost benefits of any improvements in efficiency would mostly benefit Maersk. In an industry with a large percentage of SMEs there is also a power geometry in this specific situation, which favours Maersk. Although it should be said Maersk foresees many benefits for SMEs, this initiative was led by Maersk and IBM. They invested whereas SMEs could not. The main obstacle to replicating this study for construction is that there is no economic equivalent to Maersk. Even the largest multinational construction organization is small in comparison. The alternative is the RADIUS example, where a sub-set interest group with a specific interest might establish a network to advance their interests. So, while various organizations are working on—and solving—the technical obstacles of the fledgling blockchain technology, these economic questions that are intertwined with organisation and culture remain in the short term unanswered.

5.2. Smart contracts

The topic of contracts, indeed procurement in general, has been identified as a significant factor in affecting change. During the 1990s the canonical Latham and Egan reports focused on this issue in the UK (Latham, 1994; Egan, 1998). These reports led to the introduction of new ways of procuring buildings, most notably *public private partnerships* or PPP as they were widely known. The aim of the change was to deliver a project with better and more accurate costing and construction scheduling. The results were mixed, and have been discussed by other researchers in some depth (Hill, 2001; McMeel, 2009). More recently *collaborative procurements* have emerged and have seen positive results (Ey, Zuo and Han, 2014). These aim to distribute profit or loss and engender a more collaborative spirit between participants than is found in traditional buyer/supplier contracts in the

construction sector (Cox and Thompson, 1997).

Although collaborative procurement is an improvement on traditional contracts, issues remain. Take a specific form of collaborative procurement—Alliance contracting—typically used on infrastructure projects in New Zealand. While case studies report positive results, this type of novel collaborative project structure typically operates at a high level (Chang-Richards, Brown and Smith, 2019). It might include clients and several main contractors. Beneath this much of the work of sub-contractors and suppliers continues to be in the form of traditional 'buyer supplier' contract relations. Which usually mean meeting the terms of the agreement by delivering the cheapest possible solution. In addition, contracts are typically for one project only. Building a long-term relationship requires an informal agreement based on trust. Furthermore, it is difficult to check all indemnity insurance, professional accreditations and health and safety certifications. While it may occur at the outset of a project interim checks for expiration are more difficult and typically continue on 'trust. So, while on the surface construction may seem to be based on formal contractual processes. Our workshops revealed that some key aspects of the industry remain informal and based on trust.

The Maersk case-study was of interest to workshop participants. Specifically (1) automatic creation and triggering of contracts for execution, and (2) provision of a worldview of the over-all relationships that would not otherwise be possible. Digital ledger technology (DLT) like blockchain has been likened to Hägerstraand's concept of 'time vessels' in this regard (1970). It that they afford a perspective of a phenomenon that has not otherwise been possible. Participants further unpacked the potential for this technology to track performance over time. Thus, it would start to become possible to review accuracy and disparity between specific supplier or contractor tenders and final costs. Additionally, the idea that price fluctuations might be ameliorated across the network of participants, evoked benefits of collaborative procurement. This was preferable to profits being stripped from a project on a first come first-served basis. Smart-contracting offers the possibility of this benefit being extended beyond the high-level Alliance group to include subcontractors and suppliers. Even the area of Health and Safety, which involves significant paperwork and administrative hours, was singled out as an area, which could be streamlined using DLT.

In summary, smart contracting emerged from the workshop as an area of significant interest from the industry. While we should recognise not every instance discussed may require blockchain, looking at business practice through the lens of blockchain unpacked a plethora of potential innovations that could benefit the industry.

5.3. New business models

Returning, briefly, to our original claim that blockchain offers a novel methodology for rethinking the design and construction industry. We have touched on this idea as we have discussed smart contracts and digital ledger technology in the previous two sub-sections, and we would like to discuss it directly here. In a similar fashion to the distributed communication network we know as the internet spawning a plethora of new models of business and reshaping others, we explore what opportunities might be presented by distributed 'trust' networks underpinned by DLT such as blockchain. First, we will discuss how DAOs (distributed autonomous organisations) can redefine business organisation. Where a digital infrastructure, often underpinned by blockchain, replaces traditional 'people' roles of directing, administering and decision-making in a traditional organisation.

If we take the RADIUS case-study first, a small distributed network of people with a strong feeling about a thing and a common set of values surrounding it. Setting up a digital infrastructure to handle data and currency allowed it to scale when it attracted similar like-minded people. The distributed nature meant they too could easily participate and so the initiative grew in a 'bottom-up' fashion. It circumvented the need for some of the high-value people cost that might typically go with such a venture (directors, boards, administrators etc.) and establishing the centralised hierarchy.

In our workshops, the RADIUS case-study prompted a similar concept in collaboration with the Victoria University in Wellington the form of the Trash to Things Coin (TTTCoin) a unique currency that belongs to a network and can only be traded on 'things' reusing and reusing 'trash' (Figure 2). Reducing and reusing rubbish is something that people have strong feelings about are willing to invest in. It would not require large infrastructure costs and could grow organically. This idea was pushed further into its own Token Economy. Trash could conceivably now be purchased from contractors and manufacturers who could either cash out the TTTCoin to Fiat (normal) currency or use it to buy things in this economy that are reusing trash. Either way it contributes to the reduction of construction waste.

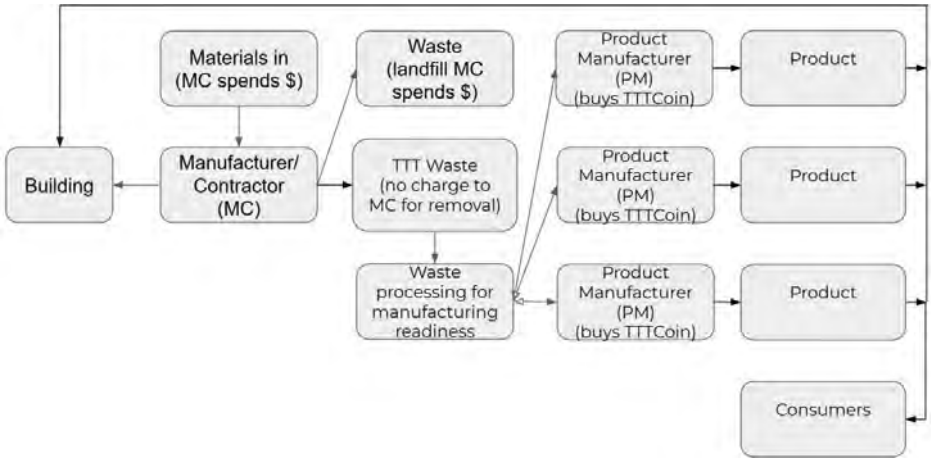

Figure 2: TTTCoin economy (source: author)

The BitBarista case-study also seeded a concept of other 'things' you might trade with. It was furthered by the introduction of two provocations. (1) The Whanganui river in New Zealand has been recognised as having the same rights as a person (Hsiao, 2012). (2) The 2019 labour pledge that a housing loan in the UK would belong to the house, not the people initially taking out the loan (Savage, 2019). Both concepts mark a shift towards things having rights and some autonomy of buying power. To reinforce the point, consider the decision a board of a multi-national coffee chain might make regarding which coffee to buy (cheapest or socially just) when the board members' salaries or bonuses may be linked to profitability. Contrast this with the decision a consumer might make when asked by BitBarista which coffee they would like and even, in an extension, how much they would be prepared to pay for organic coffee that paid a living wage to the producer (Henley, 2019). The system then purchases which most consumers vote for. Irrespective of the decision – this affects a significant shift in power within the economy and industry.

6. Conclusions

In summary, our research adds the following contribution to the body of knowledge. Firstly, we have mined deeper into supply chain and specifically looked at comparisons with other case-studies. We have delineated two specific contexts in which blockchain may or may not be successful. Secondly, we have explored some of the affordances of blockchain and the specific opportunities that could present in a 'smart-contract' environment in the construction industry. In New Zealand—which has a relatively modest economy—there is limited returns for construction companies investing in research and development and innovation within that limited economy. Blockchain, however, is a distributed technology that can support small and scalable 'bottom up' innovation, and does not necessarily require the large scale investment associated with 'top down' innovation that is associated with significant cost and structural change. Finally, we build a case showing the potential for blockchain to begin enacting a transition where other 'things' become part of our economy and have agency within it. Where houses have crypto-coin wallets and might autonomously search for cheap or green electricity to buy; in the same way a person might search for a cheap or ethically sourced product.

What we have seen with the internet, digital infrastructure, algorithms etc. is when new things become part of the digital infrastructure it presents what Stefan Michel calls new 'value constellations.' While there is no prescription here for foreseeing them, this research posits in addition to streamlining and disintermediation, blockchain and DLT's will also spawn additional opportunities for future forms of commerce and business within the construction sector.

Acknowledgements

The authors would like to thank Emina Petrovic from the Victoria University Wellington and Marie Davidova from Cardiff University who informed some of the themes in this paper. The authors would also like to acknowledge members of the blockchain special interest group Anshaal Kumar, Shaneel Singh, Alice Chang-Richards, Kingsada Sengsavang, Tiantian Lyu and Abhinaw Sai Erri Pradeep, whose meeting and discussions also informed parts of this paper. This research is funded by the BRANZ Building Research Levy.

References

Baran, P. (1964) On Distributed Communications. RAND-Memorandum RM-3420-PR, RAND Corporation. Santa Monica, California.

Chang-Richards, A., Brown, C. and Smith, N. (2019) Building risk management strategies into the vertical construction sector.

Cox, A. and Thompson, I. (1997) ''Fit for purpose'contractual relations: determining a theoretical framework for construction projects', European journal of purchasing & supply management. Elsevier, 3(3), pp. 127–135.

De Brouwer, W. and Borda, M. (2017) NeuRoN: Decentralized Artificial Intelligence,Distributing Deep Learning to the Edge of theNetwork. Avaliable at https://static2.coinpaprika.com/storage/cdn/whitepapers/448539.pdf.

Doc.ai (2018) doc.ai for Patients and consumers to initiate data trials, YouTube. Available at: https://www.youtube.com/watch?v=nWMfRnqr_cA&t=12s.

Egan, S. J. (1998) Rethinking Construction: The Report of the Construction Task Force. London: Department of Trade and Industry.

Erri Pradeep, A. S., Yiu, T. W. and Amor, R. (2019) 'Leveraging Blockchain Technology in a BIM Workflow: A Literature Review', (January), pp. 371–380. doi: 10.1680/icsic.64669.371.

Ey, W., Zuo, J. and Han, S. (2014) 'Barriers and challenges of collaborative procurements: An exploratory study', International Journal of Construction Management. Taylor & Francis, 14(3), pp. 148–155.

Fabo, B., Karanovic, J. and Dukova, K. (2017) 'In search of an adequate European policy response to the platform economy', Transfer: European Review of Labour and Research. SAGE Publications Sage UK: London, England, 23(2), pp. 163–175.

Godbole, S. (2017) How Blockchain can transform Global Trade Supply Chains, IBM. Available at: https://www.unescap.org/sites/default/files/3_IBM Blockchain.pdf.

Groenfeldt, T. (2017) 'IBM and Maersk apply blockchain to container shipping', Forbes. Available at: https://www.forbes.com/sites/tomgroenfeldt/2017/03/05/ibm-and-maersk-apply-blockchain-to-container-shipping/#7ffdf7943f05.

Hägerstraand, T. (1970) 'WHAT ABOUT PEOPLE IN REGIONAL SCIENCE?', Papers in Regional Science. John Wiley & Sons, Ltd, 24(1), pp. 7–24. doi: 10.1111/j.1435-5597.1970.tb01464.x.

Henley, J. (2019) How Millions of French Shoppers are Regjecting Cut-Price Captilalism, The Guardian, Avaliable at https://www.theguardian.com/world/2019/dec/04/french-shoppers-rejecting-cut-price-capitalism-nicolas-chabanne (Accessed: 30 July 2020).

Hill, C. (2001) 'Latham's legacy', Building, (50). Available at: http://www.building.co.uk/story.asp?storyCode=1014461.

Hsiao, E. C. (2012) 'Whanganui River Agreement', Envtl. Pol'y & L. HeinOnline, 42, p. 371.

Kenney, M. and Zysman, J. (2016) 'The rise of the platform economy', Issues in Science and Technology. Issues in Science and Technology, 32(3), p. 61.

Kling, R. (1996) Computerisation and Controversy: Value Conflicts and Social Choices. 2nd edn. San Diego: Academic Press.

Latham, S. M. (1994) Constructing the team: final report. London: H.M.S.O.

Li, J., Greenwood, D. and Kassem, M. (2019) 'Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases', Automation in Construction, 102(March), pp. 288–307. doi: 10.1016/j.autcon.2019.02.005.

McMeel, D. (2009) The Artistry of Construction, Architecture. Edinburgh University.

Nakamoto, S. (2008) Bitcoin: A peer-to-peer electronic cash system.

Pschetz, L. et al. (2017) 'Bitbarista: exploring perceptions of data transactions in the Internet of Things', in Proceedings of the 2017 CHI conference on human factors in computing systems, pp. 2964–2975.

Pschetz, L., Dixon, B. and Soares, L. (2019) FUNDING RESEARCH WORKSHOP: CariCrop, Design Informatics. Available at: https://www.designinformatics.org/research_project/caricrop/ (Accessed: 30 July 2020).

Savage, M. (2019) Labour plans to make 27m homes energy efficient, The Guardian. Available at: https://www.theguardian.com/global/2019/nov/02/labour-scheme-homes-energy-efficiency (Accessed: 30 July 2020).

Turk, Ž. and Klinc, R. (2017) 'Potentials of Blockchain Technology for Construction Management', Procedia Engineering. The Author(s), 196(June), pp. 638–645. doi: 10.1016/j.proeng.2017.08.052.

Varoufakis, Y. (2017) Talking to My Daughter about the Economy: A Brief History of Capitalism. Random House.