Use of New Technologies in Project Management and IPD Governance: An Approach to Blockchain and Smart Contracts

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Abstract

The implementation of blockchain in construction appears to be reaching the peak of the hype cycle. Its benefits are described as having the potential to create a sea change in traditional processes bringing dramatic gains in execution efficiency, trust among parties, and payment speed. However, the potential benefits are largely based on broad assumptions, industry surveys, and small trial projects. The technology has not yet crossed the chasm to broad adoption. Hype will decline as significant challenges must be addressed before pragmatic industry leaders with significant risk exposure can adopt the technology on a broad scale. Still, the industry must seek to optimize project execution. This paper reviews the state of the art of blockchain and smart contracts, evaluates four major use cases, and evaluates blockchain as a fit-for-purpose solution in each case. The use cases include discussion of a real-world implementation on a refinery megaproject in Latin America. The paper presents conclusions regarding what will be required to transition from academic to broad practical implementation of blockchain in the construction sector.

Introduction

Obligation to Optimize

The execution strategy for any major project should include an effort to optimize the tools and processes to be used during project development and implementation. Optimization efforts may be applied to project resources, supply chain, cash flow, and project controls. [1, AACE International] Optimization should consider improving legacy processes and implanting new technologies to improve efficiency, after appropriate consideration of the relevant costs, benefits, and risks.

Blockchain and Smart Contracts

The blockchain concept was initially described in the 1990s, and the model for its first and most successful implementation to date—Bitcoin—was published in 2008. [2, Deloitte] In the few years since, the technology has been expanded to support transactions that are significantly broader and more complex

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than a one-time currency exchange. Many of the proposed implementations are still in conceptual development or trial implementations. So, the technology can be described as new, especially for the construction sector, which tends to be conservative in its adoption of new technologies. Still, the interest in possible implementations of blockchain in the construction sector is on the rise. [3, Tezel]

Blockchain combines the technology of public and private encryption keys with a distributed ledger to make transactions both public and secure. Thus, blockchain is also known as distributed ledger technology (DLT). The characteristics of blockchain have been described to include "trust, security, transparency, and the traceability of data." [4, IBM] Potential benefits may include reducing the cost and speed of transactions. [5, Pratt] Whether those benefits can be achieved in practice depends on the maturity of the technology and the effectiveness of any particular implementation.

A smart contract is the application of blockchain to establish "a computerized transaction protocol" to replicate the legal relationships formed by traditional contracts. [6, Ahmadisheykhsarmast] Proponents have advanced ideas to use smart contracts to manage supply chain, track and approve work in progress, update schedules, and make payments. [7, ICE]

State of the Art of Blockchain in Construction

New technologies go through an adoption curve and must overcome significant challenges before reaching larger markets. [8, Moore] Blockchain and smart contracts are no different. ***Figure 1*** depicts the typical technology adoption life cycle and its associated "hype cycle." As Moore explains, early markets are dominated by a few visionaries or innovators, while mainstream markets are dominated by pragmatists. This is no surprise, as most potential customers do not have the risk tolerance of the visionaries. Nor do they have the same business model, as visionaries are more likely to profit from the sale of the technology itself, whereas pragmatists are more likely to profit only if the technology can deliver the promised benefits.

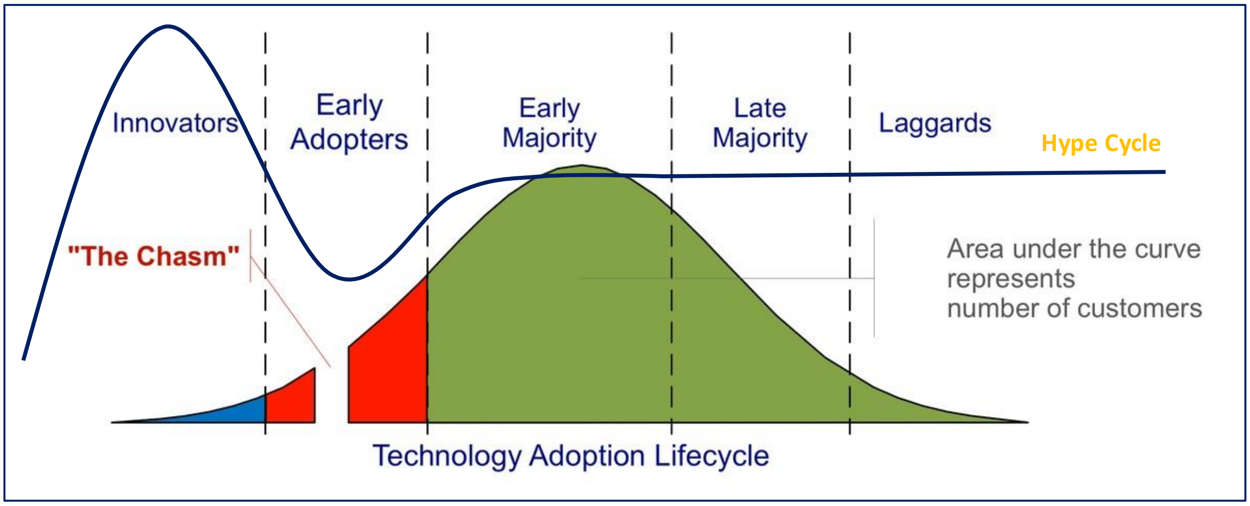

Figure 1. **Depiction of the technology adoption lifecycle** [9, Chelius] **with hype cycle** [10, Gartner]

The construction industry is in the earliest part of the adoption lifecycle for blockchain, where communication and application of the technology is dominated by the innovators. Most of the applications to date have been performed as studies, tests, or prototype implementations. The technology does not yet have broad commercial application in the industry. In this stage of adoption, it is expected that the majority of writing about a new technology will be driven by those seeking to promote it.

Much of the research on blockchain is funded by companies that stand to benefit from its implementation by selling technology or consulting services or by academics that would benefit by being in the vanguard of proponents for a technological revolution. The research is not led by dispassionate parties that have little interest in the success or failure of the technology and significant interest in how it actually affects their bottom line. In Moore's formulation, the technology has yet to "cross the chasm" and reach broad adoption. In fact, it appears to be approaching the peak of Gartner's "hype cycle," where potential impacts and the pace of adoption are overestimated. Practical limitations remain to be solved before the technology can demonstrate the promised benefits. If and when it can, it will be broadly adopted by pragmatists to achieve those benefits, but only if they outweigh the associated costs.

Evaluation of Use Cases

Considering the cost engineering obligation to evaluate tools and processes in an effort to optimize project performance, the authors of this paper have reviewed and summarized the proposed implementations of blockchain technology for the execution of infrastructure projects. The goal is to provide a pragmatic evaluation of whether blockchain is a fit-for-purpose solution to the problems presented in each use case.

The authors present four use cases, discuss the potential benefits of blockchain in each case, and provide a pragmatic view of the likely benefits, challenges, and costs associated with a real-world application.

Based on a review of the literature, the three key characteristics of the blockchain are (***Figure 2***) that it is:

- **Decentralized**—the data is simultaneously recorded and distributed on multiple devices (otherwise called nodes).
- **Transparent**—visible, traceable, verifiable. Anyone at any time can see the history of every record that has ever occurred on the network.
- **Immutable**—encrypted, secure, auditable. As nobody controls decentralized networks and there has to be a majority decision for a change to take effect, the records on the blockchain can never be changed, altered, destroyed, or forged, and are there to stay forever.

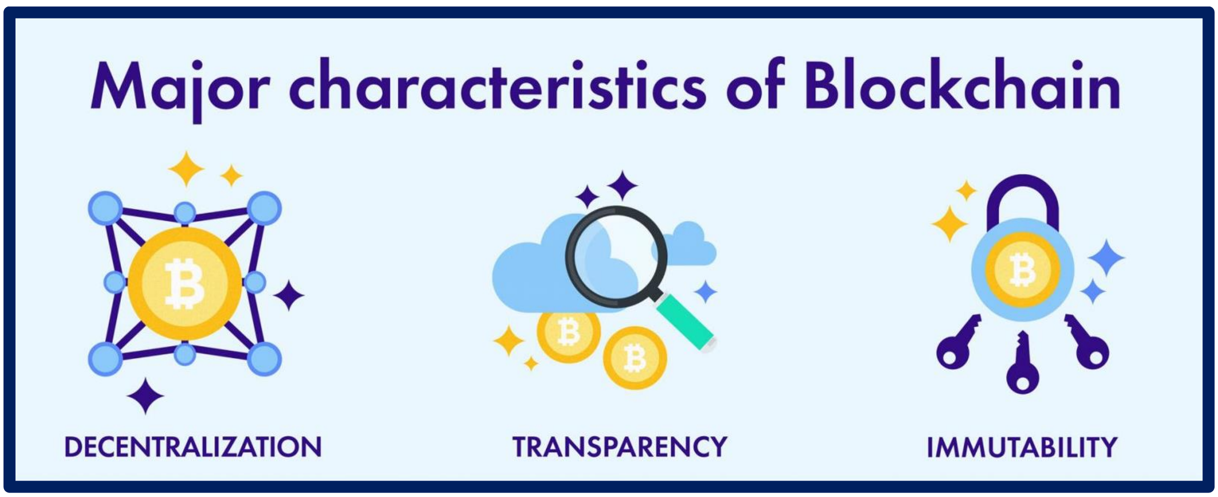

Figure 2. **Major Characteristics of Blockchain**

Those three characteristics generate **trust** by guaranteeing that proof of the details of past transactions are always available to the interested parties. With smart contracts, future transactions can also be guaranteed with properly secured escrow accounts without the need to engage a separate party as the escrow holder. The blockchain may also be public or private:

- **Public**—available to any potential user to view and/or transact
- **Private**—available only to the interested parties

Applications for a public blockchain could align with projects that are partially or wholly government-funded, where the general public has an interest in project performance. Privately funded projects could implement a private blockchain, where the data is visible only to the interested parties.

For both public and private projects, each potential use case was evaluated to determine the benefits of making the underlying transaction information visible (at least to all contracting parties) while maintaining security (the immutability of the underlying data itself). If making the data public and adding security features would improve efficiencies and enhance trust between contracting parties, that would increase any benefits associated with blockchain. On the other hand, if there was no significant benefit achievable by making the underlying data available to all contracting parties or by making the data more secure than it already is, that would reduce any benefits associated with blockchain.

The authors sought to avoid assumptions and evaluate the technology compared to other technologies and processes already deployed on infrastructure projects, based on their own experience. The evaluation includes examples from one author's practical experience implementing blockchain on the Talara Refinery Modernization Megaproject in the Piura Region of northwestern Perú. This project was one of the most important capital projects in the oil & gas sector in Perú and the largest such project in Latin America, with a public investment of USD 5 billion driving a demand to optimize project delivery. Blockchain was one of the technologies evaluated and implemented for a few selected purposes in an effort to increase the efficiency of existing project delivery processes.

Use Case 1 – Project Documentation: Registration of Evidence in the Field to Avoid Potential Controversies

Major engineering and construction projects can require millions of pieces of documentation generated by many thousands of individuals. The ability to verify the authenticity of key documents is important to avoid future disputes regarding the status of the work at any particular time. Knowing who made a verification, when, and how helps to minimize controversy—particularly if the data is incontrovertible.

Blockchain could be used to authenticate project communications, photos, technical submittals and comments, daily reports, or inspections of completed work. Blockchain could replace traditional document control processes, maintained separately by many individual parties, which may include the owner, the owner's engineer, contractors, subcontractors, and suppliers, among others. Instead of relying on each individual party to document submittal and receipt of information, the blockchain would provide one record for all project communications. Some information could be accessible to all project participants, while access to more sensitive information could be limited to certain roles.

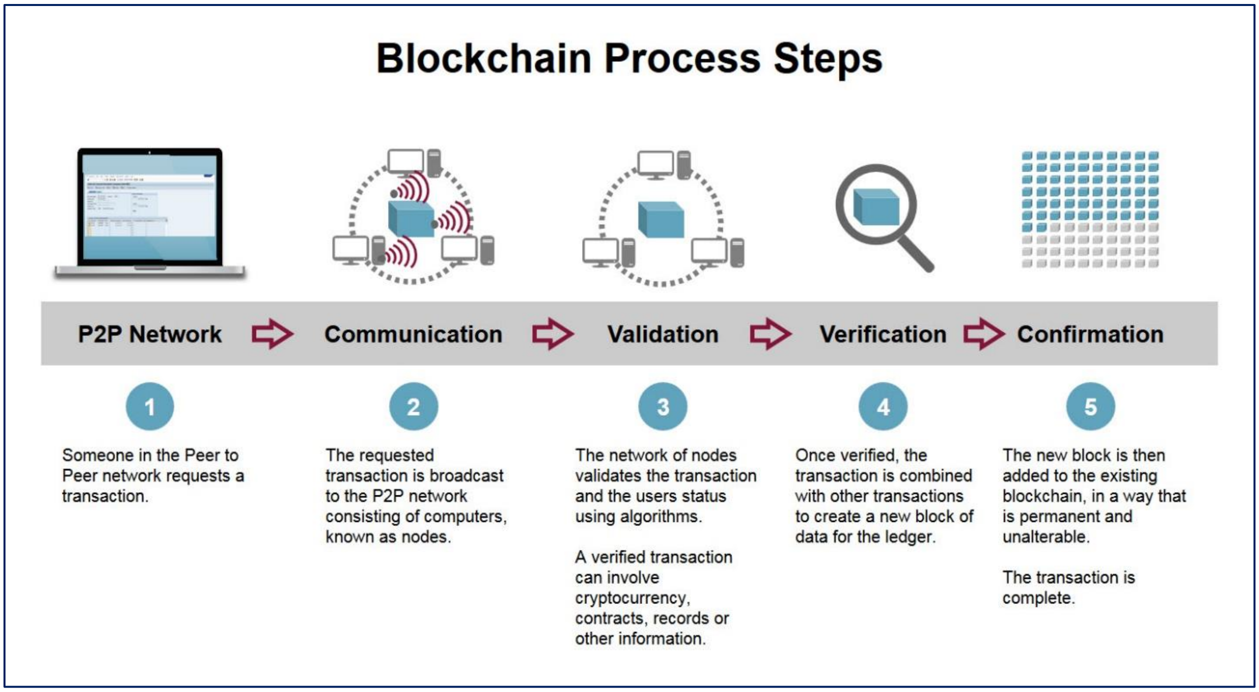

Figure 3. **Blockchain process Steps to record information (transaction) [11,** Bhavani]**.**

A robust implementation of a project-communication blockchain, making project communications more transparent, would have benefits including increasing confidence in the project record (***Figure 3***), and eliminating the need for separate document control processes. Parties could agree that communications outside of the blockchain are unofficial and would not be a part of the official project record in the event of a dispute.

Such a data set would need to be secure, leveraging the other main benefit of blockchain. Once a document is added to the chain, its contents and the date and time of posting to the project record could not be changed. While documents could be withdrawn or superseded in later blockchain transactions, the past project record—e.g., all prior submittals, versions, comments, communications, etc.—could not be altered. Blockchain could eliminate the risk of losing information due to accidental or intentional deletion by one or more parties. Furthermore, all information would be captured in one complete project chronology. Thus, the technology would have tangible benefits in this application.

However, many of the benefits that could be achieved through blockchain are already available using non-blockchain document control technologies. Modern cloud-based document management systems provide a central repository for project documents. They can be treated as an official project record, and access to various portions of that record can be controlled through secure access, including time-stamped access records, IP address identification, two-factor authentication, or biometric identification. Document control systems can provide complete chronologies of all data submitted, and those chronologies can be secured through various security protocols, including encryption. Cloud-based systems can provide simultaneous backups and use commercially available distributed networks to store information.

Any of the benefits attributable to blockchain above could be delivered by non-blockchain technologies. The only question is whether the need for an immutable project record merits the implementation of blockchain. While most systems might be compromised by an individual with administrative level access, the underlying data in a blockchain-based system could not be compromised. Still, a blockchain-based system could be compromised.

Malicious actors could add bad data to the system through one or more of the following methods: the theft of private encryption keys, accessing the blockchain-based system through a stolen computer or one affected by malware, defrauding innocent project participants, or corrupting project participants through traditional means, such as bribery. While blockchain can protect the data added to the system, blockchain by itself does not authenticate data before it is added. The data may still be corrupted through traditional means before it is added to the blockchain. Current methods of authenticating data would still need to be applied.

In summary, the benefits to the creation and maintenance of project records can be achieved through blockchain or through other means. Blockchain processes could run in the background of document control tools, adding a higher level of security to a dataset that should already be fairly secure. It is likely that document control software vendors will begin offering blockchain-based security features in the future, as some clients are likely to want the highest possible level of security.

Personnel responsible for selecting document management systems will have to weigh the benefits of blockchain-based features against any added costs, which may include software vendor pricing, personnel training costs, hardware costs, and even carbon-offset costs for running blockchain encryption on the large dataset generated by communications on a megaproject.

Use Case 2 – Scheduling and Progress Reporting: Monitoring the Procurement of Long-Lead Items and Compliance Certificates for Milestones and Factory Inspections

Every project manager knows that in a project there are many elements that are susceptible to becoming part of the critical path. In the case of long-lead items (LLI), taking the right actions to expedite the procurement process will reduce the risk of project delay. Supply chain considerations must be a part of every project execution plan. A project cannot succeed in terms of cost and schedule if key procurements meet quality and performance requirements but arrive on site very late. Project personnel may have very limited control over key vendors with long backlogs, constrained supplies of raw material, and limited or no control over logistics once items leave their factory. Irrecoverable negative impacts are even more probable when LLIs have a minimum or no float on their delivery dates.

On the Talara Refinery Modernization Project (PMRT), leadership decided to use blockchain technology to verify key points in the procurement process for LLIs. A software application was developed by the PMO to monitor the fulfillment of milestones associated with LLIs, such as factory acceptance tests (FAT), as shown in ***Figure 4***. The app requirements were agreed by the parties. The app was designed to use a tablet or cell phone to take pictures of tests on the FAT site, while simultaneously taking pictures of the inspector with the device's rear-facing camera. The app incorporated facial recognition capabilities and captured geolocation and time stamp data for every image.

***Figure 4*. Monitoring of the process of procurement of long-lead Items and compliance certificates of milestones and factory inspections using blockchain.**

But what about this is new if any cell phone could be used to document test images? The key innovation here was in the use of blockchain incorporated into the app to provide an incorruptible digital ledger of transactions, recorded in a single registry distributed among the entire network. Here, the network nodes included all those involved in the process—customer, supplier, contractor, and others. The images and associated data were added to the blockchain so that they were available to all parties to verify status. Once added, the data were immutable. The time, place, and individual verifying critical steps in the procurement process were permanently captured for all parties simultaneously. In a few words: blockchain let the parties trust the data.

Additionally, the parties were able to link the LLI milestone execution data to planning and scheduling software and reflect status updates in real time on the project execution dashboard. As soon as data was captured, it was available to schedulers and project managers. Remotely monitoring the progress of procurements in real time improved control over delivery dates by allowing the team to immediately engage when there was a deviation from the schedule to work with the supplier or otherwise work to mitigate the delay on site.

The same technology can also be used to facilitate payments for major milestones. Megaprojects often include contract requirements with payments due upon completion of specific milestones. Verification of the completion of those milestones is normally backed by evidence and agreed by the parties, but the evidence required to verify a milestone and the process for disputing completion of a milestone may not be addressed by contract. Here, the same application that was used to document procurement milestones could support payment for those milestones. The approver could use the same app to register the fact that the milestone is approved for payment based on the evidence submitted. There would be no need for an invoice as the person, time, and date of approval would be captured on the blockchain as an immutable digital signature.

While the blockchain implementation here was successful, it appears that the requirements could have been achieved without blockchain. Facial recognition, GPS data, and digital photography are independent technologies, not dependent on blockchain. The data could have been simultaneously recorded by the app, transmitted securely, and posted to the schedule database and project dashboard without blockchain. Non-blockchain apps are already used to update schedules and post data to project dashboards. So, the question is, what did the implementation of blockchain add here?

Similar to the generic project documentation use case, the answer is the high level of data security that blockchain provides. Once posted to the blockchain, data is immutable. Applications that do not implement blockchain typically rely on project personnel that have system-administrator-level access to the data. Those personnel could intentionally or unintentionally modify or delete critical data. Even if the data is backed up, system admins would likely have access to backup systems. While higher levels of security could be implemented, most projects ultimately rely on individuals that could represent a single point of failure for the system. Blockchain would resolve that risk as changing data once it has been posted is practically impossible.

In summary, whether a project should implement blockchain specifically to document the verification of major milestones for LLIs is dependent on whether there is a need to create a highly secure record of milestone status. That risk is likely low for most projects, which rely on multiple independent verifications of major milestones that are already very hard to corrupt. Major milestones with significant associated progress payments often rely on several levels of security. Payment transactions are secured through other technologies and may soon be independently secured by banks using their own applications that implement blockchain security. All features other than the security level could be achieved without blockchain.

Use Case 3 – Auditing Design Changes for Integrated Project Delivery

The concept of integrating blockchain technology with building information modeling (BIM) is a common proposal in the literature on using blockchain in construction. The typical presentation describes an automated system ultimately linking a BIM design to payments. [12, Sonmez] The concept includes:

- A sufficiently detailed BIM design
- Field verification of work in place, often through scanning by aerial drones or fixed or mobile ground cameras
- Approval of work in place by inspection-personnel using mobile apps (note: approval of work in place is not addressed in many proposals, which rely purely on automated scanning)
- Automatic payment for work in place based on pre-defined rules
- Blockchain implementation for all of the above.

The available literature on using blockchain in conjunction with BIM typically presumes that a model of the full project scope is available at the time of contract execution. The scope of work to be performed is fully understood and designed, the elements of the design are established and modelled, and pricing for each element is able to be established, such that the rules necessary for the above protocol can be defined and coded into the blockchain. This model fits the requirements for a design-bid-build contracting paradigm.

Unfortunately, the academic scenarios differ substantially from the reality today. Detailed BIM data is most likely to be available under a design-build contract paradigm (engineer-procure-construct, progressive design/build, integrated project delivery, etc.) In that context, complete design information sufficient to support the establishment of a smart contract protocol is not likely to be available at the time of contract execution. The design details are developed only after contract execution. Thus, the academic case does not fit the present reality of contracts, and the smart contract is unable to take the place of the traditional contract in the present context.

Automating payments based on BIM data raises significant challenges, which are discussed under the next use case. A better use case might be limited to publicizing and securing the BIM data itself. [13, Zheng] Integrated project delivery (IPD) raises numerous new risks for designers and contractors alike. [14, Ciotti and Pasakarnis]

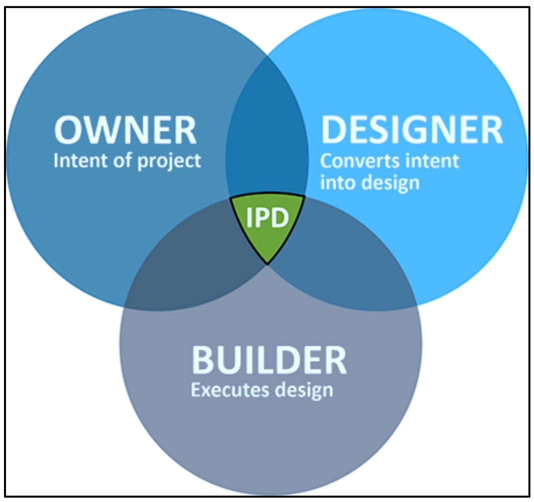

***Figure 5*. Integrated Project Delivery, stakeholders' interaction [15,** Horst].

On a typical IPD project, many parties contribute design information to a common database, as shown in ***Figure 5***. Often, one party has significantly greater administrative access to the database than others. That party is normally the design lead and may have business interests more closely aligned with some parties than others, depending on past and present contractual relationships, beyond the particular IPD project in question. In other words, IPD raises questions regarding trust and the integrity of data. Especially considering the risks of design errors and the potential for sharing those risks in an IPD environment, the integrity of data accessible by multiple parties is a concern for all.

Certainly, BIM allows for an auditable trail of design changes. All data that enters the model can be tagged with the user that made the change. However, all of that data is captured in a database that may or may not be as secure as all parties would like. As stated above, one party is likely to have system admin access to the data, whereas the others are not likely to have a similar level of access.

Blockchain creates more trust because of transparent user actions and resource flows, as well as predictive automation with smart contracts. IPD stakeholders can be identified through address-based access control and their transactions tracked visibly to all stakeholders, creating an inherent incentive to behave in a trustworthy manner, because the other stakeholders can recognize malicious behavior.

Also, implementation of blockchain would allow every change made to the BIM and the user that made that change to be tracked in an immutable record, publicly available as needed to any party. Recorded transactions on the blockchain could never be changed. This would be a significant increase in the level of security currently available in most BIM software.

Once again, the risk that would be addressed by the implementation of blockchain in this context is associated with the intentional or unintentional modification or deletion of data. If one party has administrative access to the database that contains the history of all BIM changes, that party could—in theory—change or delete the data. While this risk might seem low, a significant design error could destroy a firm's reputation in addition to having significant immediate financial impact. When the stakes could be that high, individual actions may be unpredictable.

Design and construction firms might even be advised by their own risk management consultants, attorneys, and insurers to delete data of past design changes on a routine basis to limit the cost and risk of discovery in the event of a lawsuit. Whether firms are obligated to maintain such data may vary significantly based on contracts and applicable law. [16, Gaas and Harrod] Most large companies have record retention policies that mandate the deletion of large quantities of data after defined periods of time, and those policies might not align with every company contract.

Once again, there are other methods to secure data than by using blockchain. Data could be secured by a third-party software provider using commercial cloud services. It is possible to limit system admin privileges to prevent any BIM user from modifying data that might be needed for a design audit. BIM software vendors acknowledge data security as a risk and have already taken steps to mitigate that risk. The state-of-the-art solutions are based on established and tested security protocols that are commercially available and not typically blockchain-based. [17, Procore]

Some users might desire the higher level of security created by a blockchain implementation. However, such security protocols are likely to be available from software vendors in the near future, and the blockchain implementation need not have any effect on the user experience. The security protocol can run in the background, similar to current security features deployed in BIM software.

Use Case 4 – Blockchain Smart Contracts for Supply Chain and Construction

The most expansive proposals for the implementation of blockchain in construction are termed "smart contracts." In 1994, Nick Szabo, a legal scholar and cryptographer, realized that the decentralized ledger could be used to create digital contracts. Contracts could be converted to computer code, stored, replicated on the system, and supervised by the network of computers that run the blockchain. "A smart contract is a computerized transaction protocol that executes the terms of a contract." [18, Szabo] The legal agreement between parties is written in a language that is "both human-intelligible and machine-readable, whose text incorporates an algorithm which automates some or all of the performance of the agreement." [19, Summerell and Macaulay]

As stated in the previous use case, a smart contract could link BIM data to automate payments for installed work. ***Figure 6*** shows the general way in which any project could work using smart contracts.

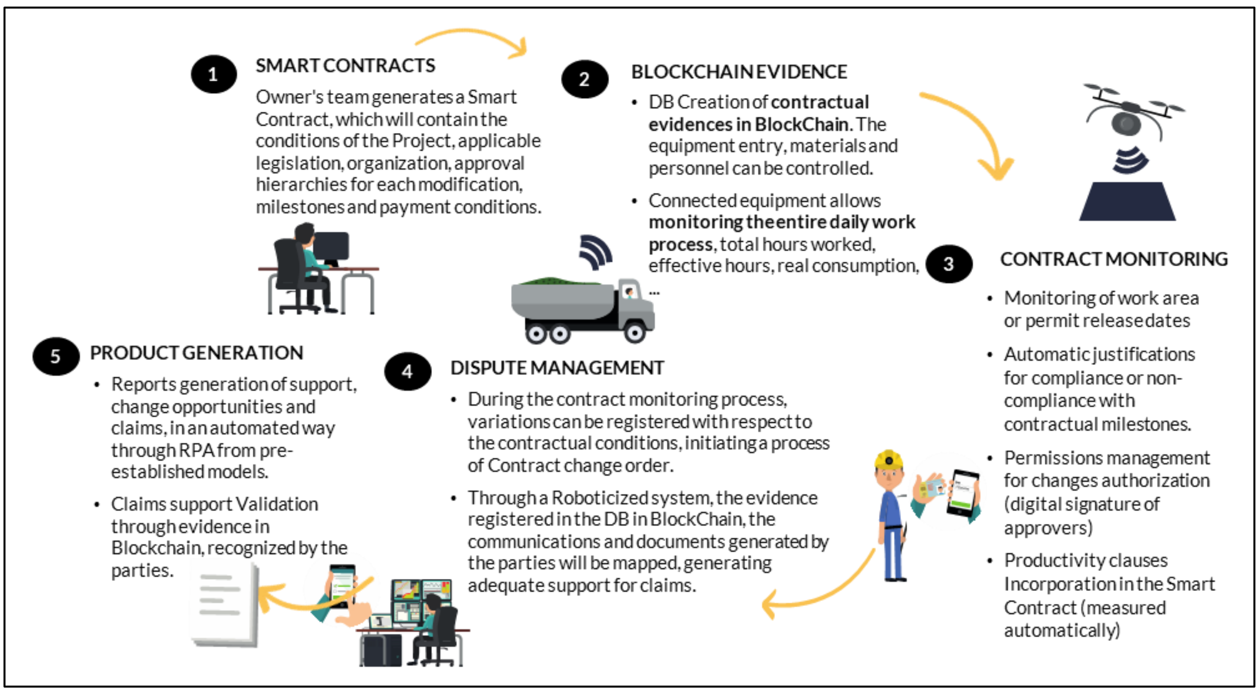

Figure 6. **Suggested use of smart contracts – steps 1 to 5 – in an infrastructure megaproject**

As seen in ***Figure 6***, the use of contract transformed to "computer code" (step 1), allows the parties to store all the contractual evidence in a blockchain database (step 2), to be compared automatically with the smart contract. This smart contract—thanks to blockchain technology—could be used to implement the terms and administer the contract. It could collate and process information about the progress of the project, and, subject to the agreed terms as translated into code, execute a specified action, like the automatic payment of a specific milestone, for example.

Now, for project monitoring and control (step 3) the system would allow storage of all the information that would help–among other things–to avoid future possible claims (step 4), and automatically prepare final reports (step 5), to help the contract managers, doing all of this in an automated way. Finally, combining the prior use cases with this case—secure project documentation, remote milestone verification, and BIM validation—any claim or payment dispute could be validated based on a secure history of pictures, attached documents, and project communications. Any claim would be documented by information stored in the blockchain, meeting any evidentiary standard thanks to the incorruptibility of the blockchain.

One key challenge to a fully automated smart contract is that the scope of most major construction contracts is incompletely defined at the time of contract execution. Change is certain on a complex construction project. Fully defining and automating a set of payment rules that are unchangeable may not be the ideal for construction contracts. Smart contract concepts have not fully explored how they would address change orders, extra work, changes in conditions, uncertainty, and risk during execution. They are largely based on an expectation that design information is complete at the time of contract execution and that the as-built condition exactly—or at least very closely—matches the design model. This is hardly the case on complex projects.

Another key challenge with smart contracts is that most suggested payment automations rely on cryptocurrency transactions. Right now, the valuation of cryptocurrencies is highly volatile. [20, Lapin] The added risk of that volatility is not addressed in most discussions of smart contract implementation. Certainly, automated transactions could be implemented from accounts that use other currencies, but those transactions would only be guaranteed to the extent that there are sufficient funds in the account. Automated and secure bank transactions are already possible without the use of blockchain technology, through the use of escrow accounts. Implementing blockchain would not eliminate the need to fund any project payment account in an amount sufficient to cover any payments that might become due.

In summary, it is not clear that trust among parties would be significantly improved by the automation of the payment process unless the availability of funds can be guaranteed. Such guarantees are currently made through tools that include credit checks, performance and payment bonds, and letters of credit.

Blockchain technologies could ultimately displace some of those forms of payment guarantee, or they could be incorporated into the backend processes that support those tools.

Conclusion

Blockchain and smart contracts based on distributed ledger technology are approaching the top of the hype cycle but have yet to achieve broad adoption. The technology has not crossed the chasm and has not yet demonstrated that it can improve project execution efficiency. Suggested implementations to date have been mostly academic and conceptual. They have not sufficiently addressed challenges associated with incomplete design information at the time of contracting and the high potential for design changes during contract execution. Many of the purported benefits of blockchain implementation have little to do with the key characteristics of blockchain itself—the ability to provide transparency while maintaining an extremely high level of security.

Blockchain technology will cross the chasm in the construction industry. It will have an influence, but that influence is most likely to be behind the scenes and implemented on the back end of software in the form of more secure financial transactions and software data security. The ability to securely automate payments through smart contracts is compelling but guaranteeing the funds to make those payments will require those funds to be available in a stable currency, and cryptocurrencies do not yet meet that requirement. Until they do, escrow accounts in traditional financial institutions and other forms of payment guarantees will not be displaced.

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