Analysis of design phase processes with BIM for blockchain implementation

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ABSTRACT: The increasing digitalization and thus evidently advancing change in the architecture, engineering and construction (AEC) industry, requires new business models, processes and strategies. Blockchain (BC), smart contracts and decentralized applications (DApps) are still underused in AEC. BC and its potential of inclusion into the communication between project stakeholders has shown that it is not just a technology that is ready to use, but requires a thorough insight into the design process of domain-specific stakeholders, their interests and their collaboration workflows for a holistic Building Information Modeling (BIM) and BC-supported solution for the design phase. This paper introduces process modeling of BIM-workflows in the design phase. We propose a conceptual framework for the implementation of a design process with BC based on the integration of three underlying theories: design theory, configuration theory and task-technology fit. The main assumption is, before we can capture processes (1) we need to understand them (design theory) in order to re-engineer them for distributed ledger technologies (DLT) (2) we need to adapt them to changing requirements (configuration theory), and finally (3) continually re-adjust Information Technology (IT) and processes interdependence (task-technology fit).

1 INTRODUCTION

Underlined by recent publications (Erri Pradeep et al. 2019; Nawari & Ravindran 2019; Hunhevicz & Hall 2020) there is great need for empirical research to investigate Building Information Modeling (BIM)-workflows and BIM-models and the requirements they would necessitate in order to be linked and used with distributed ledger technologies (DLT) such as blockchain (BC) and decentralized applications (DApps). It also needs to be explored how BIM-workflows could benefit from the decentralized and trust-independent characteristics of DApps. Hence, due to the presence of these technological advances, which are making their way into the AEC industry, there is a research gap to investigate the implementation of these technologies for building design. It is important to find out their advantages and disadvantages and to test their applicability.

Empirical research of process modeling in the design phase is still lacking as well as best practices of process research or the post hoc evaluation of process modeling in planning; primarily because it is very difficult to get accurate and transparent data concerning workflows in building design, even with the implementation of BIM. However, for the inclusion of DLT (blockchain and smart contracts) into the BIM-workflow, it is necessary to analyze and define generic processes in the design phase suitable for the implementation of these technologies.

We argue that the concept of process analysis and modeling needs an integration of multiple theoretical paradigms in order to meet the research challenges of increasing system complexity in building design. Therefore, in this paper we propose an integrative conceptual framework using three theories: design theory, configuration theory and task-technology fit. The main assumption is, before we can capture a process we need to understand it (design), further in order to re-engineer it for DLT, we need to adapt it to changing requirements (configure) and continually adjust IT and business processes interdependence (task-technology fit). The proposed framework is based on our research within the project BIMd.sign.

This paper is organized as follows: In chapter 2 we develop our research framework based on the three theories, in chapter 3 we present our methodology and use case, followed in chapter 4 by the discussion and conclusion.

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2 CONCEPTUAL ANALYSIS FRAMEWORK

The implementation of digital technologies and increasing system complexity through digitalization necessitate an integration of multiple theoretical paradigms, with different points of analysis. In this paper, we focus on process modeling of BIM-workflows in the design phase and propose a conceptual framework for the analysis of a design process based on BC and DApps grounded in three theories. This novel combination of the underlying theories - design, configuration and task-technology fit – is the basis for our framework (Table 1).

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

Our conceptual framework connects theory and practice (Fig. 1). The point of our analysis is - in order to capture processes it is necessary: (1) to understand how they are designed in the complex domain of people, organization and technology interaction; (2) how they need to be configured for BIM and DLT in human-machine systems; and further (3) how to continuously re-adjust the fit or interdependence between IT and organizational structure.

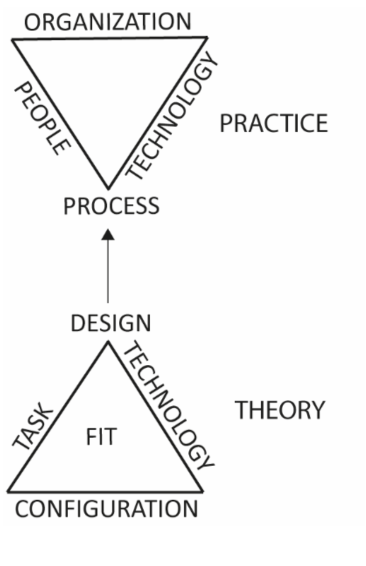

Figure1. Conceptual framework

2.1 *Design*

The design chapter focuses on the workflow analysis using design theory. First the design theory is presented, followed by the application of theory for the analysis of the design workflow in the AEC industry.

2.1.1 *Design theory*

The paradigm of design science is rooted in engineering, architecture and the sciences of the artificial (Simon 1996), and has found its way into the Information Systems (IS) discipline (Walls et al. 1992). Essentially, it is a problem-solving paradigm seeking "to create innovations that define ideas, practices, technical capabilities, and products through which the analysis, design, implementation, management, and use of information systems can be effectively and efficiently accomplished" (Hevner et al. 2004 p.76).

The IS discipline explores the use of information-technology-related artifacts in human-machine systems (Gregor & Hevner 2013) in the complex realm of people, process, organization and technology interaction. The five classes of theory relevant to IS are (Gregor 2006): (1) theory for analyzing, (2) theory for explaining, (3) theory for predicting, (4) theory for explaining and predicting, and (5) theory for design and action. The focus of theory for design and action is on explicit prescriptions *how to design* and develop an artifact, whether it is a process, technological product or a managerial intervention (Simon 1996, Gregor & Jones 2007).

Design theory is considered to be prescriptive knowledge as opposed to descriptive knowledge (Walls et al. 1992) which encompasses the other types of theory in the taxonomy of Gregor (2006). Design theory applies in a certain design context, defined by the nature of the system, its size, the design phase, the type of technology, the type of users or designers (Walls et al. 1992, 2004). Design theory´s scope and purpose is also dependent on environmental requirements such as capabilities and conditions linked to the principles of form and function of the artifact (Spagnoletti et al. 2015).

Hence design research needs to address "wicked-type problems" in planning (Kunz & Rittel 1972, Rittel & Webber 1973) characterized by: (1) unstable requirements and constraints based upon ill-defined environmental contexts, (2) complex interactions among subcomponents of the problem and its solution, (3) inherent flexibility to change design processes as well as design artifacts, (4) a critical dependence upon human cognitive abilities (e.g. creativity) to produce effective solutions and (5) a critical dependence upon human social abilities (e.g. teamwork) to produce effective solutions.

2.1.2 *Design workflow*

Under the term workflow, one can refer to a business process, specification of a process, software that implements and automates a process, or a software that supports the coordination and collaboration of people that implement a process (Georgakopoulos et al. 1995).

Design is both a product and a process and thus design theory must include both aspects (Walls et al. 1992), meaning i.e. the design workflow and the building model itself. The design process is a sequence of expert activities that produce an innovative product (i.e. the design artifact or building model) (Hevner et al. 2004) in the course of designing, planning an action in advance or during the action (including reflection in action) (van Aken 2004). The evaluation of the artifact (process, building model) then provides feedback information and a better understanding of the problem in order to improve both the quality of the product and the design. This build-and-evaluate loop is typically iterated a number of times before the final design artifact is generated (Hevner et al. 2004), meaning rework and iteration is an essential part of the design phase.

For the purpose of our research, we define design workflow as the flow of information, deliverables, specifications, and other design resources between the project stakeholders (Hattab & Hamzeh 2016)*, which are included in numerous processes in the building design phase (e.g. information process, data management process, BIM workflow)*. In practice, these processes are not linear or rigid, but rather dynamic and very complex. Hence, workflow is more than a technique to model a process. It is a method to analyze and improve a process, including its modeling.

2.2 *Configuration*

The configuration theory is used to introduce organizational peculiarities of building construction workflows as well as other artifacts relevant for the design phase. First, the configuration theory is presented; it is followed by the resulting process modeling concept proposed for the building design phase.

2.2.1 *Configuration Theory*

"Configuration refers to any form of organization that is consistent and highly integrated and where all pieces fit neatly together…there is internal consistency, synergy among processes, fit with the external context." (Mintzberg 1991 p.54). This configuration ('gestalt', 'archetype', 'generic type') (Miller 1986) or observable characteristics or behaviors which appear to lead to a particular performance outcome (success or failure) (Ward et al. 1996) of an organization, are interrelated. The coalignment or fit of multiple variables and organizational elements such as alignment of strategy, systems, or processes, is reflected in observable patterns in practice (Flynn et al. 2010). This means that the design and structure of an organization and its business processes should match or fit characteristics of certain variables both inside and outside the organizational system (Tushman & Nadler 1978) or in the case of AEC, the system of project-based organization.

According to Tushman & Nadler (1978 p.634), "organizations are information processing systems facing external and internal sources of uncertainty". As systems, their organizational structure should create and enable the most appropriate configuration of work units (as well the linkages between these units) to facilitate the effective collection, processing and distribution of information (i.e. plans, work standards, budgets, feedback on performance etc.).

Information processing is an essential feature of design workflows. Designers use information as raw material (Tribelsky & Sacks 2011), where further processing and flow of accurate and timely information enables an efficient and successful project performance (Erri Pradeep et al. 2019). This conjectures a need to explore current patterns of information processing in the design and BIM-workflow, as well as the interdependence between project stakeholders and organizational structure. Furthermore, it necessitates a configurational fit between process models and information processing requirements, especially for the implementation of DLT.

2.2.2 *Process modeling*

Process modeling is a way of capturing the operations of organizations in real-world domains (Recker 2009). It is widely used within organizations as a method to increase awareness and knowledge of business processes, and to deconstruct organizational complexity (Bandara et al. 2005). It is an approach for describing how businesses conduct their operations and typically includes graphical depictions of at least the activities, events/states, and control flow logic that constitute a business process (Curtis et al. 1992, Davenport 2005). Process models may also include, among other things, information regarding the involved data, organizational/IT resources, and potentially other artifacts such as external stakeholders and performance metrics (Scheer 2000).

From an IS perspective, information processes relate to automated tasks (i.e., tasks performed by programs) and partially automated tasks (i.e., tasks performed by humans interacting with computers) that create, process, manage, and provide information. Database, transaction processing, and distributed systems technologies provide the basic infrastructure for supporting information processes (Georgakopoulos et al. 1995). Information processes are rooted in an organization's structure and/or the existing environment of information systems, which corresponds to the before presented configurational approach, where organizations are viewed as information processing mechanisms and their organizational structure should reflect that.

Processes are relationships between inputs and outputs, where inputs are transformed into outputs using a series of activities or tasks which add value to the inputs (Aguilar-Savén 2004 p.140). One or more software systems, one or a team of humans, or a combination of these can perform a task.

Human tasks include interacting with computers closely (e.g., providing input commands) or loosely (e.g. using computers only to indicate task progress). Examples of tasks include updating a file or database, generating a blueprint. In addition to a collection of tasks, a workflow defines the order of task invocation or condition(s) under which tasks must be actuated, task synchronization, and information flow (Georgakopoulos et al. 1995). Task complexity and interdependence are sources of uncertainty. Depending on their degree of interdependence or degree of complexity, their information processing requirements can be minimal or very demanding.

2.3 *Technology*

Finally, the task technology fit theory is used to relate the process models with their practical implementation. Therefore, the theory itself is presented as well as core technologies: BIM, BC and DApp.

2.3.1 *Task Technology Fit (TTF)*

Task-technology fit (TTF) is the degree to which a technology supports the performance of tasks, where task requirements, individual abilities and the functionality of technology are in accordance (Goodhue & Thompson 1995). In the context of TTF theory, technology has to match business processes (Karim et al. 2007), enabling a tight coupling of IT function, business strategy and the organization´s information needs (Strnadl 2006).

IT artifacts extend the boundaries of human problem solving and organizational capabilities by providing intellectual as well as computational tools (Hevner et al. p.76). IT artifacts are broadly defined as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems) (Hevner et al. 2004). Many IT artifacts have some degree of abstraction but can be readily converted to a material existence; for example, an algorithm converted to operational software (Gregor & Hevner 2013).

In this paper, we use the term *artifact to refer to a thing that has, or can be transformed into, a material existence as an artificially made object (e.g., model, instantiation) or process (e.g., method, software)* (Goldkuhl 2002 p. 5, Gregor & Hevner 2013).

2.3.2 *BIM*

In the last decades Information and Communication Technology (ICT) has been widely used as a facilitator of AEC collaboration (Lee and Jeong 2012), with the implementation of BIM - a modeling technology (Eastman et al. 2008) respectively a joint digital knowledge domain supporting activities of all stakeholders in AEC; based on various data models with geometrical and/or non-geometrical information; allowing data generation, exchange and processing within the life cycle of built structures (Sibenik & Kovacic 2019). Nevertheless, successful implementation of evolving digital technologies, such as BIM, and furthermore the generation of innovation processes in the digital economy require changes in traditional organizational processes, a dynamic strategic fit and the development of adequate organizational capabilities for competitive advantage.

2.3.3 *Blockchain and Decentralized Applications (DApps)*

The literature review of blockchain and its potential of inclusion into model-based communication (Erri Pradeep et al. 2019, Nawari & Ravindran 2019) has shown that it is not just a technology that is ready to be used, but requires a thorough insight into the design process of domain-specific stakeholders, their interests and their collaboration workflows in order to find a holistic BIM-BC-supported solution for the design phase.

In an industry in which collaboration is based on expert knowledge and a high degree of trust, the potential of DApps should be examined, as these could enable innovative forms of collaboration between project members and teams in segments of the value chain. They would be expressed automatically (running on a BC network), especially if this could save costs and time for administrative work, reporting, control, monitoring of responsibilities and risk transfer. For this purpose, it is also necessary to examine the role of intermediaries and to understand them better, and what added value they create at what cost for the project and the design process, respectively.

Potentials of making BIM processes and design procedures in building-design more transparent, traceable, more consistent, more efficient, more cost-effective and cheaper with BC and DApps remain unused so far. The implementation of these technologies would also result in the possibility of real-time communication in the model and compliance checking.

In general, BC and DApp technologies make it possible to determine a consensus on the current state of a workflow in a decentralized fashion. The state of the individual BIM artefacts (model) could be fixed with links in the BC that uniquely reference the artefacts content at every step of the BIM-workflow. Additionally, any new version of such an artefact could reference the previous one, which creates a distinct trace of the workflow progress. Such a clear history of the design process would make it possible to determine the responsibilities for individual steps retrospectively. Smart contracts included in such a DApp offer possibilities to determine the roles during the workflow and pass responsibility for the next step as well or approve the completed steps. The potential benefits could however be much greater than these examples.

3 DESIGN PHASE PROCESSES WITH BIM FOR BLOCKCHAIN

In our research project BIMd.sign (BIM digitally signed with blockchain) we are analyzing the design workflow from the initial information search to execution design (phases according to the HOAI) in the design phase. Empirical research on process modeling in the design phase is missing, as well as research on the implementation possibilities of BIM with DLT in building design. In our project, we aim at closing this gap. Therefore, the main premise of our research is to first analyze stakeholders, processes and data flow in the design workflow and next propose a conceptual framework for the analysis of process modeling for BC, smart contracts and DApps. A further step includes proposing a conceptual process model for BC implementation. The exploration is grounded in our conceptual analysis framework integrating three theories – design, configuration and task-technology-fit. The point of departure is - in order to capture processes it is necessary, first to understand how they are designed, second how they need to be configured for BIM and DLT and third, how to continuously adjust the fit between these technologies and business processes. Concisely said, in this research step, we are exploring the system interdependence between processes, stakeholders (people) and data flow in the design phase, based on our presented conceptual framework.

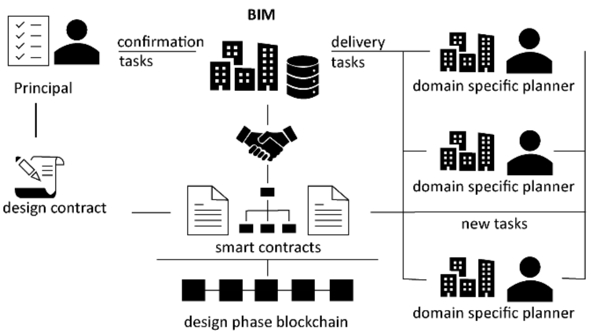

Figure 2. Interaction of stakeholders, BIM and smart contracts

Figure 2 shows the general setup of the proposed concept for BIM and DLT integrating four elements: stakeholders/blockchain actors, BIM model, blockchain, smart contracts/DApps.

3.1 *Use case*

The selected case study is based on an Austrian architecture company offering general planning services in the design phase (Fig. 3). The General Planner (GP) is the lead consultant and appoints all the domain-specific planners, in disciplines i.e. architecture, structural engineering, building services engineering, building physics, fire protection engineering and landscape design The GP delivers all the usual specialist services required for a project, is a single contractual partner for design and engineering and therefore takes on overall responsibility in the design phase. Predominantly, the architect assumes the role of the GP and appoints sub-planners to undertake work in the other disciplines for which they have signed a contract. The GP undertakes a range of coordination tasks, as well as managing and coordinating his specialist design consultants' works. He carries responsibility for all of the services assigned to them, particularly in respect to design, program and costs. The GP is free to choose own subconsultants, and is therefore able to influence the quality of the overall project design. The principal has thus only one contractual design partner. The GP assumes responsibility and liability for the individual design services, and provides the principal with a guarantee that the individual design services, including all interfaces, are correct. The GP owes the principal a model as planned and contractually agreed.

In Figure 4 we can see the configuration of the workflow in the design phase, including information processing of data (data-flow) and coordination of tasks and activities between the different project stakeholders (process flow). Each step in the process flow has stakeholders responsible for their own domain-specific tasks and the appropriate fulfillment of those. As mentioned, the GP is coordinating and organizing the timing of the tasks and is acting as the interface between the principal and the domain-specific planners.

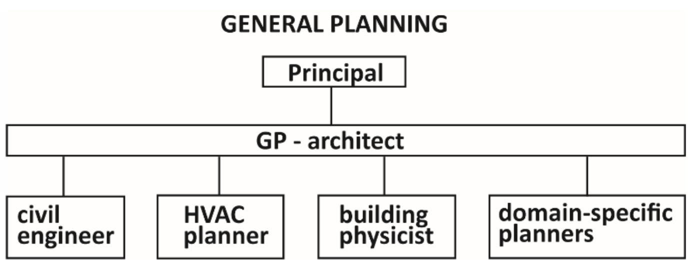

Figure 3. General planner procurement model

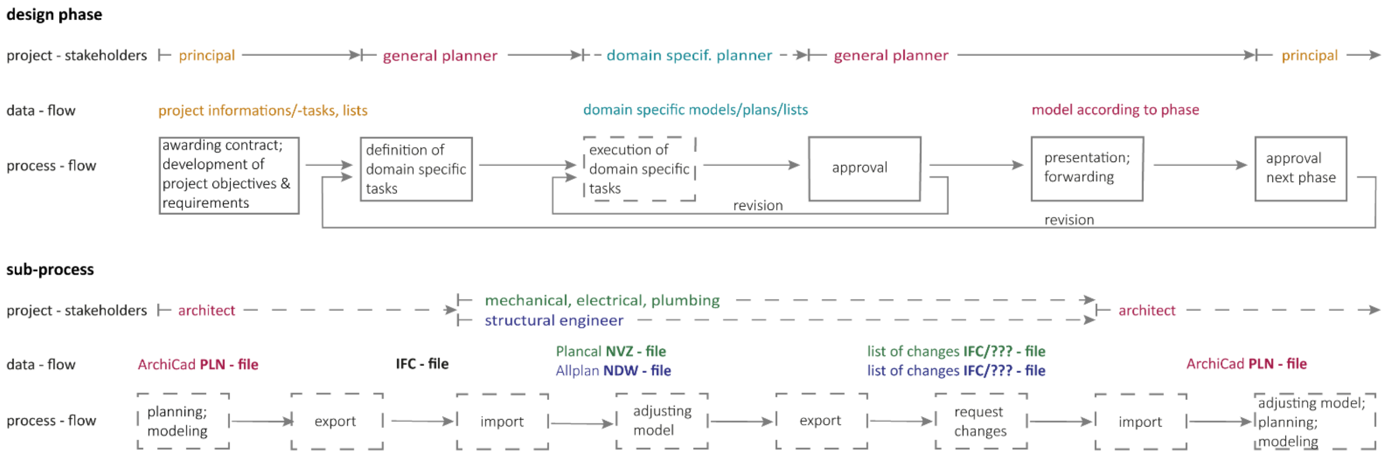

Figure 4. Workflow & sub-processes in the design phase

At the end of each process in the design phase, the GP presents the results to the principal, who either approves to move forward or requires changes, which end in iteration loops until the revision is approved. The sub-process "execution of domain-specific tasks" reflects the data exchange between the different stakeholders during a design task showing the complexity and interrelatedeness in the information processing of different data-formats.

Figure 5 shows a conceptual process model for BC implementation. Due to the data stored in the blockchain, the smart contract monitors the status of progress as well as gives permission of further processing the data, if certain requirements are met. A simplified example would be an architect, who develops a conceptual design and forwards it to the structural engineer, who is responsible to check its functionality. If not approved, a list of required changes is transferred back to the architect, who will adapt the design and again send the model back to the structural engineer. If approved by the structural engineer, the architect then authorizes further steps. In this case, the smart contract would be able to track the changes and responsibilities of the involved parties, as well as give clearance for further steps, when all approvals are met. This means that individual BIM artefacts (e.g. model, drawing) could be fixed with links in the BC that uniquely reference the artefacts content at every step of the BIM-workflow. In addition any new version of the BIM Model could reference the previous one, which creates a distinct trace of the workflow progress.

4 DISCUSSION AND CONCLUSION

In this paper, we introduced a conceptual framework for the analysis and process modeling of BIM-workflows in the design phase. We argue that for the inclusion of DLT (blockchain and smart contracts) into the BIM-workflow it is necessary to understand and capture the entire design workflow (encompassing numerous processes/stakeholders/data formats). In conclusion, this means: (1) to understand how processes are designed and who the participating stakeholders are (2) how processes need to be configured and aligned for the implementation of these technologies and finally (3) how IT needs to be

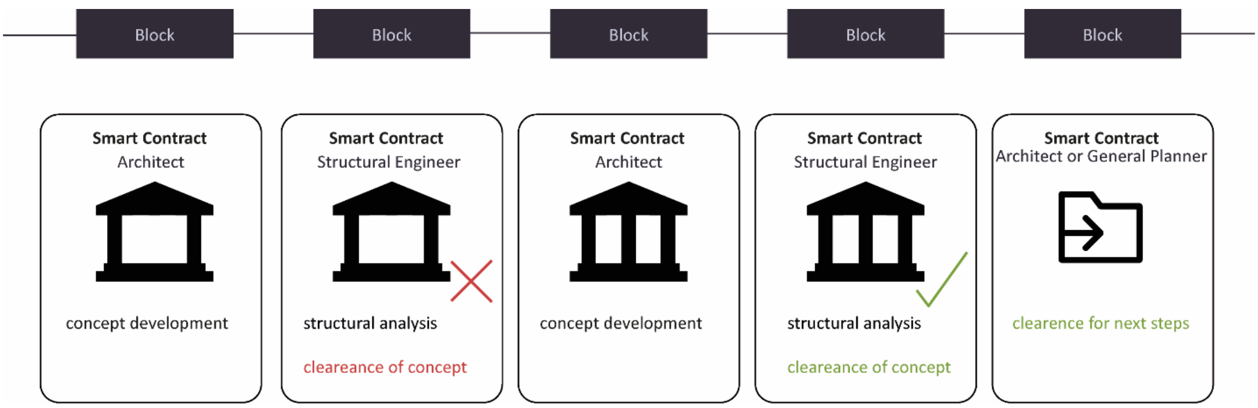

Figure 5. Blockchain schema in the design phase

continuously adjusted to fit the organizational structure and processes in the design value chain.

This work serves as a guideline for the incorporation of BC implementations in the design phase. Further steps in the project will involve a framework development for the design phase processes for which BC shows the greatest potentials for the model-based communication.

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