Chapter

Automating the Chaos: Intelligent Construction Contracts

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Abstract

At the centre of all construction projects is the contract between the client and contractor and, as any construction project is a relatively complex process, the industry has demanded contracts of greater sophistication as the sector has evolved. The construction industry has a reputation for being adversarial and motivating dispute and the deep-rooted cultural aversion to trust. It is postulated that the solution to the trust issue is to make contracts trust-less. Truly autonomous, intelligent contracts would minimise the need for conventional human management. Put simply, intelligent contracts (or 'iContracts') are computer protocols that facilitate, verify, or enforce the negotiation or performance of a contract, or that obviate the need for a contractual clause. The proposal of embedding the terms and conditions of an agreement into a digital entity contrasts immensely from a traditional paper contract which is generally only used only as a reference when parties are in dispute. By creating an all-encompassing contract process—that: ensures all parties adhere to the terms agreed; offers protection of payment, insurance and data; as well as the potential to increase efficiency and reduce risk—it should make the successful implementation of iContracts the top priority for the construction industry.

Keywords: iContracts, intelligent contracts, digitalisation, automation, blockchain

1. Introduction

Globally, construction spending is projected to reach US$12.4 trillion by 2022 [1]. In the United Kingdom alone, it is estimated £600bn will be spent over the next 10 years on public and private infrastructure resulting in efficiency and productivity improvements in the delivery of construction projects becoming strategic priorities for the UK Government [2]. The construction sector faces many challenges including; low productivity, poor regulation and compliance, lack of trust, inadequate collaboration, information sharing, and poor payment practices [3, 4]. Whilst productivity is a major problem it also presents as one of the biggest areas for potential improvement with McKinsey Global Institute [5] reporting a global productivity gap of $1.6tr that can be addressed by improving the performance of the industry. The industry is perceived as slow to innovate, particularly in its adoption of digital technology but digital transformation is slowly gaining traction with increased use of Building Information Modelling (BIM) and emerging technologies based on Blockchain, Internet of Things (IoT) and Smart Contracts being touted as a solution to the industry's problems [6]. However, the integration of these digital concepts and technologies has not yet been achieved due to the embryonic nature of the field with further developments required to build a case for widespread adoption.

The construction sector is becoming more digitalised with BIM being the main catalyst for digital transformation seen in the sector in the last 15 years [7]. Smart contracts are seen to be one of the key complementary concepts to BIM due to the increased capabilities the automation of contract clauses will afford any user [8]. New digital technologies are emerging to address some the key concerns hindering collaboration in the construction industry and have the potential to change the way the sector operates, leading to better auditability and traceability encouraging more collaboration and information sharing [9]. In an industry that has historically lacked technological advancement and innovation, the construction industry is slowly being dragged into the digital age but there are many challenges to be addressed before true digital transformation is realised. Examining barriers to implementation and prevailing stakeholder attitudes are also crucial in envisioning this departure for construction and engineering contracts.

This chapter will define the iContract technology along with a state of the art of current research. It will highlight the challenges and barriers implementation of the concept will face, along with the opportunities it would bring as the construction industry enters further into the digital age.

2. Background

2.1 Striving for collaboration through contracts—is standardised really the standard?

The level of collaboration and the nature of a contractual relationship are usually dependent upon the proximity of the parties. Historically only simple contracts are adopted where person to person relationships are created and where high levels of trust already exist. The evolution of society and commercialism has now meant that more personable relationships are harder to come by or do not exist at all, and it is necessary to express more aspects of any commercial relationship through more defined contracts. Open competition and globalisation of contracting activity can be a barrier to developing trust leading to the creation of more sophisticated and detailed contractual arrangements in lieu of existing trusting relationships.

Standard forms of contract, so lauded by the construction industry, have the downside of restricting the freedom to contract upon one's own terms and therefore are contrary to an open market approach. Standard contracts certainly have their place in bringing consistency to the industry's contractual practices, but it must be remembered that most construction projects are a one-off prototype that require more specific terms. Standardised contracts would have a greater impact in a more heavily planned and regulated sector, which the construction industry would certainly benefit from but does not possess. The alternative, to adopt non-standard forms of contract, produces higher transaction costs and loses the benefits of familiarisation leading to extended contract formation and negotiation periods. However, digitalisation offers solutions to these problems and can improve the efficiency and communication process promoting instant collaboration and mitigating the level of disputes.

The reliance upon looseness of language and implied terms in an attempt to achieve flexibility, and reduce the content of contracts, is a practice that offers the double-edged sword of alternative interpretation and opportunity to act against the spirit of collaboration. A road well worn by construction companies put under pressure. This practice is only worth considering if the implied terms are such that they are well known and fully understood by all parties, which is generally only built from past engagements. Digitally coding such terms may assist but there are

limits to the help this would offer and the logical coding of flexible arrangements has its challenges.

There is an apparent trade-off between a standard contract which in a general sense is understood but does not meet the real needs of the parties, and one that meets this need by producing a bespoke and detailed contract. Some commentators have argued that users do not 'really' understand standard forms of contract. The compromised situation of producing bespoke contracts with common clauses may actually improve standardisation and understanding when compared to the current practice of bastardising a standard form of contract beyond recognition to suit one's needs.

2.2 Industry 4.0—the digital dawn

Industry 4.0 is the era where computer power becomes more embedded within society and possibly even inside human beings [10] and has been used to describe the 4th Industrial Revolution by pointing out its huge technological potential, comparable to technical innovations which led to the first industrial revolutions [11]:

1. the field of mechanisation;

2. the use of electricity and;

3. the beginning of digitisation.

In the United States, construction is the least digitalised sector and has been publicly perceived as an industry with poor productivity and a low level of technology implementation whilst the financial industry and business services show the highest levels of digitalisation [12]. Construction is one of the largest and most significant industries in Australia, contributing to economic growth and jobs (ca. 9% of jobs). In 2010, the industry was considered the fourth largest industry in the country [13].

The Farmer Report [3] outlines a case for digital disruption in the UK construction industry and sees the following as 'critical symptoms of failure and poor performance':

- Low productivity
- Low predictability
- Structural fragmentation
- Leadership fragmentation
- Low margins
- Adversarial pricing models and financial fragility
- A dysfunctional training funding and delivery model
- Workforce size and demographics
- Lack of collaboration and improvement culture
- Lack of R&D and investment in innovation
- Poor industry image

This is set against an industry which is not applying for billions of pounds of R&D Tax Credits, set up by the UK Government to stimulate innovation [14].

Joseph Schumpeter explained the challenges when new innovations disrupt the traditional way of life as, 'Creative Destruction… Just as the day Samuel Morse invented the telegraph was a bad day for the horse back messenger, significant technological disruptions can be destructive for older more established workflows that do not adapt' [15].

From a technical point of view, Industry 4.0 can be described as the increasing digitisation and automation of the manufacturing environment as well as the creation of a digital value chain to enable the communication between products and their environment and business partners [16]. The industry specific definition of the Industry 4.0 concept for construction comprises a large range of technologies to enable the digitisation, automation and integration of the construction process at all stages of the construction value chain. Central technologies like BIM, Cloud Computing or the IoT are only a few of them some of the main, well known technologies. Typical base technologies and concepts of Industry 4.0 are: The IoT/Internet of Services (IoS), Cloud Computing, Big Data, Smart Factory, 3D-Printing and the Cyber-Physical Systems (CPS) or Embedded systems. There are also emerging technologies: Augmented Reality (AR)/Virtual Reality (VR)/ Mixed Reality (MR) and the Human-Computer-Interaction (HCI) are major components of Industry 4.0 to enable a digitised and automated construction environment.

These technologies are at different levels of maturity. Scheduling, communications and BIM, among others, have reached market maturity and thus are currently available whilst others, such as IoT and AI, are still at the formative prototype stage. Despite the maturity and availability of many technologies, their widespread adoption by the construction sector has been slow but there are signs that there are practical ways for the successful adoption of new technologies to digitise and automate the construction process. Even though these technologies can have hard to predict cost savings due to the increasing need for data security and data infrastructure. From the technical point of view, there are several unsolved problems and challenges to be met due to the lack of standards for many new technologies and the higher standard of IT infrastructure required to run them. Regulatory compliance and legal uncertainty are other issues to be considered. Considering all these challenges, it is clear that companies must be motivated to commit to the adoption through government initiatives or funding programs [17].

The adoption of the Industry 4.0 concept would help the construction industry transform to a technology-driven sector and help keep up with other industries in terms of performance improvement. The Mckinsey Group 2016 report suggests that, 'the adaptation of currently demonstrated automation technologies could affect 50% of the world economy, or 1.2 billion employees and USD $14.6 trillion in wages. Just four countries—China, India, Japan, and the United States—account for just over half of these totals' [18]. The digital revolution is here, and the construction sector needs to be on board, or it will be left behind.

The increased rate of technology in society today is undeniable with the number of sensors in devices set to pass 25 billion mark by 2020 [19]. As the huge amounts of data that IoT will bring to the table will have to be managed, the implementation of Big Data solutions can help to collect the right data from all data-generating devices and to make them accessible to stakeholders [20]. The analysis of big data allows the identification of patterns and probabilities of construction risks for performance optimisation in real-time or on future projects [21].

The harnessing of all this data to a central source of analysis is where the iContract technology can excel. By having an endless supply of sophisticated data along with

the ability to analyse at computational speed, an iContract could address the current problems with communication, accuracy of data and speed of action, rife within the construction sector due to the reliance on paper contracts administered manually.

3. The current digital construction landscape

3.1 Current and emerging technologies—new kids on the blockchain

The blockchain concept was brought to prominence in 2008 when Satoshi Nakamoto published the white paper 'Bitcoin: A Peer-to-Peer Electronic Cash System' which based the Bitcoin crypto currency concept on blockchain technology. A blockchain is a ledger, or a database of transactions recorded by a network of computers' [22]. Often referred to as distributed ledger technology, transactions are grouped in blocks and the chain forms the history of these transactions (the blockchain). It is widely believed to have been created as a way to distribute crypto-currency in a way that maintains publicly, and by multiple people a record of the transaction [23]. Trust is built into the technology through its decentralised nature and basis of consensus representing a paradigm shift from trust to a 'trustless' system in which third parties become redundant. Blockchain-based Intelligent Contracts would therefore be more sophisticated, following the stigmergic ideology first coined by Pierre-Paul Grasse in his research on termites, and qualify as computer software code that is autonomous and independent as it cannot be controlled by any one entity [24] (**Figure 1**).

A blockchain is a distributed database (ledger) that maintains a list of records or transactions [1]. These records are called blocks and each block has a timestamp, a link to the previous block, and contains the history of every previous block that came before it. This 'chains' the blocks together, hence the name 'blockchain'. The whole system is fully encrypted with every transaction given a unique cryptographic signature (called a hash function) that is easy to verify and nearly impossible to falsify. This is because the blockchain is hosted by not one single source of truth, but rather

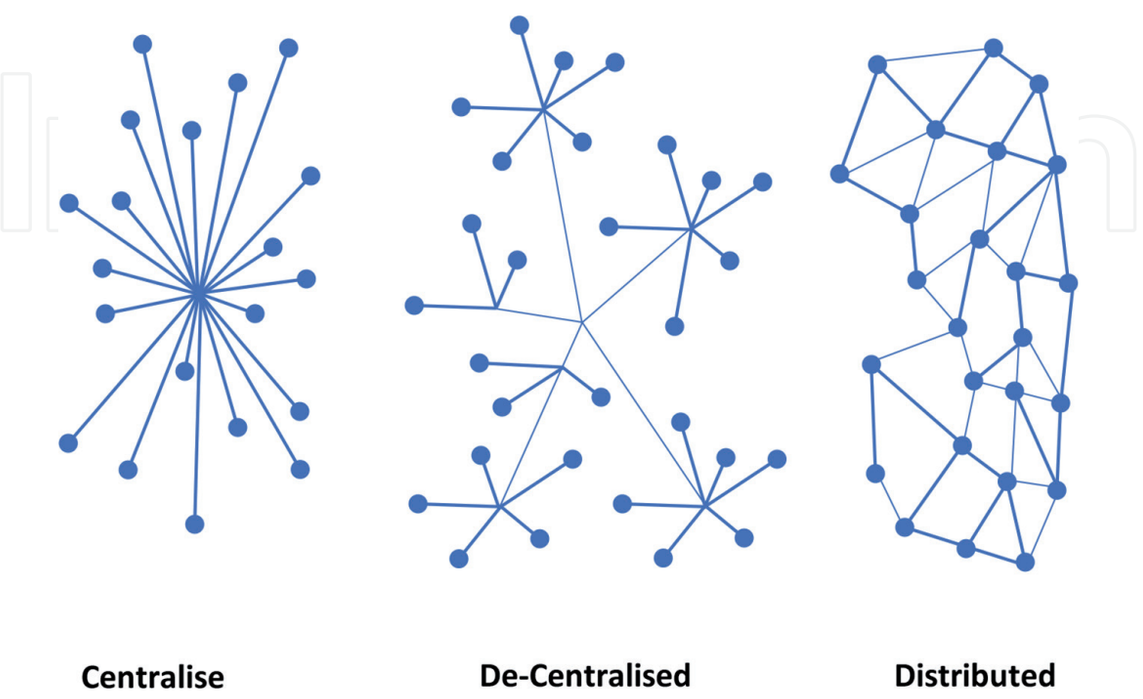

Figure 1.
Centralised network vs. a decentralised network vs. a distributed network (blockchain).

a network of computers. Each computer is a 'node' in the system and each node monitors every other node on a continuous basis verifying consistency of information. Each node checks its local record (block) with every other block in the chain and if it discovers a discrepancy, it looks for consensus and, if necessary, replaces the block with the consensus. This means that to alter a record it is necessary to simultaneously change the majority of the nodes in the system as oppose to one single source. It is not impossible but increases in difficulty as the length of the blockchain grows. The use of the blockchain has moved on from simply being the platform for crypto-currency, to ideas of cheaper transaction processing, crowdfunding and smart contracts. Blockchain 'holds promise for being the latest disruptive technology,' [22]. The heavily transactional nature of any construction project would lend itself to optimisation through a blockchain process allowing for 'automated' trust to be engrained into the acceptance of the next wave of digital technologies. **Figure 2a** shows a typical transactional/relationship map of a construction project and how the general contractor is often the central point to any operation. The disjointed nature of the relationships in this traditional process lends itself to inefficiency and error due to the linear transaction paths. **Figure 2** shows how a distributed network with an unrestricted flow of transactions verified by an immutable blockchain would remove reliance on any one party to validate or confirm data.

BIM is currently the expression of digital innovation within the construction sector. If BIM is the main enabler for promoting collaboration, information sharing and data management, blockchain is a possible solution to eliminating the trust element related to the vast transactions of data [1]. Although it is generally accepted that BIM would benefit from integration with blockchain technology, there is a consensus that the degree of collaboration enabled by Level 2 BIM is insufficient, and BIM usage must reach Level 3 before this can be realised [23]. Level 2 BIM is a collaborative way of working, in which 3D models are created by the various disciplines engaged on a project according to a set of guides, standards and specifications. Level 3 BIM relates to open process and data integration enabled by web services and also focuses on working within a new contractual framework that promotes consistency, clarity, openness and collaboration. With the expected increase of more sophisticated data becoming available through emerging IoT technologies the possibility to realise level 3 BIM may be soon.

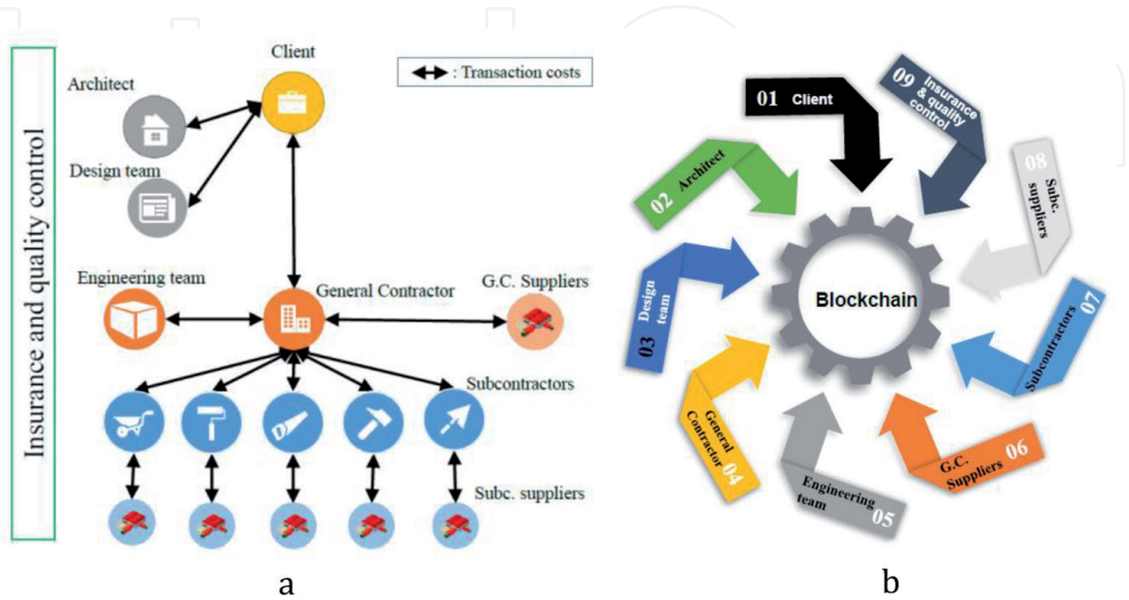

Figure 2.
(a) (The contractual relationships and the flow of money) and (b) (blockchain-based construction). Images from 'The Potential of Blockchain in Construction' [25].

According to a recent report by McKinsey & Company, IoT technology can offer savings of between $160 billion to $930 billion annually on construction sites and other related industries such as the resources sector [26]. It has been reported however, that uptake of the technology within the construction sector has been slow as within the research on IoT within construction, there are many articles to promote IoT without a tremendous amount of real world construction case studies [17].

IoT is described as a combination of sensors such as Radio-frequency identification (RFID), other communication devices, cloud applications and business intelligence technology. With billions of low-cost sensors becoming available, Big Data will flow from previously untapped sources to help improve decision making. The sensors can be embedded in physical objects, such as vehicles and heavy equipment or robotics and even building components themselves with the ability to connect to the Internet and communicate data [5]. These sensors can then send performance data to any other source to be analysed.

In the asset management phase of a project's lifecycle the technology would help the Asset Manager to reduce reactive maintenance practices in favour of predictive maintenance by allowing maintenance managers to repair the components and equipment before damage occurs from the information flowing automatically from sensors imbedded in building components, thereby reducing costs [17].

The obvious evolution to iContracts in maturing the level of automation is already well documented to be heavily linked with the development of blockchain technology and cryptocurrencies [8]. This weighs heavily on the Code is Law concept [27] that has become popular following the widespread deployment of the internet and society's dependence on digital technologies [28].

Smart contracts and blockchain are technologies that have been made a significant contribution in various industries such as the healthcare and finance sectors [29, 30]. The construction industry requires a disruptive influence in order to force it down the route of digitalisation and adoption of cutting edge of technologies seen in other sectors. The BIM platform has set the foundation for iContracts to launch from and provide a completely digital construction process solution, but the technology faces many barriers to achieve implementation. A popular, and valid, view is that construction contracts would be too complex and difficult to code and that they would not cope with legal wriggle-room words such as reasonable and satisfactory often relied on in the sector. This is where further investigation into a semi-automated approach, where the verification of tasks is still carried out by a human interface yet executed via the iContract, is needed to mitigate the discomfort of users handing over control to an untried technology.

As BIM and data management technology drive these new approaches in the construction industry, there will be a need not only to consider the contractual regime, but also to challenge the traditional competitive procurement and tendering processes with more collaborative structures and approaches [31]. By using Blockchain and BIM in tandem, along with other quickly advancing technologies, there is an opportunity to create leaner procurement methods which pushes the collaborative agenda. This will result in cost reductions by removing the multitude of intermediaries currently embroiled in the traditional process and will give a client greater control and transparency of cost, time and scope [32].

3.2 From paper to smart to intelligent contracts

Law and management were traditionally separate disciplines in the construction sector until realisation that law and management could co-exist which has driven the contractual developments in the last few decades championed in part by the

Latham and Egan agendas of the 1990s. The next breakthrough in the field is likely to involve the connection of law, management and technology.

Traditional contracts which are formed through a prolonged period of negotiation between parties, have elaborate drafting phases and require the contribution of lawyers in order to establish the contracting party's obligations. The manual nature of the traditional process is rife with inconsistent and ambiguous drafting practices that are the source of the majority of dispute in the industry. Poor contract administration continues to be the number one cause of construction dispute with errors and translation of contracts being within the top three causes [33]. Unfortunately, the onerous nature of contract administration leads to many human errors which have a detrimental impact on construction projects due to the inefficient nature of manual contracts.

Smart contracts are considered a key influential development that will support Britain's achievement to becoming a digital economy as set out in the government report—Digital Built Britain [34]. Smart contracts have the potential to remove the need for a trusted third party to administer a contract in a truly autonomous state by integrating Building Information Modelling and the IoT, to inform the smart contract of actual progress and performance. The concept of smart contracts, conceived in 1994 by Nick Szabo, is a computerised transaction protocol that executes the terms of a coded contract [35]. The general objectives of smart contract design are to satisfy common contractual conditions, minimise exceptions both malicious and accidental, and minimise the need for trusted intermediaries [40]. Related economic goals include lowering fraud loss, arbitration and enforcement costs, and other transaction costs. The effect of such contracts on contract law and economics, and their opportunities were said by their originator to be 'vast but little explored'. Szabo had a broader expectation for the smart contract concept that through specification of clear logic, and verification or enforcement through cryptographic protocols and other digital security mechanisms, smart contracts might offer an improvement over traditional contract law for efficiency in initiating contractual clauses that could be brought under the dominion of computer protocols.

Smart contracts have also been defined as 'Contracts that are fully executable without human intervention' [36], or 'Self-enforcing, monitoring external inputs from trusted sources in order to settle according to the contracts stipulations'. The key characteristics of smart contracts were described by the Norton-Rose-Fulbright report [37]:

- Digital form: it is in code form
- Embedded: contractual clauses (or equivalent functional outcomes) are embedded as code in hardware or software
- Performance mediated by technological means: the release of payments and other actions are enabled by technology and rules-based operations
- Irrevocable: once initiated, the outcomes for which a smart contract is encoded to perform cannot typically be stopped (unless an outcome depends on an unmet condition). It performs automatically.

Smart contracts translate the legal terms and processes into software code; therefore any contractual response is the outcome of the programmed code. Once initiated, it typically cannot be stopped or reversed once commenced without built in protocols allowing for alterations. Artificial Intelligence (AI) also has the opportunity to be included in smart contracts to assist with decision making as the technology develops [38]. There are several levels of smart contract models, ranging from a fully

autonomous contract where the conditions are entirely in code, to a semi-automated natural language contract where only the payment mechanisms are encoded.

The application of smart contracts in the financial sector would appear easier to establish given the relative straight forward nature of the instruments involved as oppose to the construction sector where every construction project is different, with a specific design and scope of works, this type of contract drafting is complex, and trying to account for all contingencies is not possible. The general rule of thumb is that the longer the contract, the less straightforward its automation.

iContract is the term used when a contracts purpose is to manage itself [23]. An iContract will set out the requirements and decision inputs (hold points) in order to start a series of if/then that will execute the terms of the contract between the client and different members of the project team; main contractor, sub-contractors and any consultants or specialists involved. The iContract clauses are executed when the coded contractual conditions are met allowing digital transaction information such as performance criteria, physical existence of materials on site and works complete to verify a payment amount to be embedded and automatically transfer among the contracted parties once the agreed parameters are met [8].

The 'black and white' or '1 or 0' execution of an iContract is a huge obstacle to overcome in adopting the potential technology due to the complexities of the construction process requiring judgement and discretion which would normally be handled through subtlety and refinement in the language of traditional contracts. These challenges along with the potential benefits of the concept are explained further in the next section.

4. iContracts—an outlook

4.1 Benefits and applications

4.1.1 Optimised contract formulation and negotiation

As clients rush to proceed with the construction of projects, the industry's complex contract formation and protracted negotiation process remains very time consuming and expensive. The current practice requires a great deal of resources for the negotiation of contracts and seemingly self-defeating nature of amendments. The benefits of standardisation in terms of ensuring minimum quality standards and the potential to reduce disputes through un-ambiguous contract drafting is apparent but presently where standard forms are used, they are often modified to the point where they are no longer standard negating the advantage of their purpose. The potential to optimise the drafting of contracts in a logical format that will avoid individuals interpreting contract clauses differently due to the way they are written would be a major advantage of iContracts.

An evolution towards the automation of the contract formation and negotiation process could not only reduce the expenditure of resources, but it would also alleviate the ambiguous nature of current contract drafting as the iContract would be more logical in nature. The possibility for a digital database of clauses and terms to be automatically recommended by the technology, based on criteria set by the user, would offer the opportunity to greatly reduce the drafting and negotiation period.

4.1.2 Contract admin efficiency

Poor contract administration continues to be the number one cause of construction dispute with errors and translation of contracts running as a theme

within the top 5 causes [33]. The construction sector has a reputation for being adversarial and lacking in collaborative and efficient practices. The largest contributing factors to this problem are the behavioural and adversarial attitudes to the administration of what are generally convoluted and inconsistent contracts whilst the heavily onerous nature of contract administration detracts construction managers from the actual delivery of a construction project [39]. A reduction in human error can be achieved through the automation of tasks, using IoT sensors, artificial intelligence and smart contracts. Certification and verification of tasks through blockchain protected interfaces feeding an iContract would provide increased quality assurance for construction projects. Many contract admin tasks could be automated changing how organisations operate which would benefit the industry by speeding up the payment of funds linked to, or possibly embedded via crypto-currency with, an iContract.

The potential for the redeployment of people and resources to other tasks due to the efficiencies an iContract solution could offer would offer any project a huge benefit. iContracts would increase the collaboration, transparency and improving accountability and project control as workflows supported with an automated iContract would allow the waiting time for 'sign-off' to be eliminated as *input* for completed tasks links through an automatic *forward* in the communications protocol. This would bring efficiency to the project schedule by removing disruptive contract bottlenecks allowing continuance of work [1].

Whilst workflow and process control has already emerged through communication and document control systems such as *Aconex* and *Teambinder*, the execution of those workflows are still managed manually based on what is interpreted from the construction contract. An iContract could easily link to these systems and extract the necessary data thus populating the relevant workflows automatically and accurately. Any resultant transactions or tasks would then flow through an iContract giving it a contractual checks and balance function to every transaction on a project.

An iContract solution would alleviate the onerous contract administrative tasks currently handled manually allowing greater speed and accuracy of the process whilst diverting the effort of management to project delivery.

4.1.3 Improved communication, collaboration and trust

The developments and trends studied in the last decade have centred on partnering arrangements and the promotion of more collaborative working relationships. The barrier preventing these initiatives from gaining traction has been the propensity of the sector towards the distrustful and adversarial approach inherent in the industry. The mere term 'business ethics' has been deemed an oxymoron [23].

Lack of trust and limited collaboration between parties has been one of the most frequent cited issues within the construction sector with digital technologies being heralded as the ultimate solution to finally address these downfalls. As digitalisation takes hold the need to become more transparent, improve communication, and increase collaboration and trust is promoted between parties through necessity of adopting digital technologies [40].

Through automation, processes are clearer and more transparent by their nature allowing the trust between the contracting parties to improve. The idea that collaboration is part and parcel of the automated process and that, far from being a casualty, is part of the DNA of a potential iContract is something that could finally demand what has been sought for decades. The construction industry may well have exhausted its ability to collaborate through traditional mechanisms due to the human based factor allowing for digitalisation to disrupt.

4.1.4 Supply chain efficiency

Proof of source of materials can be achieved through digital technology with the potential to provide better record keeping across the entire supply chain for a project through a traceable, immutable digital capture of actions and transactions. This would give the ability to immediately pinpoint where problems exist should they arise as people are held more accountable for their actions through increased transparency.

Tracking of goods and services throughout the supply chain offering near real-time data as well as live data about components in the construction to the BIM model providing updates on the 'as is' state of the building can be achieved by a complete digital ledger solution. Performance and reputation ratings implemented through a digital supply chain would also be possible promoting strategic partnerships as trust would be auditable and earned, much like the driver ratings system found in Uber. The digital integration of real time analysis along with efficiency of the process through the digital procurement process that an iContract would drive could achieve an optimisation of the supply chain in an industry that is seen to be heavily fragmented. The possibility of actually removing intermediaries from the construction project supply chain has also been proposed by some commentators [41] as the structure of the British construction industry is shown to be dominated by main contractors who are essentially intermediaries between the owner and the lower supply chain relying solely on cash flow for profit.

4.1.5 Real time scenario analysis

Quick response rates are a crucial element for any construction project due to the ad-hoc nature of construction activities. A construction contract provides a mechanism for setting the original timescale as well as the direction to vary the relevant parameters upon the occurrence said events. Unfortunately, applying these mechanisms are incredibly onerous, time consuming and offer opportunity for inaccuracy due to the manual nature. The processing power computers could not only accomplish this task but also apply added analysis through prediction and remodelling of a schedule as eventualities occur.

An iContract could run scenarios for any scenario, be it legislative changes in requirements impacting on construction methodology or materials, to any number of events that arise on a construction site daily. By having an intuitive and sophisticated digital contract engine, a user could run a scenario, either as a simulated possibility or based on a real event with the iContract informing the user what the contract consequence will be. The iContract can then, acting in either an advisory or automatic fashion, execute the appropriate contractual workflow to remedy the situation. As the flow of data from external sources such as BIM models, schedules and cost control software becomes more reliable, the iContract can begin to run autonomously and begin to incorporate artificial intelligence in contract clash detection and forecasting dispute avoidance as trends are recognised. Optimising change management through the speed and accuracy of a digital solution would be extremely benefitable to the decision-making process in any construction management team.

4.1.6 Performance analysis and forecasting

Imagine we wanted to record the temperature on site an extreme climate location, every 5 min whilst pouring concrete for quality control purposes. This would be very labour intensive, error prone and tedious. IoT technologies have made

measuring the physical world and submitting measurement data much easier and safer. Much like the pivotal role iContracts could play in real-time contract scenario analysis, the opportunity to analyse contract performance from real world data sets would allow the verification of real time performance against that of the contract requirement. The capture and analysis of performance data could capture upward or downward trends in contract performance immediately, or even before, the fact allowing the project team to address the situation.

4.1.7 Increased traceability and accountability

Current practice in the construction industry demands a need for accountability and for liability to assign to those who err with blame being attributed to the culpable party. The notion of moving away from this blame culture has been recognised as a step towards a more collaborative environment with the potential to encourage this using a central 'project insurance'. Having a central project insurance policy in place of the multiple policies normally encountered on a construction project forces all parties to work together through problems encountered due to the shared policy held by all. The iContract concept would complement this prospect and contribute a concise 'central truth' to any claims made to the project insurance from the data the iContract would hold, all in an easily searchable, digital format.

Traceability of every contractual transaction would be far more accurate and easily found due to the digital nature of the iContract. Not only would data of any project be searchable, the prospect of missing or incomplete data due to manual input would be minimised due to the automated nature of the administration process. Through blockchain technology, an iContract could create an immutable record adding more transparency to every transaction of a construction project.

4.1.8 Stability of payment process

Payments in construction contracts have long represented one of the biggest challenges for the industry [42] and iContracts have the potential to offer a solution to this fundamental problem. The alleviation of this through a transparent and reliable payment process would be welcomed and is one of the major benefits of the iContract adoption. A contract with a self-executing function making automatic payments upon completion of defined obligations, thereby speeding up payments for contractors removes the human element of wrong-doing so prevalent in the sector [43]. Combined with cryptocurrencies, the potential for guaranteed payments increases significantly.

An iContract could be comprised of not one but multiple mini-contracts, all self-executing, transferring data as they execute whilst generating the relevant payment once relevant parameters such as performance achievement have been met. An iContract could act as a 'trustworthy contract administrator by introducing an error-free process'.

Recent advances in cryptocurrency, big data sensors and project bank accounts could lead, at the very least, to a semi-automation solution to the payment function with completion of the work being verified either by a human or external data technology.

Through a central iContract system payment could automatically flow, not only to the head contractor, but also to subcontractors, consultants and suppliers, where cashflow is critical to the survival of construction businesses. An iContract would dictate when, where and how a party is being paid and what for based on a more accurate digital process. The services rendered by the contractor must obviously be made clear and the coordination of BIM, program schedule and cost model may be needed to triangulate the parameters for which the money is released. The capability

for the iContract to be central to automated payments is something that will be a huge benefit to the industry as the capability for 'pay for work' becomes an instant process resulting in 'inch-stone' payments as oppose to the traditional longer milestone payment terms that are extremely onerous to many players in the industry [7].

4.1.9 Reduced dispute

Adversarial behaviour is common place within the industry with contracting practices being the main cause of dispute costing the industry hundreds of billions of dollars every year globally, with the average dispute costing US$42.8 million globally with the average length of disputes taking 14 months to resolve [33]. The potential to significantly reduce dispute is a major part of the business case for the adoption of iContracts as they have the potential to radically reduce the scope, type and size of contract dispute. The immutable nature of an iContract system would present a contract environment where facts are harder to dispute due to the optimised and efficient data management leading to less disputes. The onerous nature of human administration in any construction contract dispute is something that could be potentially alleviated through automation of the process.

4.2 Challenges and barriers and possible solutions

4.2.1 Innovation adoption in the industry

The construction industry is seen to be typically slow at adopting new technologies and historically resistant to change. Some commentators offer the opinion the sector is not yet ready for the level of collaboration and information exchange required for a digital automated contract to be successful [39]. Some believe that due to the technological state of the industry being insufficient, implementation of blockchain and other digital solutions is likely to be costly [40]. Generally, digital technologies are presumed to increase productivity, but this is not always the case as, if it is not combined with efficient and streamlined processes or when organisations lack a collaborative environment, it can struggle to make an impact.

The key to evolving construction will be having a robust enough central management system that will allow digitalisation and automation to flourish. The construction contract between the stakeholders of any construction project is the central point that all data must flow in order to be analysed and actioned. The construction contract must therefore have a greater capability in operating in a digital world, where the abundance of data to be considered will only continue to increase. The industry must overcome the institutional inertia that is ingrained its culture to present the appropriate digital environment for the iContract to flourish.

4.2.2 Handing decision making to an automated process

When contemplating the prospect of an iContract process the question of whether a party has the right to challenge any decision made by the automated process and what protocols would be required to retain a user's right to question a decision without negating the purpose of the automation in the first place. Commentators on iContracts have discussed the need for the ability to regain control of any automated system in the event of an unpalatable outcome to be perhaps agreed by all parties. Acceptance of the iContract certainly leans towards a semi-automated version of the iContract where the majority of the groundwork is carried out by the software with a human supervisor. This may offer an element of comfort as the concept evolves towards a more ingrained autonomous role in the future.

An element of surrender to an automated system has been identified as a limitation to the industry [39]. Traditional construction contracts require judgement and discretion which is extremely different to code. The benefits of iContracts are diluted by the logical '1 or 0' process it must rely on. The alternative is that computers are a tool and can perform a good deal of the repeatable aspects of construction whilst allowing for human input on the more sophisticated tasks or act as a hold point for any critical decision. This is the semi-automated position advocated as likely to be the work around in the short to medium term.

A phased based approach, much like the BIM levels, appears to be the likely roadmap with a semi-automated process being developed using existing contractual procedures. Identification of the processes that would achieve the greatest cost/quality/time saving, whilst achieving confidence in the process by giving an element of human control, should make the concept more appetising for the industry.

4.2.3 Technological and data requirements

BIM's establishment in recent years has laid the foundation for iContracts to operate. The counter-argument that iContracts would not need to align so closely with the BIM agenda due to basing themselves as not one multi-party contract but a collective of possibly thousands of contracts is also something to be considered.

Given the embryonic stage of the iContract concept and the lifecycle of new technology in general, it is expected that many of the challenges highlighted will be solved as existing technologies evolve. Through cloud computing it is possible to access and combine data from various emerging construction software applications through data virtualisation and an Application Programming Interface (API) that allows data from one application be used by another.

The appropriate regulatory and technological infrastructure must exist in order for the iContract to thrive long-term. Facilitating its adoption and integration with other established technologies such as BIM, scheduling software, communication and document control software and other Project Management tools will be critical to the success of any iContract platform. **Figure 3** shows the possible relationships between the physical world, the construction information environment and an iContract based on a blockchain platform.

4.2.4 Perceived legal inflexibility of a digital contract

The adoption of an iContract faces many challenges from a legal perspective as the irrevocable nature of a coded document poses problems in terms of satisfying the contracted parties that the coding is operating within the same parameters of a traditional manual contract. The element of trust required in the system is something that is not required within the traditional model.

Manual construction contracts deal with uncertainty by containing wording allowing a flexible approach to be taken when situations arise. One of the main perceptions of automated contracts is that they will be incapable of dealing with the 'wriggle room' that exist in traditional contracts. A computer programme is made up of algorithms which are essentially 'if x = y then z' and the ability for iContracts to deal with change and uncertainty will be a major barrier preventing their adoption. The difficulty in replacing subjective 'loose' wording with computer code is a huge challenge in order to cover the multitude of variables encountered on any construction project but this is again where a semi-automated human-interaction hybrid model may ease sceptics of the technology.

The recurring theme in most commentary on the automated contract subject is that construction projects are unique, and the size and complexity of projects

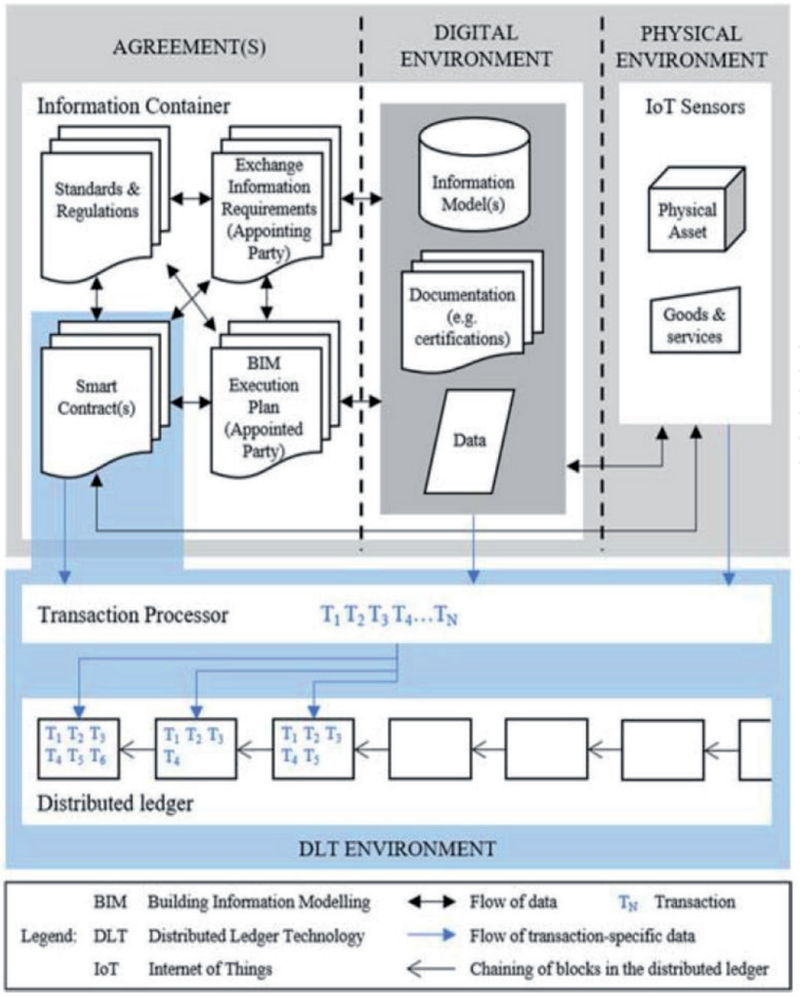

Figure 3.
Integration of BIM, IoT, iContract and Blockchain with the physical data from a construction project [41].

will be a substantial obstacle for the iContract to overcome. The degree to which they are truly unique is certainly open to debate as the industry evolves to a more manufacturing-based model and fact that all construction projects involve elements of repeatable processes that can be automated lends itself to automation.

5. Conclusion

Technological innovation is occurring at a growing pace as society has entered the digital age, and the construction industry is in a race to catch up with the digital capabilities of other sectors. Unfortunately, the construction industry has a historically short-sighted view on innovation with investment relying on immediate value. Knowing the antecedents of usefulness for any technology gives organisations the tools to present the case for adoption more effectively and convincingly. The iContract must present value to its users through the identification of the repeatable processes that it could be applied to. By the careful targeting of the technology to address the 'low-hanging fruit' problems of current contractual practices, the iContract can gain acceptance and begin to push the boundaries of digital automation into the contract process.

The notion that iContracts will be autonomously controlling construction projects based on data from advanced sensors acting as a certifying authority will not be achieved overnight. The advances in BIM, in multi-party contracts, in project insurance can all be seen as a pre-cursor for the type of paradigm shift required to

achieve autonomous construction. Ultimately, addressing the current technological barriers is a waiting game for the iContract concept to reach the stage of maturity where it is indisputable from a legal perspective.

The iContract concept would bring enough disruption to reform contract practices within the construction industry and support its advancement into the digital revolution. This would allow the industry to better manage resources, reduce costs, reduce project durations and reduce dispute. As the iContract concept evolves, many of the challenges identified would be addressed and further opportunities will become apparent as trust in digitalisation increases.

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