Incentivizing High-Quality Data Sets in Construction Using Blockchain: A Feasibility Study in the Swiss Industry

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Abstract –

Data sets are often incomplete and low-quality at the end of a construction project. This creates rework or hinders opportunities to use data during future activities of the facility lifecycle (e.g. facility management, renovation, demolition). This research prototypes and evaluates a novel process to use blockchain and smart contracts in construction projects to incentivize high quality data sets. The proposed solution is defined in collaboration with construction professionals. The process traces and saves project data while incentivizing participants to create high-quality data sets through reward tokens. To validate the process, an Ethereum-based blockchain prototype is developed. A simple case study is conducted in collaboration with local industry professionals to simulate how the prototype can function in a typical design bid build process used in Switzerland. The early findings and possible subsequent research steps are presented. Overall, it was found that such a blockchain based incentive systems has the potential to not only incentivize high-quality data sets, but also change the way of tendering and related construction processes.

Keywords –

Blockchain; Incentives; Data Management; Construction Projects

1 Introduction

As digitalization in the construction industry increases adoption of building information modeling (BIM) and other digital tools, there are new opportunities to better optimize and manage the operations, maintenance, and deconstruction over a facility lifecycle. The oft-mentioned goal is to create a real time digital twin of the asset.

However, usually digital data sets at the conclusion of construction projects are of low-quality. There can be many reasons for this, such as poor documentation in the first place, difficulties to find the data, or low reliability of the information [1]. When not done properly, the operations team must reconstruct a vast amount of the "as-built" or "as-is" BIM at great time and expense.

To avoid this, construction project teams should seek to handover complete, high-quality data sets at the end of the project. The data gathering should take place from as early on in the project as possible [2]. This challenge is not only technological but also process related [3]; it is important to also consider personal and organizational incentives to provide the data in the first place [4].

Blockchain is seen as a technology to improve transparency and collaboration in construction [5]. Blockchain can track transactions over time and store them in a trustworthy, distributed manner. It enables the building of trust between transacting parties and devices. Blockchain also offers the potential to decrease transaction time and reduce costs associated with intermediaries [6]. Most blockchains can execute *smart contracts,* which are code protocols running on top of a blockchain. On more sophisticated platforms like Ethereum [7], touring complete smart contracts can be used to automate workflows through predefined functions (often conditional if… then... statements), as well as to create so-called *tokens* to represent different kinds of transferable value. Since these tokens represent value, incentive systems can be designed to influence the human behavior when interacting with the created blockchain based process.

In the broader blockchain research space, there is much interest in this topic of crypto-economic systems design – i.e. creating a blockchain-based incentive system among multiple parties to align them towards a higher level goal [8]. For example, Zavalokina et al. [9] investigate a blockchain reward system for maintaining high-quality records for used cars in Switzerland. However, in reviews of proposed use cases for blockchain in the construction context, cryptoeconomic systems design is less often mentioned than other potential use-cases [10]. Only two studies have proposed use-cases where a token is used to incentivize multidisciplinary design teams [11,12]. Having said that, crypto-economic incentive systems could be a novel opportunity to tackle existing challenges of integrating technology and processes in the fragmented construction industry [13].

This paper introduces a use case of crypto-economic system design to incentivize complete, high-quality data sets at the handover of construction projects. The novel solution proposes smart contracts and tokens to create a trustworthy track-record of data drops, to automate information flow activities, and to incentivize participants in the construction process to share high quality data sets.

2 Methodology

The systems design was conducted in collaboration with construction industry professionals. Research began with a preliminary feasibility study in collaboration with the blockchain workgroup of the buildingSMART chapter Switzerland. The group consisted of construction professionals with diverse backgrounds such as owner, architect, BIM manager, engineer, supplier, contractor, and facility manager. Over the course of one year, the group of industry professionals and researchers held monthly workshops to discuss various aspects of implementing blockchain in the proposed use case.

First, the group discussed the information flow and information categories needed to create a complete data set (chapter 3.1). At the same time, the group defined a use case demonstration (chapter 3.2) and construction process (chapter 3.3) to simplify and focus the investigations. The prototype consists of a basic house represented by a simple BIM model. The home should be procured and constructed using the design bid build (DBB) construction process that is typical in Switzerland.

After the process and data flow for the use case was defined, a first blockchain implementation was prototyped with Ethereum smart contracts (chapter 3.4). Finally, the potential incentive system for high quality data was described (chapter 3.5).

To validate the design, the workgroup participants were then asked in a subsequent workshop about their opinion of the solution (chapter 4). The early results are discussed regarding limitations, opportunities and future research areas for implementation of such a system (chapter 5).

3 Use Case

3.1 Information Flow

To design the subsequent blockchain prototype to incentivize complete data sets, there needs to be an understanding of the information that is typically shared and relevant for later use phases. In the mentioned workshops, potential information categories and relevant data fields were identified. Furthermore, expectations regarding high quality data sets in the scope of this use case were discussed.

3.1.1 Information Categories

Two information categories were identified throughout the workshop: technical and commercial information. Technical information was defined as data important for the subsequent use phase and later recycling of the elements. Commercial information is defined as data relevant and needed during the actual construction process and to control the process for data capturing.

Technical Information

For technical information, various efforts categorize important information for facility management. The data structure for the prototype was based in part on the data fields of the Construction Operation Building Information Exchange (COBie) [14]. COBie is an information exchange specification that defines a consistent structure about a projects facilities, spaces, floors, systems, installed equipment, and related documentation. It was developed especially for asset data without geometric information, which make it very convenient for the later blockchain prototype. Even though COBie represents a first step in the direction of addressing life cycle data challenges related to facility management, it still faces many challenges [2,3].

Commercial Information

For commercial information, the project workflow and the project participants provide the backbone of the process. During the workshops and prototype implementation, commercial data about the project was vital to design the blockchain system. Without this information, the smart contracts would not know from whom and when to request and reward data drops.

The commercial information required was identified during the workshops. Most of the commercial information comes from the tendering process. This also includes the associated prices and quantities of the items in question and the information about the bidding contractors such as insurances and declarations. In addition, information about the project's progression as well as deadlines or contractual information is important. This includes the documentation of decisions, the confirmations for tendering, and the final selection of tendered offers.

3.1.2 High Quality Data Sets

The workshops identified three attributes necessary for high quality data sets: completeness, correctness, and structure. *Completeness* is necessary to ensure that all information is stored. However, completeness should be balanced with complexity. A focus on the important data reduces cost and complexity in the process, since typical buildings or infrastructure exists for many years. This is especially true for expensive systems such as blockchains. As little data as possible to create a complete date set should be saved. *Correctness* is important in order to draw the right conclusions from the information. Incorrect information can lead to subsequent mistakes and/or costly reconstruction of data. *Structure* is crucial to organize data for later use. Without a standard structure (naming, file type, database) the retrieval and processing will be challenging. The challenge is to fulfill these three attributes as best as possible through the blockchain based workflow and incentive system.

3.2 Use Case Demonstrator

To investigate the described use case in a realistic context, a simple house demonstrator is created using openBIM. The demonstrator has four elements: a door, wall, floor, and pump (Figure 1). These four elements represent the typical diversity of building components (e.g. make-in-place products, semi-finished products, and finished products). The demonstrator acted as a base to investigate the construction processes and related data to build these.

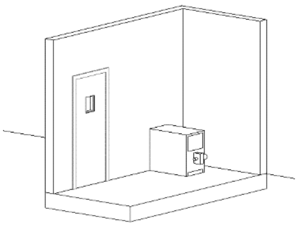

Figure 1. Demonstrator with four elements: floor, wall, door, and pump.

3.3 Construction Process

To start the investigation, a typical design bid build (DBB) process for Switzerland was analyzed for the use case demonstrator together with the buildingSMART Switzerland focus group, resulting in the process diagram pictured in Figure 2. The DBB process was chosen since it is still the most commonly used project delivery model in Switzerland. Furthermore, it simplified the communication with the construction experts, because they were all familiar with it.

Because the process scope should be as focused as possible, some simplifications were made. First, only four stakeholders were considered: the owner, planner, contractor, and supplier. In reality, many more stakeholders exist, including numerous sub-contractors. However, the most important interactions and tasks can be demonstrated with these four stakeholders. Second, some of the contractor tasks are compressed to keep the process diagram as short as possible.

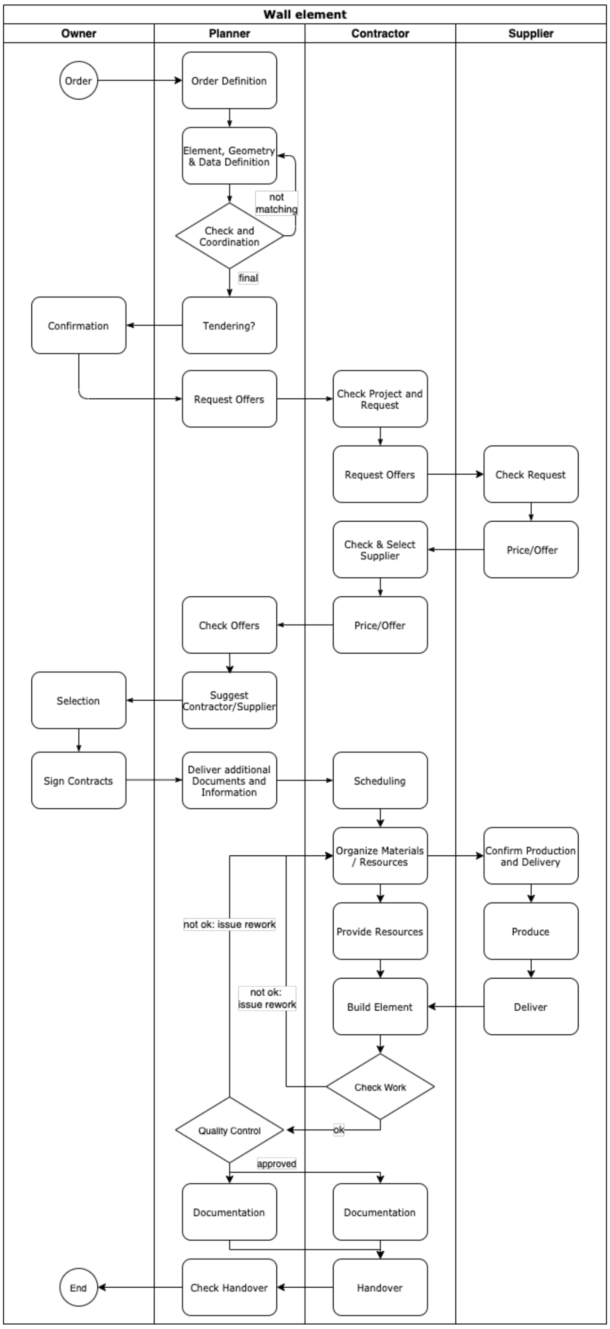

Figure 2. Process diagram of the construction process for the wall element of the demonstrator.

3.4 Prototype

A preliminary blockchain prototype was developed in order to test the feasibility of such a system. The focus was only on the first part of the construction process (see Figure 2): the project phase of element definition and tendering until the contract is signed (Figure 3). Furthermore, the supplier was not considered in the prototype; it is assumed the functions of the supplier would be similar to the ones of the contractor. The prototype was developed for the Ethereum blockchain. Ethereum was the first blockchain that introduced touring-complete smart contracts [7]. These smart contracts can encode logic that will be executed when the according functions are called. Furthermore, they can hold and save data on the blockchain. The feature of smart contracts is essential for the proposed use case. Although there are many other blockchains that support smart contracts nowadays, Ethereum is still the biggest network with vast documentation available. It should be noted that there is no claim that Ethereum is the only blockchain framework for this use case. The proposed logic could be implemented on any other system that supports smart contracts.

3.4.1 Smart Contract Logic for Workflow

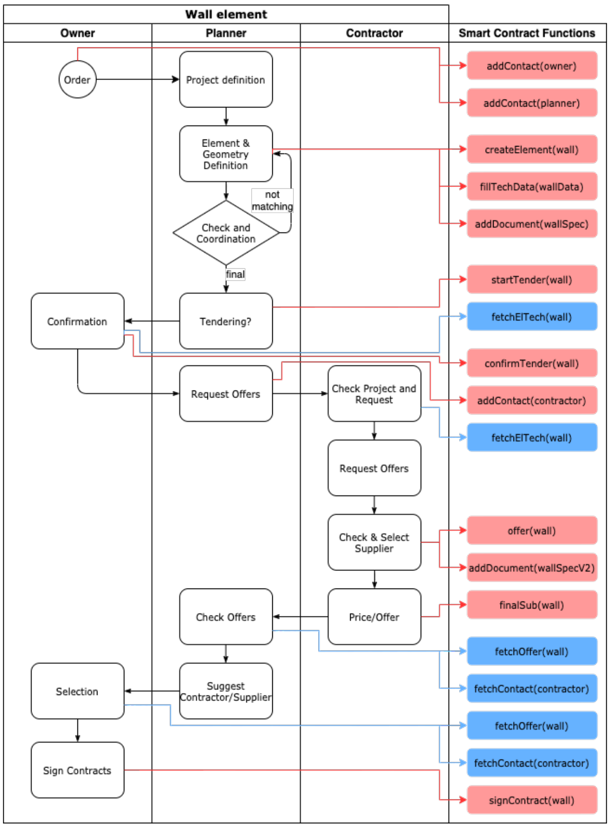

Figure 3. Workflow for the built prototype with smart contract functions. Red: write functions; Blue: view-functions to retrieve information.

The workflow pictured in Figure 3 was realized by coding the related functions for each necessary transaction into a smart contract. To write and test the smart contract in the Ethereum-specific language Solidity (https://solidity.readthedocs.io), the brower-based open-source tool Remix (https://remix.ethereum.org/) was used. Remix allows for fast writing and testing of the smart contract functions through an integrated JavaScript compiler that simulates the Ethereum virtual machine environment.

The smart contract includes different functions. Through so-called "state variables" the process order is defined. The variable is changed if a project step is completed. This is a very restrictive approach, because the next phase can only be started when the previous step has been completed. Each construction element contains these state variables, and the smart contract only allows to execute the associated functions. For example, if an element is in the state *ReleasedForTender*, only then can the owner confirm by calling the function *confirm()*, which would put the element into the subsequent state *Confirmed*. The function *offer()* would for example fail, since this is not the next workflow step. Furthermore, the smart contract logic ensures that functions can only be called by the correct parties. Each party has their own network address to identify itself. With the associated private key (similar to a password) the stakeholders can identify themselves and sign transactions, e.g. the execution of a specific function.

3.4.2 Data Structure

The data structure for the prototype has been defined based on the identified categories in chapter 3.1.1. The storage type *struct* was used in Solidity to store the information. A *struct* for both the technical information and commercial information was defined, which means it defines the data fields that need to be filled in during the work flow. If multiple entries are expected for one field, arrays are used. The *struct* is then applied to each element or product in the construction project. This was found to be the best suited solution because the BIM-based tender process is based upon each individual BIM element.

Different functions take care of filling the information related to the various data drops in the process. This is displayed in Figure 4. For example, the function *confirm()* only alters the state variable through the contractor signing that function. In contrast, the function *createElement()* called by the designer takes all the design parameters as input and stores them in the respective struct entries. The different data drops can be defined including who will need to do the data drop by calling the respective function and when this function can be called. The different view functions allow to retrieve and validate the information.

Finally, a *struct* for contact information was defined (Figure 4). This allows to save additional information about the stakeholder next to their Ethereum address. With only the public address-string (e.g. 0x25213E8E0964a98A017Ebbf36c633eFd006fe2ce), it is hard to see in reasonable time who belongs to which address.

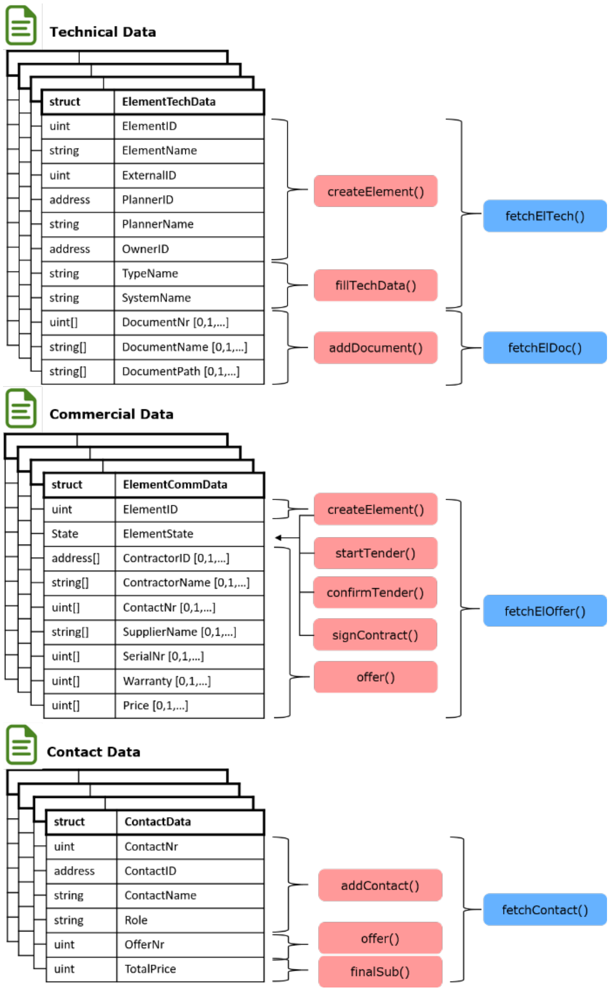

Figure 4. The data *struct*'s used in the prototype: technical, commercial, and contact. The functions modify the respective elements when called.

3.5 Possible Incentive Structure

The implemented prototype allows to build a blockchain-based incentive system along the introduced work flow. Tokens can be issued, transferred or burned together with the introduced blockchain function (see Figure 3). As briefly explained in the introduction, blockchain-based tokens represent value containers that could be used for currency, reputation, securities, or other value types [15,16]. Tokens are also coded through smart contracts. In the case of Ethereum, the most used token-types are called ERC20 (fungible) and ERC721 (non-fungible). Depending on the use case, both tokens types could be useful.

Figure 5 presents a schematic view on a possible structure. The idea is to incentivize data suppliers to only write high-quality data. This mainly applies to the correctness of data. To some extent, the smart contracts already take care on the structure and completeness aspect, since they force the actors to input the data as specified in the workflow rules and defined data fields. However, the quality of that data could be still low. As a solution, an additional role in the process of a data verifier can check the data transactions and confirm the quality. For now it is not further defined who will take on this role, but in general every capable stakeholder could do this. If the data quality is good, the data supplier receives some kind of reward token.

The challenge is then to design the right incentive system out of countless possible combinations. For this construction case, the authors imagine either financial rewards (tokens for micropayments or a stake in the project) or a reputation system (tokens represent reputation). Also a combination of both and/or multi token system is possible. Different solutions are part of the ongoing research. They should then be carefully tested to exclude possibilities of cheating or negative side effects. It is important that all actors in the system are incentivized in the intended way. Next to the considered construction participants, this also applies to the role of the data verifiers.

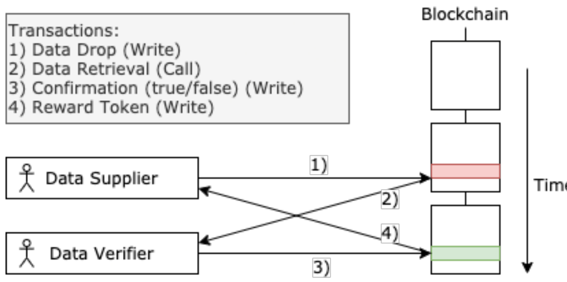

Figure 5. Schematic representation of the imagined incentive system to achieve high quality data sets.

4 Participant Assessment

The prototype implementation and ideas on how to incentivize high quality data sets through tokenization were presented to the buildingSMART workgroup. A first brainstorming session took place for each of the stakeholder's role in the system and potential benefits and drawbacks associated to it. The insights will be used in future research to iteratively improve the incentive system design. The following presents some preliminary insights and feedback from the participants.

All participants agreed that the blockchain based process can add value to today's working practice. The strict nature of smart contracts and the transparency of the process could already mitigate many of today's challenges regarding data structure and information completeness. Furthermore, the participants saw the blockchain-based incentive system as promising to incentivize correct content (either through financial or reputational rewards), but also to potentially create a self-sustaining infrastructure. The construction professionals wondered who would pay for such a system, either in terms of transaction fees (in public blockchain network) or the overhead for the infrastructure and maintenance (private blockchain network) (see Hunhevicz and Hall [10] for more information on different blockchain network types). While in the first case the fees could be covered by each individual party (similar to post stamps for official sharing of documentation nowadays), the second case would need to be financed out of the system (e.g. through participation fees) or by the stakeholders. An independent funding source not related to one project stakeholder would support the adoption of such a system also across projects. The system should ideally be opt-in and attract the users through the associated benefits. The participants agreed that this would be the better option than forced participation through powerful parties, e.g. the owner. However, the exact design of the system – including both the incentive for high-quality data and the financing of the system – was seen as not straightforward and a major future challenge for adoption.

Overall, the participants perceive the system in two different ways. Some see the system as a project-specific implementation. Others considered it a market-wide system. This is surprising because the research initially targeted a data management system for a construction project. However, a market-wide integration would affect the tendering process and ultimately lead to a market protocol on which competitive offers for construction projects can be automatically managed in a transparent way. This could be done based on the reputation system where reputation can be derived from past data saved on the blockchain. Market-wide consequences of incentive systems might need to be considered in future research.

Furthermore, the need for privacy of sensitive information becomes apparent (especially from the viewpoint of suppliers and contractors). This creates potential issues with data visibility and privacy on public blockchain systems.

The owner was considered to be the stakeholder to benefit most from such a solution. Potential benefits include the higher data quality for the operation, more transparency for data and process analysis, fewer disputes, simplified contract signing (transaction signatures), more competition in tendering leading to better prices, price transparency, and subjective selection criteria for choice of contractor (in case of a reputation system).

Finally, it was challenging to identify if the perceived advantages by the workgroup stem really from the blockchain-based (incentive) system, or the more structured documentation process in general. There is need for future work to identify what can be achieved with conventional data structures and technologies, but better data management – and what can be achieved only with a fully-implemented cryptoeconomic system design for complete data sets.

5 Discussion

Since blockchain-based incentive systems for construction projects is a new concept, there is potential and challenges alike. The following sections discuss the limitations in this paper and point to future research work for improvement.

5.1.1 Use Case

The considered use case focuses on the DBB construction process in Switzerland with only a very limited amount of stakeholders. This should be extended and generalized for future implementation.

Also, a better differentiation between construction elements should be considered. Typical unfinished products and elements that need to be completed on site involve more stakeholders. In contrast, finished and prefabricated products could be ordered directly from the supplier. All these different possibilities would need to be captured. The process was conceptually developed for all four elements of the demonstrator, but it turned out that the project steps are largely identical for the different elements. They might differ though in the amount of needed suppliers to provide the products. For a use case of supply chain traceability, this would be important. But for the investigated use case of incentivizing data sets, the amount of suppliers is conceptually not further relevant to showcase the functionality. Having said that, this could change for scalability of the solution later on.

Finally, the implemented information flow, data categories, and high-quality data attributes are based on the workshop discussions. There should be more investigation on each aspect on the state of the art. Therefore, the chosen structure (based on COBie in the technical case) should be seen as a starting point to identify important information attributes, not as a final recommendation. Furthermore, the data categories might need to be extended. One example could be a definition of the required material information to track and implement a circular economy for building elements.

5.1.2 Blockchain Prototype

The main point of the prototype was to investigate if and how such a system could be implemented with the available tools. The implemented logic and functions will need to be refined.

In the future, investigations should target how to create the user interfaces (e.g. web based front end application) to conveniently interact with the system. Also, the smart contracts would need to be optimized to better capture ownership properties, optimize gas consumption (i.e. cost for computation on-chain) to save on costs, allow for updatability of the contract, and comply with the latest coding best practice for security reasons.

All the data is currently saved on-chain, which is known to be very expensive and potentially creates issues with storage size down the road. A future solution could store part of the data off-chain with notarization on the blockchain. While this would allow to check whether data is changed, data would still need to be fetched off-chain. This complicates the use of smart contracts and is sometimes referred to as the "oracle-problem."

A public permissionless system (Ethereum) is used because the system is intended to exist thoughout the long life cycle of the facility. The Ethereum network incentives contributors to maintain it independently of who uses the network. This avoids efforts required to run a private network server infrastructure over such long time durations. However, there are many possible DLT design options available [10]. A more detailed investigation on the best suitable system should be part of future research. This should be also aligned with current construction and BIM software.

Finally, there are still challenges related to privacy protection of on-chain data (especially in public blockchains) and how to deal in general with the very strict nature of smart contracts in the context of processes that require some flexibility.

5.1.3 Incentive System

This paper introduces an initial incentive system concept. While the imagined incentive mechanism seems promising to motivate stakeholders to provide correct data drops, there is need for future research to study different and specific incentive systems for the introduced purpose based on financial, reputation, or other possible tokenized reward structures. As a starting point, a better understanding of each stakeholder's position and motivation in the system is important. It is also possible that there needs to be specific roles associated with the incentive system, e.g. the mentioned data verifiers. More investigation is needed on how to properly reward stakeholders for their work.

6 Conclusion

The paper proposes an innovative way to incentivize high-quality data sets in construction through blockchain based process management linked to reward systems. It makes use of blockchain to combine technological aspects of data management with personal and organizational aspects to share data in the first place.

The prototype demonstrates how such a solution can be built, as well as technical challenges that still remain. The most important include scalability, on-chain data storage, privacy of sensitive data in public systems, and the coding of smart contracts to remain somewhat adaptable to different construction processes.

The main area of future research is related to the design of possible incentive systems. Many combinations exists that should be assessed and validated. Furthermore, implications to the construction process and markets should be investigated. There could be consequences of beyond one construction project on general market forces and project delivery practices.

Also, the proposed system would benefit from a more detailed analysis on the effect of different parts of the proposed blockchain implementation on high-quality data sets. A blockchain based process without any tokenized incentive system might already benefit the structure and completeness aspects of data sets with data transparency and automation through smart contracts. Having said that, this alone might be also achievable through conventional IT solutions. The need for blockchain in this case should be carefully assessed.

The proposed incentive system has the potential to improve data correctness and completeness at the conclusion of a construction project. The use of such tokenized incentive systems would be a strong argument to use blockchain as a technological tool, since its real strength applies to (semi/automatic) value transactions in an environment with low trust.

Overall, blockchain-based incentive systems show promise to align construction stakeholders. This study intended to showcase this with a concrete example on how blockchain and smart contracts can enable a trustworthy track-record of data drops, automation of information flow related activities, as well as a token-based incentive for participants in the construction process to share high quality data sets.

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