A BLOCKCHAIN APPROACH TO SUPPLY CHAIN MANAGEMENT IN A BIM-ENABLED ENVIRONMENT

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Abstract. The blockchain is a distributed ledger managed by a peer to peer network that stores all transaction records. The distributed ledger technology offers new possibilities, promising to ensure that data is secure, decentralized and incomparable. In the Architecture, Engineering, Construction (AEC) industry, Building Information Modeling (BIM) has quickly become a standard platform where all parties work together on a single and shared model for collaboration. The issues of Supply Chain Management (SCM) within BIM can be identified in BIM maturity level, based on PAS1193 that developed through Common Data Environment (CDE). The research strategy is to make model and simulation of SCM using BIM and create CDE to become decentralized and integrate the blockchain technology. The smart contract system validates every material and configuration of components within the model from the design stage until the operation stage. Traceability and auditability through an immutable historic eventually be more visible and allow real-time tracking of a material to a construction site providing a history from the origin.

Keywords. Blockchain; BIM; Supply Chain.

1. INTRODUCTION

In more recent times, blockchain applications have appeared to go far beyond their first application domains in virtual currencies, for instance, they are now important in fields such as domain registration, crowdfunding, prediction markets, and even gambling. (Peters & Panayi, 2016) In order to truly appreciate the complex technology known as blockchain and the impact it will have, one requires some understanding of various topics such as decentralization, consensus mechanisms, incentives, encryption, peer-to-peer systems, network effects, and economics, all of which this report covers. (Kinnaird & Geipel, 2017). The development of blockchain is currently a promising concern in future technological developments. The Blockchain continues to develop after being discovered by Satoshi Nakamoto in 2008 to serve as a public transaction ledger from bitcoin cryptocurrency. The blockchain is currently entering a wave of massive research, providing several high-profile proofs-of-concept (PoCs)

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and applied programs in various industries. Identification and valid analysis of blockchain ecosystems and application scenarios impose a prevailing issue for practitioners and researchers. (Glaser, 2017) The scope of research and development is strengthened and the extent of the industry that explores expanded blockchain. According to Ashley Lannquist from WEF Blockchain team at Berkeley, the financial sector has historically led research and development on blockchain investment, with implementation projects starting in 2015 or earlier, 2017 seeing more activities from retail, shipping, telecommunications, aviation, automobiles, and several other industries. In this paper, the author explains how blockchain can be applied to Supply Chain Management (SCM) by adopting Building Information Modeling (BIM) in supporting the activities of architecture, Engineering, Construction (AEC) industries. There are 3 things that are briefly presented, namely : (1). Blockchain (Smart Contract, Decentralised Application); (2).BIM (BIMmodel, BIM Level2); (3) Supply Chain Management (Input-Output, Actor, Delivery Product). The role of the blockchain in SCM-BIM activity leads to the development and improvement of coordination, integration, and products in the activities of AEC industries.

2. BACKGROUND

2.1. BLOCKCHAIN TECHNOLOGY IMPROVING THE SUPPLY CHAIN MANAGEMENT IN AEC

A supply chain encompasses all of the activities that go into the delivery of goods or services, beginning at the earliest stage of creation and ending at the final stage of destruction or extinction. They can also vary significantly in terms of length (i.e. the number of tiers across the supply chain) and depth (i.e. the number of suppliers or customers within each tier), depending on the good or service in question. The complexity of a generic supply chain network is illustrated in Figure 1.

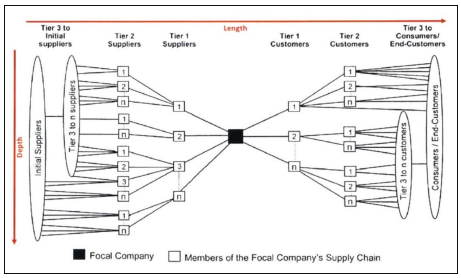

Figure 1. The Complexity of Generic Supply Chain Network (Law, 2017).

Again, recently the construction industry has been specifically challenged to reduce construction costs for government contracts by 15-20% by 2015, from the baseline of 2012(CabinetOffice, 2011). Globalization, diverse regulatory policies, and varied cultural and human behavior in supply chain networks make it almost impossible to evaluate information and manage risk in this intricate network (Sarpong 2014; Ivanov, Dolgui, and Sokolov 2018).

According to ARUP's book series, Blockchain technology could solve these issues in a number of ways: (1.) Increasing the speed and scale of decision making and procurement processes. (2.) Providing consistent reporting for subcontractors, contractors, and owners. (3.) Providing objective data on the best people for a job. Some of the methods explain the blockchain that supports Supply Chain is able to build a certainty in perfecting digital contracts safely and surely with supporting features (digital signature, timestamp).

2.2. HOW WILL SMART CONTRACT SUPPORT SUPPLY CHAIN

Blockchain enables the creation of smart contracts, with terms and conditions both sides can specify and that assure trust in the enforceability of the contract and the identity of the counterparty. Contracts must be written to ensure fairness even when counterparties may attempt to cheat in arbitrary ways that maximize their economic gains. (Delmolino et al. 2016) Smart contract execution can be compared to atomic transactions, i.e., the transition from the current database state to the next database state by changing data. (Glaser, 2017)

This system of distributed trust allows for lower transaction costs in the short term, but this is just the beginning. In the long run, it will enable more agile value chains, closer cooperation with business partners and faster integration with the Internet of Things (IoT), among other things. Also present in the system are numerous IoT devices (e.g., sensors and actuators), which are connected to the P2P network via the IoT gateways (Zhang et al., 2018). By using smart contracts to handle the multiple exchanges between parties, blockchain technology can reduce complexity and allow for greater transparency and trustless verification across the supply chain. This will help to speed up the supply chain, make it more agile, and foster stronger relationships among partners. Smart contracts can improve SCM in three key ways: transparency, traceability, and efficiency.

The most recent and innovative approach in that regard is Etherum platform, which includes a Turing-complete programming framework aiming to realize smart contracts. (English, Auer, & Domingue, 2016) Smart contracts are written and executed as computer code linked to a digital currency such as bitcoin or ether (the Ethereum blockchain's native currency) as the payment or the representation of an asset. (Kinnaird & Geipel, 2017). Smart contracts as special protocols can contribute to verifying or implementing negotiations or contract performance. In the context of blockchain and cryptocurrency, smart contracts are pre-written logic that is stored and replicated on a distributed storage platform such as a blockchain run by computer networks and can also produce ledger updates. Therefore, if blockchains provide reliable, distributed storage, it is very possible that smart contracts give us reliable, distributed calculations.

2.3. BIM AND SUPPLY CHAIN MANAGEMENT (SCM)

Building Information Modeling (BIM) is a technology-driven approach that offers benefits to both products and processes of AEC, by collecting and representing building project information and hence supporting information sharing. (Papadonikolaki et al., 2015). Inter-disciplinary collaborations within

the AEC industry have revolved around the exchange of 2D-drawings and documents for a long time (Thomassen, 2011). Nowadays, BIM adoption and SCM are only conceptually combined. Although there are reports on changing dynamics in the roles of the stakeholders induced by BIM (Arayici et al, 2011; Sebastian, 2011), only a few include organizational aspects of integration through SCM in AEC (Vrijhoef, 2011). The combination of BIM-based technologies and SCM practices have been studied as an opportunity for the remaining and persistent AEC challenges pertinent to inefficiencies, poor coordination, information redundancies, and waste. (Papadonikolaki et al., 2016)

More broadly, Supply Chain Management activities integrated with BIM are a form of collaboration from digital information exchange management within the scope of AEC industries, prior to the development phase. This is specifically indicated in the PAS1192 document. PAS 1192, which provides specific information management requirements associated with projects delivered using BIM. Furthermore, and for the avoidance of doubt, all project information, whether in conventional data formats or single collaborative data environments (CDE).(PAS, 2013) . PAS 1192 specifies the requirements for achieving building information modeling (BIM) Level 2 during the capital/delivery phase of projects. It builds on the existing code of practice for the collaborative production of architectural, engineering and construction information, defined by BS 1192:2007.

The Common Data Environment (CDE) is defined as a common digital project space, which provides well-defined access areas for the project stakeholders combined with clear status definitions and a robust workflow description for sharing and approval processes. (Preidel, Borrmann, Oberender, & Tretheway, 2017) Furthermore, the CDE leads to a higher rate of reusability of information, simplifies the aggregation of model information and simultaneously serves as a central archive for documentation. (Preidel et al., 2017) This setup of a CDE can depend on a variety of ways affected by the application, project volume and participated parties. Nevertheless, a more detailed implementation of such a CDE shall be presented exemplarily. In general, the architecture of a CDE can be described as a layered structure. (Preidel et al., 2017) (see Figure 2)

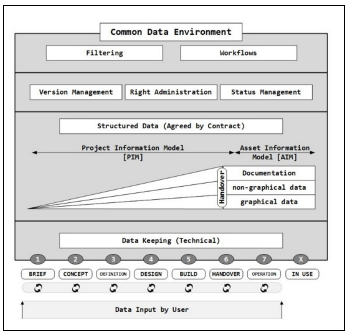

Figure 2. Layer model of a Common Data Environment, inspired by British Standard Institution (Preidel et al., 2017).

3. METHODS

The methodology used in representing Supply Chain Management in BIM activities, with the Blockchain approach, is to build models and simulations. The model that is built is a form or concept of the relationship of the system in SCM, with various scenario concepts. Then the results of the concept are simulated in the implementation chapter.

3.1. BUILD CONCEPT FOR SUPPLYING BIM MODEL TO CDE

The BIM supply chain contains important information from all data supply processes in the form of digital information represented in graphical, non-graphic and documentation data. In this chapter, the authors build a simulation, how to bring the BIM3D model (Supply properties, Material of elements information, and Material Properties) as digital data into CDE. Information for each of these components has a list of milestones and time slots scheduled by planners to ensure that the materials needed for operations will be on site before the start of operations. (see Figure 3)

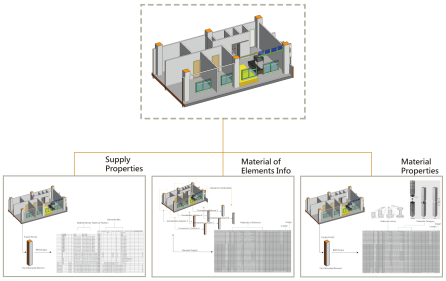

Figure 3. The example of BIM product's type (Author, 2018).

At Figure 4(a), it is shown that the BIM product to be delivered to CDE starts from BIM3D, where data information is taken in the form of 3D models, Material Properties, Cost Properties, Material Properties, and CoBIe Data. The development of BIM data is related to the SCM system built in CDE, which is divided into 3 main platforms, namely: (1). BIM's Platform, (2). Opera's Platform and (3). Information Exchange's Platform.**BIM's Platform** is a space for storing databases from BIM products that have developed decentralized storage systems through Blockchain Technology. Data stored in the BIM Platform is digital data related to PIM, AIM in the form of graphical, non-graphical and documentary data (see explanation in chapter 2.3.) **Operation's Platform** is part of CDE to support integrated BIM Data with products that have been realized post - procurement in the real world with IoT system support, using sensors, RFID and GPS. As an example in Figure 3, how can RFID inform the supply of material according to the material properties in the model that has been distributed in the CDE? **Information Exchange Platform** is a system built on CDE that is supported by the Application Programming Interface (API), as a gateway for information and

transaction exchange by clients or customers registered on CDE.

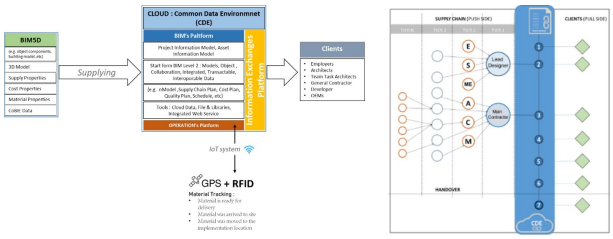

Figure 4. (a) Proposed Concept for Supplying BIM Product into CDE (b) Organisational Model BIM-SCM within CDE (Author, 2018).

The author provides an alternative organizational model in the BIM product distribution process in CDE. This concept is a development of the Supply Chain Organization in the PAS1192-2: 2013 document, in explaining how the implementation of product delivery and information exchange on BIM products in CDE. This model (Figure 4(b)) describes the process of assessment and validation in supply delivery through Tier 1, Tier 2, Tier 3, and Tier n. Tier as a gateway, where Tier 1 parties are the controllers and decision makers of CDE, to validate and assess that BIM products are eligible to be on a CDE system. The number of layers affects the number of suppliers involved in the supply chain process here. And the number of suppliers affects the number of members from each Tier.

3.2. CONCEPT BLOCKCHAIN TO BIM-SCM

3.2.1. Building Smart Contract for Supply Chain Management (SCM) of BIM

Angwei Law stated that there are 3 challenges to using Smart contracts in supply chain management activities, namely determining the provenance of goods, tracking the progress of goods to the supply chain, and building trust through an open database of supply chains partners, including their reputation. (Law, 2017) These three things form the basis for developing smart contracts to support supply chain management at BIM.**Smart Contract for Provenance**: Each supply chain runs on a blockchain, where each SCM actor is connected to access certain functions, especially in the case of provenance validation. From Figure 5(a), it is explained that suppliers of BIM products or can be called producers, manage records of their properties and are distributed through the Blockchain. This system builds trust that is effective and efficient in verifying the products it produces.

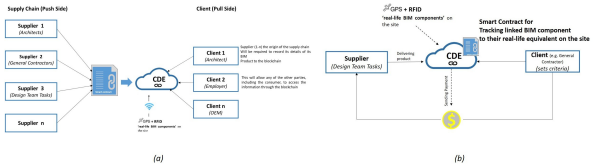

Figure 5. (a) Concept of Smart Contract for Provenance (b) Concept of In the Tracking phase the BIM-Product to the real-life product on site (author, 2018).

In the Tracking phase the BIM-Product to the real-life product on site: All transactions in the supply chain are recorded by the parties involved in the transaction, which will then be verified if the delivery has been successful. Products related to data components when in the field integrated with IoT systems, will be verified by sensors. For example, RFID tracking at this time allows for this and can be directly controlled by related companies, whereas, with a blockchain based approach, data is available and publicly distributed. As the tracking concept, can be seen in Figure 5(b), explained that there is a sending of product BIM by Supplier (e.g. Design Team Task) to the client (e.g. General Contractor). Before arriving at the client, Smart Contract verifies the product and ensures that the product is on the site, through IoT systems (sensors, RFID). Then a verified payment is made in CDE, that the payment matches the criteria. **Smart Contract for supply chain reputation**: There is a reputation score when the transaction in the SCM process is successful or unsuccessful. Some product shipments that are successful in the form of goods, quantity, location, and correct time, as a percentage of the total shipments made. Reputation scores can be done by calling a contract and can be repeated or renewed. The CDE database is open publicly, which can be accessed by all parties involved in transactions in a good reputation. (Figure 6)

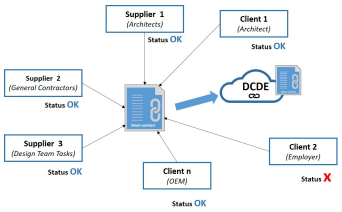

Figure 6. Concept of Supply Chain Reputation (author, 2018).

4. IMPLEMENTATION

Smart Contract implementation in SCM is by demonstrating Proof-of-Concept by using Ethereum which is a Blockchain-based platform with Decentralized Application support. The Smart Contract implementation is written using Solidity IDE, a contract-oriented programming language for implementing smart contracting that runs on Ethereum Virtual Machine (EVM). According to Angwei Law(2017), proof-of-concept demonstrations refer to 3 types of smart contracts,

namely: provenancetracking products and supply chain reputation. Furthermore, this study developed from several resources regarding the use of Remix - Ethereum and then the Functions will be adjusted to the activities of Supply chain management at BIM. (see Figure 7) Building Provenance of BIM Product: In this process use an Oracle-based contract that provides a way to get outside data from any web API onto the blockchain. Then make a simulation to validate Provenance. Starting with input data, namely addBIMProducer, for example, XYZ Consultant and then addBIMproduct, example: door001. In Figure 7, what needs to be known is success information in applying Smart Contract to Provenance, and also displays the hash value of contract address. In this simulation, partner models are built in the SCM process. There are 5 suppliers or producers involved in the transaction.

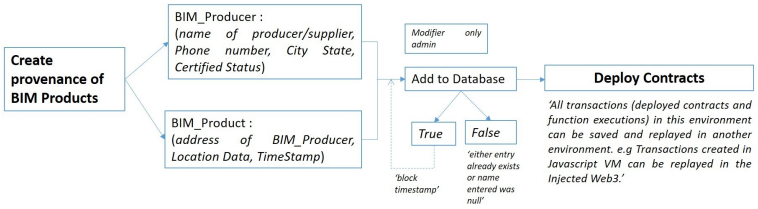

Figure 7. Simulation Create Contract of BIM Product.

In the data input stage, the success of the transaction is executed and the status is informed. This shows that the CDE admin has validated the Producer / Supplier BIM product to enter in the part of the Supply Chain. Furthermore, the data that has been entered will be validated in EVM, as shown in Figure 8, an important point that can be taken from these results is, each transaction always produces a hash value, as a validation hill. And every transaction and function execution has a cost value. (see Figure 8)

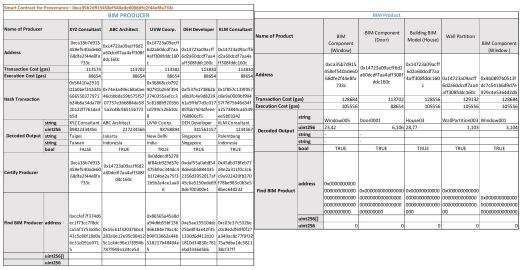

Figure 8. Result of Simulation Smart Contract for Provenance.

Tracking BIM product: These functions will be deployed to represent Smart Contract for tracking product. The Tracking smart Contract allows parties in the supply chain to track the shipment of goods and automatically execute a payment in the form of tokens once every leg of shipment is completed, provided that certain predetermined criteria are met (Law, 2017). To show the validation of the smart contract tracking is done by simulating the shipment from BIMProducer

(as a supplier) to the client. For instance, XYZ Consultants send BIM products (window001). When the product sends out, it is automatically validated by the Blockchain and recorded (see Figure 12). Then proceed with the validation of product shipments arriving at the site, (see Figure 13) and validate payments by including information tokens, payment status, and value of the transaction hashes (see Figure 14).

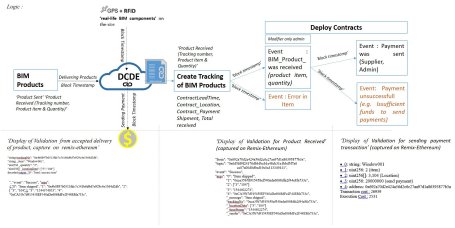

Figure 9. Smart Contract of Tracking BIM-Product (Author 2018).

Building trust of Supply Chain Reputation: After the validation stage on the smart contract tracking, and the payment process, then an assessment of each supplier / BIMproducer is then carried out. This process provides an assessment of suppliers/producers. (see Figure 15) The suitability of items and quantity and predetermined criteria is a determinant in supply chain reputation value.

Smart Contract for Reputation : 0x6431fd0c29d024c5b04c7dab157fccd329e62e55

		BIM PRODUCER				
Name of Producer		**XYZ Consultant**	**ABC Architect**	**UVW Coorp.**	**DEH Developer**	**KLM Consultant**
Address		0xca35b7d915458ef540ade6068dfe2f44e8fa733c	0x14723a09acff6d2a60dcdf7aa4aff308fddc160c	0x14723a09acff6d2a60dcdf7aa4aff308fddc160c	0x14723a09acff6d2a60dcdf7aa4aaff308fddc160c	0x14723a09acff6d2a60dcdf7aa4aff308fddc160c
Transaction Cost (gas)		113574	113702	113382	113830	113830
Execution Cost (gas)		88654	88654	88654	88654	88654
Decoded Output	**string**	XYZ Consultant	ABC Architect	UVW Coorp.	DEH Developer	KLM Consultant
	uint256	89822334456	217234566	98768894	341563157	1234567
	string	Taipei	Jakarta	New Delhi	Singapore	Palembang
	string	Taiwan	Indonesia	India	Singapore	Indonesia
	bool	FALSE	TRUE	TRUE	TRUE	TRUE
Name of Product		BIM Component (Window)	BIM Component (Door)	Building BIM Model (House)	Wall Partition	BIM Component (Window)
Decoded Output	**string**	XYZ Consultant	ABC Architect	UVW Coorp.	DEH Developer	KLM Consultant
	uint256	89822334456	217234566	98768894	341563157	1234567
	string	Taipei	Jakarta	New Delhi	Singapore	Palembang
	string	Taiwan	Indonesia	India	Singapore	Indonesia
	bool	FALSE	TRUE	TRUE	TRUE	TRUE
uint 256 (Reputation Score)		**67**	**80**	**65**	**76**	**80**

Figure 10. Results of Reputation Smart Contract.

5. CONCLUSION

According to PAS 1193 and BSI 2013, supply chain management able to run on the BIM level 2 corridor. This is indicated by supply chain organizations that are configured in layers (Tier-1, Tier-2, Tier -n) to the process of filtering and validating the Supply Chain actors (supplier, clients) in determining the reputation of producers and their products. However, SCM-BIM can be elaborated to BIM level 3, 4, and level-n. The improvements can be conducted by optimizing BIM-products within The asset management of life cycles that supported by collaborative capabilities and interoperable data. In reach organizational of SCM-BIM configuration, the role of the blockchain is quite significant for entire the BIM product supply activity and transaction processes. The Smart

Contract with a proof-of-concept mechanism is able to support the effectiveness of transaction validation without involving a third party. Furthermore, smart contracts are able to provide an assessment for representing the reputation of suppliers/producers and product transactions as well. At the simulation stage, Remix-Ethereum and its environment could exposure the SCM process, quite clearly. EVM that runs on the blockchain platform of SCM-BIM, could represent CDE as Storage. That platform capable be a model for the development of CDE as a cloud of data in the exchange of digital information related to BIM and the environment, which is mutually integrated and must be accessible to all projects supporting for a BIM-based collaboration process.

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