A New Perspective of Accelerated Bridge Construction

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ABSTRACT: This paper applies a novel application of Blockchain Technology to Accelerated Bridge Construction (ABC) techniques[1,2] to reduce transaction frictions, solve trust[3] and communication challenges in bridge design and construction, reduce disputes, streamline regulatory requirements, and strengthen partnership and empower community involvement. A disciplined approach is taken to expose both the benefits and possible shortcomings of combining these methods while also providing estimates of time, cost, quality, and "social capital" savings on a use case of urban bridge replacement. Finally, it is proposed that ABC may serve as a formative use case for future applications of blockchain in the built environment.

1. INTRODUCTION

The challenge of the infrastructure industry will always be to deliver more and better products faster and for less money. The only way to meet our nation's current demand will be to somehow introduce enormous improvements in productivity and efficiency of traditional project delivery systems. Efficiencies on this scale have been observed in modern network platforms such as Facebook, Uber, and Google by adopting structures based on social value. More recently, technologies such as Blockchain provide the ability to measure, incentivize, and account for social value in new ways. The engineering and construction industry is just starting to raiseU its head to blockchain technology as new business models appear in other industries, which increasingly impact engineering decisions and outcomes. The industry is faced with a dilemma of adoption without increasing risk or invalidating the endowment of knowledge upon which our industries are built.

2. CHARACTERISTICS OF BLOCKCHAIN

Blockchains are a new type of database that solves a single problem that computers in general all possess[4]. Computers are good at copying things – not good at ***not*** copying things. This makes it difficult to send a single document, or contract, to many people where any one of them could alter the contents. There is no reliable way to keep track of the valid contract and revisions unless each and every user is tracked and vetted – a costly and error prone proposition.

Blockchain is a technology for databases to be modified directly by multiple non-trusting writers. Blockchains truly shine where there is some interaction between the transactions created by these writers – if revision B is dependent on revision A. Additionally, a blockchain may contain embedded rules useful for restricting the transactions that can be performed and by whom. Ultimately, a blockchain's job is to be the authoritative final transaction log. At first glance, we see potential applications for the built environment. That said, there are many excellent project management and database programs that perform many similar tasks in superior ways and are not blockchains. It is essential to understand why blockchain is advantageous while also recognizing the specific advantages that legacy databases possess. Then, we must discern when each is appropriate and how they should interoperate.

2.1 The handshake problem

One way to describe the mechanics of blockchain is to consider a public marketplace in the Middle Ages before the invention of money, municipal courts and regulatory agencies. Producers would all travel to a central market to trade goods among each other. Suppose that one vendor raised chickens and another grew corn. If they did not trust each other, they would hold hands (much like a modern handshake), lay their produce on a table and inspect the other vendor's product with their free hand. Once they agree to the transaction, they release hands allowing for each to depart their separate ways with their acquisition. All of this happened in view of several witnesses who would attest to the validity of the transaction.

An analogous condition occurs in everyday transactions from retail commerce to accepting a change order for a construction project involving two or more persons in a financial exchange. Each party to the exchange must be able to transact reliably and verify the quality of the exchange. A blockchain is simply a computer program that enforces agreements between parties that cannot be reversed and where no third party escrow service or centralized authority (such as bank, court, or government) is required. This requires specialized programming that allow no person or machine the ability to reverse an agreement, and therefore cheat the other participant. Given that computers are unable to "not" copy data, a clever programming technique is employed to make data unique and uncopiable.

2.2 The Mechanics of Blockchains

The following is a theoretical description of how a typical blockchain works. Consider an infinite chain of lockable files – like computer vaults chained together. The computer software applies the following three rules to that chain of vaults:

1. The combination for each vault is stored in the prior vault

2. Each combination can only be used once

3. No two vaults can be edited at the same time.

If you think through what these rules entail, it is easy to envision a train of vaults that can only travel in one direction – one cannot go backwards on a blockchain. Not unlike the Medieval market place, once the trans-actors release hands, once the vault closes, the transaction is final. The only way to corrupt the transaction would be to corrupt at least half of the witnesses into testifying that the handshake never occurred. In this analogy, the probability of corrupting the database falls precipitously with the higher number of witnesses who can view the transaction. At some point, it becomes far more costly to corrupt the database than the value of whatever item that the malicious actor would attempt to steal. Security is established as a function of economic probability.

Blockchains are efficient because security is established by way of an algorithm instead of human administrators performing vetting, management, login, logout, revision records, badging, record keeping, timekeeping, validation, etc. Blockchains operate comparatively fast, reliably, and at scale. Herein lies some efficiencies that Blockchain may reveal for the built environment.

In general, we can say that for some circumstances,

- Blockchain may provide a permanent chronological record of transactions
- Blockchain can only travel in one direction with respect to time
- Blockchains require no third party "escrow" or administration management
- Blockchain allow people who don't know each other to transact reliably
- Blockchain rules and records are applied uniformly and are auditable
- Blockchains are extremely difficult to corrupt.
- Blockchains operate comparatively fast, reliably, and at scale.

3. HOW CAN BLOCKCHAIN APPLICATION BENEFIT ACCELERATED BRIDGE CONSTRUCTION

Blockchain may shorten the duration for planning, design and construction in a cost-effective manner. Reductions in total contract time can be achieved not only by transparent blockchain mechanics, but also by changing the incentives of the participants who transact on the blockchain. If applied judiciously, Blockchain may provide a robust platform for planning, contracting, design approval, and construction payments.

3.1 Streamline the environmental/ regulatory compliance

The construction of a bridge project is frequently subjected to environmental compliance process and permitting requirements to minimize its impacts on aquatic resources, historic and cultural sites, endangered species and critical habitats to name a few. Often this imposes limitation to the timing and duration of the construction activity "window". A streamlined environmental process would alleviate the tight "window" by reducing the duration for compliance procedures from months to weeks, or from years to months.

The agencies will first need to establish a plan and agreement that establish formal processes and checkpoints. These checkpoints may be represented by a smart contract on the blockchain where the next step is contingent on the consensus that the objectives of the checkpoint have been achieved. The blockchain would facilitate the robust execution of these formal processes and validated events. This would avoid the disruption or delay which is not uncommon in communications among the agencies, project owner and intermediaries due to human activities in record keeping, time keeping, revisions and records, vetting, validation etc. The Blockchain can be accessed by multiple writers such as agencies, project owner, stakeholders and general public (if needed), who can view or modify the contents directly. Equipped with embedded rules restricting the environmental compliance approval, the blockchain would serve as a synchronizer and recorder for the "transaction" activities and their provenance and ownership during the environmental review and approval process. The record would be immutable and auditable, enforcing the "trust" among the writers through accountability and strengthened partnership. It incentivizes responsiveness and other good behavior and significantly enhances the efficiency and transparency of the entire process.

3.2 Reduce project costs by proper risk allocation during procurement and design development

In ABC construction, increased risk (e.g. variance in expectations) equates to increased costs. From the level of details the owner placed in the procurement, to the constructability review at the preliminary design stage and semi-final design stages, blockchain could provide an efficient and transparent platform where risks could be better identified, evaluated, mitigated, or assigned to the party that can best address and control it with an understanding of the cost and time implications. A wide group of writers of the database could include but not limited to owner, bidder, designer, construction industry and groups, and third parties such as railroad or utility companies. The "transactions" of risk allocation are recorded in the blockchain and transparent to the writers for their reasoning and ownership. This inclusive and synchronized communication on the blockchain could lead to flexible bid specifications, timely ROW arrangement or temporary easement, adapted foundation design, adjusted time and access to procure additional subsurface investigation, less noise restrictions and less demand by local events etc. As the result the owner will achieve more constructible design, expedited decision making, expedited submittals, lower construction costs and optimized construction schedule.

3.3 Talent liquidity

When special expertise is required for ABC construction, it can be time consuming to locate the right talent who is also available for the given period of time. Project owners can establish criteria for pre-qualification and a list of pre-qualified contractors and subcontractors in the blockchain. The criteria can include examples of successful projects and the experience of key personnel on the contracting team. The blockchain can enforce a resume that predates the requisition in order to avoid fluffing. The project experience can be validated within the blockchain and become immutable records for future references.

3.4 Construction supply chain and smart payment

A complete history of the construction materials may be tracked and validated for its origin, manufacturer, specifications and the "hold points" required by design and construction. Payment can be promptly initiated by a "smart contract" that contains pre-defined "rules" based on the specifications. The contractor and subcontractors would experience a much shorter payment cycle, which reduces their capital costs and actual or perceived risks. The transparency in quality validation will incentivize efficiency, reduce disputes, and expedite construction schedule that leads to social capital savings such as shared understanding, mutual trust and cooperation.

4. USE CASE

In this section, a use case for bridge replacement in an urban setting illustrates how a blockchain may be introduced as a means to articulate the estimated time, cost and social capital savings that could be achieved. In this case, all critical requirements are met for using a blockchain over traditional database.

A three-span historical bridge was built in 1920's and carries 45,000 ADT in an urban setting. The bridge needs to be replaced and expects federal funding. Given the major artery this bridge carries, the owner considers using accelerated bridge construction to minimize the traffic and community impact. The project requires NEPA and SEPA environmental compliance processes by the federal and local agencies. The project also needs to meet the expectations from stakeholders such as the city's historic preservation department, utility division, bus operations and the local community businesses affected by the construction.

The estimated ABC schedule indicates an 8-month environmental compliance, 6-month procurement, 8-month design and 8-month construction. A blockchain application could potentially reduce the schedule by 25% to 60% for various tasks. For clarity, environmental compliance, design and construction are analyzed to illustrate how a blockchain would work as generalized in Figure 1. "Work Element" represents the item to be validated or concurred as compliance process, design concepts, design components, or construction submittal. "Approval" represents an acceptable completion. "Claim" and "Validation" represent a key mechanism i.e. the "handshake".

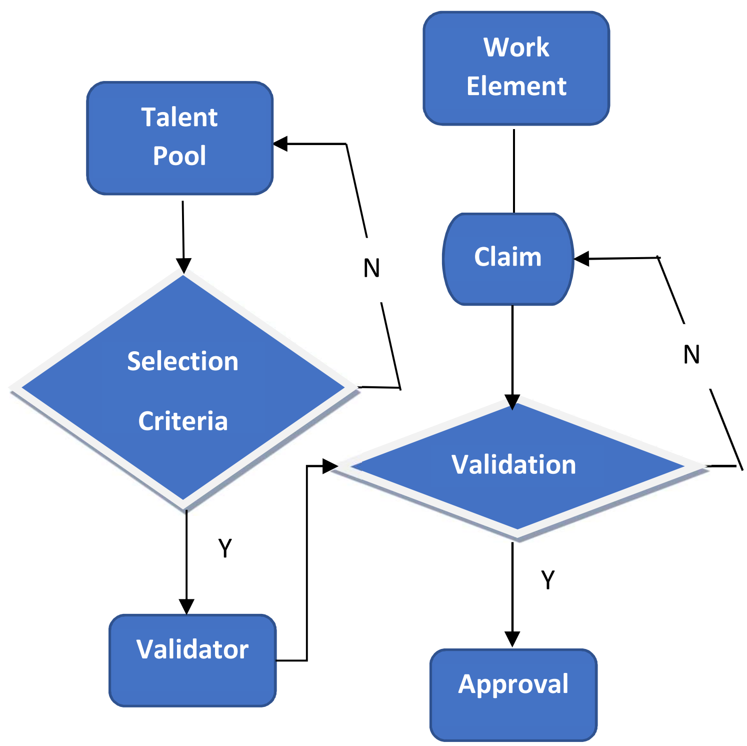

Figure 1 Claim and Validation

The SEPA approval process starts with "peer-to-peer" communications among project owner, agencies, and stakeholders. The information will be stored on a distributed ledger (databases) and all participants can see exactly the same record. The "claims" can be made by the project owner meeting the compliance requirements while the "validations" can be performed by the agencies or a designee. Stakeholder comment period is expected and could be performed on the blockchain. The record indicates clearly when and what were submitted, reviewed by whom, and how the comments were addressed to the validator's satisfaction etc. There is pre-defined and agreed upon "clock" embedded in the blockchain and all participants can see the specific actions to be taken and their status as recorded. This setup prompts responsiveness and minimizes the delay by inefficiency in communications. It will automatically issue the compliance for the project to move forward once the pre-defined "rules" are met.

For the community and public, the blockchain enables "transparency" and "synchronization" for them to view the latest development and progress. This will empower the community involvement and also strengthen the effectiveness of owner's public outreach with less dedicated time and staff but deeper penetration of diverse community groups.

The design development and validation start with "peer-to-peer" communications among owner, contractors, designer and industry. The peer-to-peer agreements are built in distributed databases which record the "preferred" design developments that is considered constructible with reasonable costs and targeted schedule. The "brainstorm" type discussions are routine working process and will not be recorded to the blockchain, only agreements are. The distributed ledger will see the same record of design concepts, their ownership, and the key data consideration behind them. The consistency and transparency the blockchain provided to all participants will minimize surprises and costly re-design. It also minimizes miscommunication among multiple stakeholders involved in a complex ABC project. It incentivizes prompt decision-making and reduces negligence and moral hazards as the entire process is alive and available to all or designated participants to view. The claim-validation process enhances quality of the design and minimizes the costs of human errors.

During construction the blockchain facilitates the contractor's work flow through a pre-agreed upon "clock" in the blockchain by contractor, prefabricator, rigging and placement specialist, trucking company, crane operation etc. This could reduce the time for waiting and idling significantly through well predicted logistics and labor demand. The city's mobility office and public are among the participants of the construction "chain", they are well informed and have access of real-time updates. Minimizing traffic delay through data-driven traffic management becomes achievable and dependable. The community and business affected by the construction will likely provide more constructive feedback when well informed of what is next. The community is empowered as they can "see" their voices are heard and being utilized. This social cost saving by the reduced travel impact and minimized business impact will bring great value to the community.

5. CRYPTOGRAPHIC TOKEN AS A SCOREKEEPER

Many people are familiar with cryptographic currencies such as Bitcoin and associated implications - both positive and negative. Despite this, cryptographic tokens are not necessarily currencies, and may have very useful effects in being able to shift incentives that can modify legacy behaviors, reward desirable behaviors, and eliminate moral hazards. It may also help mitigate the natural resistance to organization change that new technologies often encounter.

Any application of blockchain to the built environment could include the "cryptographic token" as a marker – or a scorekeeper – that memorializes critical transactions in time and place. This will be elaborated in a separate paper but here are a few key points,

- Data entry of claims and validations may be rewarded with electronic tokens stored in electronic wallets
- Tokens issuance marks points where risk is transferred from one party to another
- Tokens could help reconcile internal accounts, payments, chargeback's, and contingencies
- Token transactions can represent financial incentive in real time and instantaneously.
- Tokens can represent performance adjustments and bonus
- Tokens provide consideration for finalizing, "Sealing" a design, work order, Inspection, Certificate of compliance, etc.

6. WHEN YOU DO NOT USE BLOCKCHAIN (SHORTCOMINGS)

Blockchains are very good at some things, but not everything – it is important to know the difference and apply technology appropriately. Blockchains cannot and should not replace enterprise solutions databases such as BIM, Salesforce CRM, MS Project. These applications have been developed over many decades, they have great user interface, and provide as much security and immutability that most companies and projects need. They also communicate fairly well with other databases through APIs and other techniques. Any private database with few writers sharing servers under private control should probably not be a blockchain – the vast majority of database applications probably should not use a blockchain.

In a practical sense, the day-to-day jobsite activities may be too volatile and frequent and inconsequential to warrant scripting on a blockchain. However, the large consequential events such as points of risk transfer between contractor A and Contractor B, the owner and the contractor, the bank and the owner, the insurance company and the bank, etc.

Internal documentation that does not involve sub-contractors, public interface, or multiple parties would likely be best kept on local servers or a departmental share point.

7. FUTURE DEVELOPMENT

Like any new tool or machinery, users need to identify appropriate use cases[5,6,7] using both traditional and emergent feasibility criteria as with any comparative assessment. Engineering has the added constraint that errors can be costly and dangerous. Care should be taken to test use cases with both systems (blockchain and legacy) in place to measure and compare efficiency and risk.

Blockchain applicability should be progressive. For example, the validation of credentials should be in place before validation of events since your "validators" would themselves need to be validated, etc. It follows that validation of performance would be contingent on a validated installation, etc. "Blocks" on a blockchain are nested in this manner as well.

Perhaps the most difficult hurdle that the built industries will encounter is the sharing of information among organizations that are otherwise competitive or adversarial. A large engineering company may have 6 billion dollars in business, but this is less that .05% of the total value of their global market. By hording information, this large company only has access to .05 of the applicable data. If all companies could agree to share some strata of data among each other, then a whole new world of Big data can emerge to vastly increase the operational efficiency overall for the built environment.

Only these steps would deliver enough efficiency to achieve the cost reduction goals for meeting the infrastructure needs of a developing civilization.

8. CONCLUSION

Blockchain is not a single application, it is an ecosystem that will need to be applied correctly and rationally among other data technologies in order to realize the benefits. This requires an industry wide consensus of appropriate use cases, the development and multi-agent collaboration of pilot projects, consensus on business protocol and methodology, and the development of industry partnerships. The anthropology of token awards is another area that would need careful optimization.

Due to the broad and diverse stakeholders in bridge construction, where there may be limited alternatives for a traveling public, we believe that the Accelerated Bridge Construction would be an excellent use case to test the ability for blockchain to both increase efficiency and promote organizational change. Blockchain has reached a point of maturity that many organizations such as the Integrated Engineering Blockchain Consortium, the National Society of Professional Engineers, and providers such as IBM and Microsoft have the accumulated knowledge and experience to apply what is known to what is unknown such as ABC in the built environment.

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Design Build Institute of America PNW Chapter

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