ECPPM 2021 – eWork and eBusiness in Architecture,
Engineering and Construction – Semenov & Scherer (eds)

Digital traceability for planning processes

D. Breitfuss, G. Šibenik & M. Srećković
Institute of Interdisciplinary Building Process Management, TU Wien, Vienna, Austria

ABSTRACT: The increasing complexity of communication and collaboration processes due to the use of building data models and object-based change management, create the need for efficient ways of transparency and traceability within planning processes. The growing presence of BIM (Building Information Modelling) digitalises the AEC industry and produces numerous assets in digital form, but their added value is not completely exploited. Blockchain (BC) and Smart Contracts (SC) might deliver improvement to communication and collaboration in the design phase. Based on a framework for assessing BIM based workflows, processes are analysed according to three sub-categories: project-stakeholder involvement, data-flow and single actions, which form a process-flow. The information gained with the application of this framework, grounded in a use case, is further explored in a conceptual model for SCs in the design phase of a building project. The focus hereby lies on existing processes which can be translated into a SC, and not on the alternation of currently applied workflows. SCs will be used as a tool, for supporting mandatory actions by each project stakeholder and to create a digital reference of changes in a BIM model on a BC.

1 INTRODUCTION

With the increasing application of BIM in the AEC industry, a number of challenges have arisen, hitherto many of them have remained unresolved (Erri Pradeep et al. 2019; Nawari & Ravindran 2019). One of the main challenges in BIM workflows is the traceability of changes within a BIM model and closely coupled with it, the accountability for clearances and the sharing of model information (Coyne & Onabolou 2018). In order to understand BIM-workflows and find possible intersection points with the newly arising technologies Blockchain (BC) and Smart Contracts (SC) within the Architecture, Engineering, Construction (AEC) industry, an extensive exploration of process participants, data exchanges and process-steps is imperative. SC are mainly implemented in financial industries, although recent examples (Fridgen et al. 2018) show an effort in process modelling with SC as well.

In our research project BIMd.sign, we investigate if SCs and BC can be implemented in BIM-based planning and if they can deliver sufficient support as project management tools, and in a further step automatize certain aspects of the planning processes. In this paper we focus on the research question, if process-based SCs could contribute to a BIM-workflow, by enabling traceability and transparency through the entire design phase of a building project. The analysis of a scenario from a use case and the development of a conceptual model which will be presented here, form the base layer for further steps in our research. We argue that SCs could possibly serve as a key element, to enforce certain pre-defined process-sequences, as well as enable a revision-safe database for the enforcement of traceability throughout an entire design phase of a building project.

This paper is organized as follows: In section 2 the state of the art will be presented with the focus on processes in BIM workflows, SC and their application in the AEC industry. Section 3 demonstrates a framework for process analysis and section 4 presents a possible implementation of SC in the planning process followed by a conclusion in section 5.

2 STATE OF THE ART

2.1 *Design phase processes and BIM*

According to Chi et al. (2014) building projects can be mainly divided into three phases: conceptual development, structural detailing and construction. In all of those phases modelling, analyzing and optimizing plays a significant role in the progress of the project. Conceptual development and structural detailing have an extensive impact on the life-cycle cost of a building, due to the importance of delivered design decisions (building as planned). Hence, it is important to mention, that during the construction phase changes in design are significantly more expensive, due to the lack of flexibility and increasing rework (Singh & Ashuri 2019). Thus, creating a better environment for collaboration and cooperation in the design phase is imperative for planning efficiency.

The development of computer aided design (CAD) and later building information modelling (BIM) and

DOI 10.1201/9781003191476-18

3D CAD has greatly contributed to a higher flexibility in modifications and efficiency for planners in the AEC industry. BIM is especially delivering advantages in process efficiency and in collaboration in general. Nowadays, BIM is one of the most widely used planning methods, but its full potential is still not exploited, where compatibility of BIM and organizational culture (Son et al. 2015) are mentioned as some of the reasons for that problem. BIM basically fosters the exchanges of data and information during design, construction and operation of buildings. The innovation to more traditional methods is, that the information is mostly directly linked with model data and can be accurately detailed according to the project phase (Chi et al. 2014).

2.2 *Smart contracts*

Smart Contracts are computer protocols, able to digitally facilitate, verify and enforce contracts between two or more parties (Wang et al. 2019). The term contract in this context is often misleading, as a SC basically enforces an agreement and is not a contract in a legal sense. Literature suggests that SC are either code, which represent legal contracts or act as software agents, which simply fulfill their pre-defined duties (Clack et al. 2016). The latter definition is also the focus of this paper, as a beneficial use of SC is seen in a process-based implementation.

SC were first mentioned in the mid-1990s, but firstly implemented with the BC technology, which offers a decentralized environment to ensure disintermediation of third parties and equality between participants. Transactions which are conducted through a BC are sent directly to the receiver and therefore can't be controlled by a third party (Zheng et al. 2017). Within a BC context, SC can also be seen as computer codes and scripts, which are stored on the BC. SCs are triggered, when they are addressed by transactions and then they execute a pre-defined task (Christidis & Devetsikiotis 2016).

As SC are closely linked to BC technology, they are also profiting from its unique properties. (Wang et al. 2019). A BC is a revision-safe distributed ledger where all transactions are verified through so called consensus mechanisms. These mechanisms serve as a fundamental agreement between all participants, as they are vital to the network (Nguyen & Kim 2018) and creating new blocks. As SCs are stored in the blocks of a BC, they also need to be verified through the consensus mechanism and therefore from each stakeholder who takes part in the verification process. Once stored and deployed on the BC they can't be tampered with, due to the unique "chaining" of the blocks and the distribution of copies over the entire network. Each block references its predecessor with a so-called HASH reference and each HASH reference is the product of all data in the block being hashed (Nawari & Ravindran 2019). If a SC or any other data in the BC is changed, the copy wouldn't be identical to all other copies. Therefore, it is almost impossible to tamper with a BC, if not all copies are changed at the same time.

SC & BC in the AEC industry

Smart Contracts could streamline the potentials of BC to an efficient process progression, by automating certain tasks, saving enormous amounts of time and money and enforcing actions on the BC. According to McNamara & Sepasgozar (2018) a set of predefined rules dictates the progression of a process. If- and Then-conditions which resemble the business agreements can be programmed and embedded in the transaction database and indicate a suitable procedure (Nawari & Ravindran 2019).

SCs are seen to automate performance by monitoring all incoming data and managing it accordingly to pre-set rules to settle the stipulations. This could help to prevent disputes, as possible friction points between participating parties can be avoided upfront by an automated protocolling mechanism enabled by SCs. Additionally, emerging disputes can be resolved easier, due to the tamper-proof records. The records ensure a proof of provenance from the data recorded (Erri Pradeep et al. 2019), which allows to track the author of changes in the context of a BIM model, as they reflect all incoming data to the blockchain and enforce different actions if triggered (McNamara & Sepasgozar 2018).

Furthermore, SC could possibly help with a standardization (Mason & Escott 2018) of processes, which can lead to higher quality in the building design, as well as faster and more efficient process design, due to an easy adaption for each project through modular sets of SCs. The information filtered from a BIM model could help to automatize certain tasks during a project. This automatization requires a step-by-step description (Bore et al. 2019) of each process and possible outcomes to fully use all potentials. An overall automatization is not seen at this point, as there will be a need for human input to start and direct certain processes (Mason 2017).

On the other hand, what is problematic in the context of SC is that, once they are deployed on the BC, it is hard to change them. Wrongly coded SCs could therefore affect entire projects and cause tremendous amounts of damage (Mason 2017). Additionally, frequent changes in workflows are seen to be problematic. Changing a SC after its deployment is difficult and linked with a vast amount of work. A workflow standardization, as mentioned before, might help to build up a SC system easier, but also makes the whole workflow less flexible and more difficult to react to unexpected issues (Fridgen et al. 2018). Therefore, a standardization demands a comprehensive and broad preliminary planning of a project.

3 METHODOLOGY

The methodology used is first based on the review of existing literature on the state-of-the-art application of SC and BIM in the AEC industry (section 2). Further, it is grounded in a conceptual framework (Table 1) that

Table 1. Integration of 3 theories.

Theory	Main idea	Point of our analysis
Design	Prescriptives for design and action	Design workflow
Configuration	Alignment of structure, process, environment	Process modeling Information processing
Task-technology fit	Fit between IT and business processes	BIM, Blockchain, DApps, data exchange & transferability, data formats

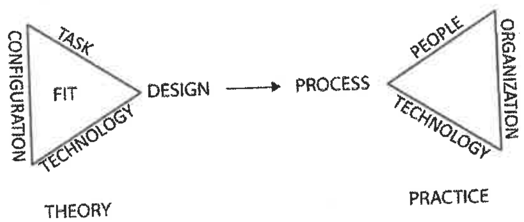

Figure 1. Conceptual framework.

was developed in a previous step in our research project for the analysis of planning processes. And finally, it includes the exploration of a use case scenario for the conceptual model development (section 4).

An implementation of SC and BC in the increasingly complex system of BIM-based planning requires an analysis from different points of view. In order to investigate a BIM workflow during the design phase of a building project, and keep the focus on process modelling, a framework was developed, based on three underlying theories – design, configuration and task-technology fit as presented in Table 1 and Figure 1.

The conceptual framework showed in Figure 1 connects theory and practice. The analysis framework constitutes the connection between people, organization and technology interaction. Hence, the design of a process with a task-technology-configurational fit requires an adaptive interaction of implemented processes (through people), organization (actions and delivery order) and technology (software and data) (Sreckovic et al. 2020).

At first, for the analysis of our processes the information delivery manual (IDM) was considered. IDM is a standard, which *"provides help in getting the full benefit from a BIM"* (ISO 29481-1, 2016). ISO 29481-1, (2016) and ISO 29481-2 (2012) describe a methodology to identify and describe processes within the context of BIM to support use cases by providing the information in a satisfactory quality at the required time. It is another component, which forms a fundamental part of our analysis framework. Nevertheless, for our research purposes, a deviation from IDM was necessary - where the focus is in the detail on the comprehensive procedures of the complete project; whereas our framework connects aspects from a theoretical point of view and a practice point of view, delivering an integrative configurational fit of task-technology-people, embedded in an organizational structure resp. environment. Additionally, the focus in our presented conceptual model development is on smaller and more scaled process-scenarios, which furthermore are the entry points for a SC implementation.

4 CONCEPTUAL MODEL DEVELOPMENT

4.1 *Conceptual framework*

The conceptual framework was used to analyze a scenario from a use case in the design phase of a medium sized-office building. The aim was to explore relevant data and define the interaction of people (project-stakeholders), technology (data-flow and software) and tasks (process-flow) for the creation of a conceptual model of SCs.

To describe this conceptual model, we chose the following scenario as base-layer: the architect makes a necessary change in design to a load-bearing wall. The next step includes a needed verification and clearance from the structural engineer, as the aforementioned change includes a structural element.

Figure 2 shows this process with an implementation of SC. The proposed system is divided into four columns: Action, Blockchain, Database and Smart Contract. The first column describes the actions, which are taking place during this process. The framed actions are additionally indicating a SC implementation. The blockchain hosts the SCs and the model references, the database mainly contains the model data in an exchangeable format.

A SC is basically addressed through two different approaches. Firstly, a manually triggered input is needed. This could be for instance the upload of a new model-version to the system. In this case, the SC is responsible for creating a reference and storing it on the BC. Secondly, a SC could be triggered by another SC. When the beforementioned SC creates the reference, it parallelly can monitor the changes in the model-version.

Due to an object-based file (see 4.2 Data Management), object parameters could be one possible indicator for an automatization, such as the parameter load-bearing indicates a verification from the 2structural engineer, who then will be automatically informed. The project manager in this case, will only be notified of the progress and will not be bothered to intervene.

4.2 *Data management*

Within the scenario that we analyzed, data management in the context of BIM-workflow has been file-based. However, to achieve object-based change

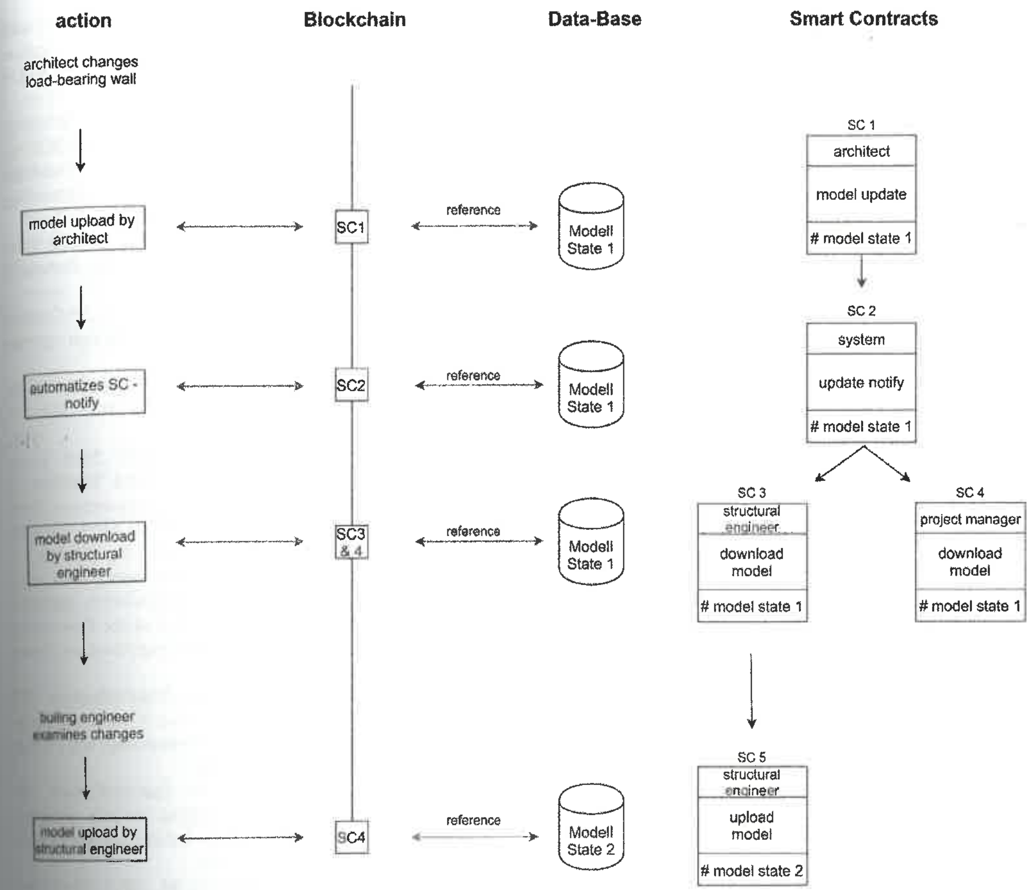

Figure 2. Conceptual model.

management a data-centric approach is required. The potential of data-centric management has not been fully exhausted within the AEC industry (Chassiakos & Sakellaropoulos 2008). In order to provide a suitable data management concept, we reformatted the industry foundation classes (IFC) models to a JSON format. In that way the IFC models can be used on a database such as Mongo DB (Sibenik & Petrinas 2020).

IFC is the most widely used standard to define neutral building models. This format can be used for the file-based data exchange which is still burdened with many problems (Sibenik & Kovacic 2020). Lack of standards, heterogeneous building model representations and slow digitalization makes this task highly complex. As a first step, we use the available IFC models, but the issues as inconsistent building element IDs and non-synchronous link with the database prevent it from being suitable for all data management aspects which are required. The existing solution provides a way to reference a building element from the SC, but it does not fully correspond BIM-based workflows form the technical side. To further improve the data management, the aim is to directly connect proprietary software tools with the central database.

5 DISCUSSION

The conceptual model shows mainly three factors, why BC and SC can be considered to deliver benefits to a BIM process if implemented:

- Documentation: Traditionally, documentation was not an issue, as each document was stamped and in paper version (Singh & Ahsuri 2019), but due to BIM-methods, the exchange rate of data increased drastically, which often leads to data loss, unused information (Erri Pradeep et al. 2019).
- Transparency: Due to the process design conducted through SC, a new level of process integrity can be reached, which is transparent to all project-stakeholders and agreed upon, before the project starts. This could foster and strengthen a new way of trust between the project stakeholders (Li & Kassem 2019).
- Traceability: Documentation and Transparency create the base layer for traceability in the design phases. SC can enable automatized reference-making on a BC and therefore create a revision-safe database. With a BIM element-based system, SCs facilitate the traceability of each change in the

model. Author and date of a change, can be tracked on the BC. The traceability enforces a responsible decision-making process and can help avoid legal disputes upfront, as well as minimize the restraint of using BIM in an interorganizational setting.

6 CONCLUSION

Although BIM has become an important method within the AEC industry, it still faces a lot of challenges. In this paper we introduced a conceptual model for the implementation of SCs in the conventional BIM processes, with the aim to a) enforce a more regulated process-flow, b) create a digital traceability of alterations to an interoperable BIM and c) track changes of actions/decisions made in the planning phases of a building project (BIM as planned) and amendments to design during construction (BIM as built). In conclusion we argue, that the implementation of process based SCs could foster a better environment for BIM based projects, due to a standardization of these processes, which would also deliver benefits in the form of efficiency and speed.

Limitations in this paper are the small amount of analysed processes so far as well as a lack of standardized actions (in the context of a taxonomy necessary for a standardized use of SC in the planning processes). Hence, the identification of intersections between people (project-stakeholders), technology (data-flow and software) and tasks (process-flow) has not yet been fully adjusted to the needed requirements for SC.

In this paper we established the guidelines for the implementation of SC with BIM through the development of a conceptual model. The next steps will include an exploitation of further scenarios and use cases, a standardization of terms for SCs (taxonomy) and the development of a practice-based Proof of Concept within our research project.

ACKNOWLEDGEMENT

The research projects BIMd.sign - BIM digitally signed with blockchain in the design phase, Grant No. 873842 is funded by the Austrian Research Promotion Agency (FFG), Program ICT of the Future and Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT). The authors are grateful for the support.

REFERENCES

Abanda, F. H., Vidalakis, C., Oti, A. H., & Tah, J. H. 2015. A critical analysis of Building Information Modelling systems used in construction projects. *Advances in Engineering Software*, 90, 183–201.

Bore, N., Kinai, A., Mutahi, J., Kaguma, D., Otieno, F., Remy, S. L., & Weldemariam, K. 2019. On Using Blockchain Based Workflows. *Paper presented at the 2019 IEEE International Conference on Blockchain and Cryptocurrency (ICBC).*

Chassiakos, A. P., and Sakellaropoulos, S.P. 2008. A web-based system for managing construction information. *Advances in Engineering Software*, 39, pp. 865–876. doi:10.1016/j.advengsoft.2008.05.006

Chi, H.-L., Wang, X., & Jiao, Y. 2015. BIM-Enabled Structural Design: Impacts and Future Developments in Structural Modelling, Analysis and Optimisation Processes. *Archives of Computational Methods in Engineering*, 22(1), 135–151. doi:10.1007/s11831-014-9127-7

Christidis K, Devetsikiotis M. 2016. Blockchains and Smart Contracts for the Internet of Things. IEEE Access, 4, 2292–2303

Clack, C. D., Bakshi, V. A., & Braine, L. 2016. Smart Contract Templates: essential requirements and design options. *arXiv preprint arXiv*:1612.04496.

Coyne, R., & Onabolu, T. 2018. Blockchain for architects. *Architecture Research Quarterly*, 21(4), 369–374. doi:10.1017/S1359135518000167

Erri Pradeep, A.S., Yiu, T.W. & Amor, R. 2019. Leveraging Blockchain Technology in a BIM Workflow: A Literature Review. *In International Conference on Smart Infrastructure and Construction 2019* (ICSIC). 371–380.

Fridgen, G., Radszuwill, S., Urbach, N., & Utz, L. 2018. Cross-organizational workflow management using blockchain technology-towards applicability, auditability, and automation. *Paper presented at the Proceedings of the 51st Hawaii International Conference on System Sciences.*

ISO, International Organization for Standardization, ISO 29481-1:2016: Building Information Models - Information Delivery Manual - Part 1: Methodology and Format, ISO, Geneva, Switzerland, 2016.

ISO, International Organization for Standardization, ISO 29481-2:2012: Building Information Models - Information Delivery Manual - Part 2: Interaction Framework, ISO, Geneva, Switzerland, 2012.

Li, J., Greenwood, D., & Kassem, M. 2019. Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in Construction*, 102, 288–307. doi:https://doi.org/10.1016/j.autcon.2019.02.005

Mason, J. 2017. Intelligent contracts and the construction industry. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 9(3), 04517012.

Mason, J., & Escott, H. 2018. Smart contracts in construction: views and perceptions of stakeholders. *Paper presented at the Proceedings of FIG Conference*, Istanbul May 2018.

McNamara, A., & Sepasgozar, S. 2018. Barriers and drivers of Intelligent Contract implementation in construction. *Management*, 143, article number 0251-7006.

Nawari, N.O. & Ravindran, S. 2019. Blockchain technology and BIM process: Review and potential applications. *Journal of Information Technology in Construction* 24(12): 209–238.

Nguyen, G.-T., & Kim, K. 2018. A Survey about Consensus Algorithms Used in Blockchain. *Journal of Information processing systems*, 14(1).

Sibenik, G. and Kovacic I. 2020. Assessment of Model-Based Data Exchange between Architectural Design and Structural Analysis. *Journal of Building Engineering* [In press]. https://doi.org/10.1016/j.jobe.2020.101589

Sibenik, G. & Petrinas, V. 2020. *IFCtoJSON* [Software]. htts://zenodo.org/badge/latestdoi/246248514 (accessed 31.7.2020)

Singh, S., & Ashuri, B. 2019. Leveraging Blockchain Technology in AEC Industry during Design Development Phase. *In Computing in Civil Engineering 2019* (pp. 393–401).

Son, H., Lee, S., & Kim, C. 2015. What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions. *Automation in Construction*, 49, 92–99. doi:https://doi.org/10.1016/j.autcon.2014.10.012

Sreckovic, M., Sibenik, G., Breitfuß, D., Kastner, W. & Preindl, T. 2020. Analysis of Design Phase Processes with BIM for Blockchain Implementation. *Available at SSRN 3577529.*

Succar, B. 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357–375. doi:https://doi.org/10.1016/j.autcon.2008.10.003

Wang, S., Ouyang, L., Yuan, Y., Ni, X., Han, X., & Wang, F. 2019. Blockchain-Enabled Smart Contracts: Architecture, Applications, and Future Trends. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 49(11), 2266–2277. doi:10.1109/TSMC.2019.2895123

Zheng Z, Xie S, Dai H, Chen X, Wang H. 2017. An overview of blockchain technology: Architecture, consensus, and future trends.: *IEEE*, 557–564.