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MODULAR PROCESS PATTERNS IN THE DESIGN PHASE

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ABSTRACT

Numerous stakeholders contribute to building projects, which mainly deal with digital assets during the design phase. Design workflows are project specific and not standardized, therefore digital tools supporting and improving these are not widely present. However, the activities within the workflows are similar and constitute patterns that allow for workflow standardization. We analyze an existing document exchange platform in order to identify those activities and patterns in a way which unveils their automation potential. The proposed modular patterns can serve as a base for workflow automation, facilitating the use of technologies such as blockchain and smart contracts.

INTRODUCTION

The design phase during a building project involves numerous stakeholders, dealing with a single and unique real-world object. The flow of activities between stakeholders is not predefined nor standard, and gets established on the go (Knotten et al 2015). Activities cannot be digitally traced, change management is unorganized, however the related information is often needed in the follow-up, especially for the implementation of building information modelling (BIM) (Turk and Klinc, 2017; Singh and Ashuri 2019). The workflows reflect the design process, which most commonly involves temporary organizations of multiple stakeholders, meeting in a unique constellation in order to deliver a specific project. Several organizational models with the appropriate list of services performed by stakeholders exist (e.g. PMI, 2017). In practice however, they are too vaguely defined for automation purposes and hard to follow, as they list the services, but do not relate them to each other.

Digitalization and standardization are desired to solve some of the aforementioned problems. Approaches such as common data environment (CDE) or information delivery manual (IDM) are recognized as attempts to improve the design process, and will be addressed in the literature review. 4D BIM refers to the sequencing of a construction workflow by relating BIM models with construction schedules. It mostly results from a single stakeholder, usually a project manager, working in a specialized software tool and managing sequential construction activities. On the other side, a similar approach for the scheduling of a design workflow, as part of design process management, is challenging due to numerous iterative and reciprocal activities, especially in the early design phase, where relations follow a different logic (Knotten et al 2015). Introducing lean design management in the design phase is regarded as a possible improvement to design management (Herrera et al 2021), which after its implementation in the manufacturing industry is evermore present in the AEC industry. These lean approaches are mostly investigated for their presence, although modes and technologies for their introduction are not necessarily existing or obvious (Reifi and Emmitt 2013). The lack of digital thinking leaves the design workflows stuck in traditional ways, where potentials of existing technologies cannot be fully exploited (Lavikka et al 2018). New technologies such as blockchain (BC) or smart contract (SC) provide alternative ways to model a business process.

In this paper, we explore the possibilities of bringing traditional design workflows into the digital space. The workflows as a whole are represented by highly diverse activity combinations for each project or organizational model. However, we claim that modular patterns can be identified if the design phase is split into smaller processes or sub-processes, and brought to the atomic level, which is here named **activity**. Therefore, the question we aim to answer is “Which modular patterns exist and are they suitable for standardization and/or digitalization of the design phase?” Hence, the aim of this research is to find modular patterns, concerning actors, activities and assets, in the documented design phase.

The paper will present the literature concerning processes within the design phase, modularization, existing digital solutions and the technology that we aim to exploit. The methodology is introduced in the follow-up. The analysis results demonstrate the standardization potential, and the modular patterns are presented in the discussion section.

LITERATURE REVIEW

Processes in the design phase

Knotten et al (2015) describe challenges within building design management, a counterpart of the more frequently researched construction management. They identify four types of processes: pooled, sequential, reciprocal and intensive, ordered by complexity, stating that the standard project management approaches can help with pooled and sequential, but not with the reciprocal processes. The design process can be viewed as an endless reciprocal process (Knotten et al., 2015), where its dependencies need to be understood (Kalsaas and Sacks, 2011) in order to be managed. Design process definitions exist in various forms as plans of work and services or organizational models in building projects – specific to country (e.g, RIBA, 2020; HOAI, 2013; LM.VM, 2014) or field, such as project management (PMI, 2017). They explain the stages, their desired core tasks and outcomes, as well as necessary information exchanges in each stage. Although this literature on design processes can be useful as a point of departure for further development - since it promotes common structures in the highly heterogeneous AEC industry, it can also slow down innovation while referring to traditional workflows without considering the latest technological developments (Succar and Poirier, 2020). The aforementioned literature will be used for terminology, as described in the methodology section.

Senescu and Haymaker (2013) use an experiment to capture the processes between multiple design stakeholders, concluding that capturing of processes improves collaboration. The capturing of processes was performed manually by relating multiple software tools. Golzarpoor et al. (2018) propose industry foundation processes (IFP), named after the IFC, which improve the interoperability of design workflows. The need for process patterns is recognized in the construction phase as well (e.g. Benevolenskiy et al 2012).

Both processes and standards need to evolve together if the digitalization potentials are to be fully realized (Succar and Poirier 2020). There are approaches to standardize the processes as information delivery manuals (IDMs) ISO (2016) and ISO (2012) which originate from the work of buildingSmart organization. buildingSmart (2021) recognizes that the development of IDMs is difficult for some domains, and that it should be accompanied by software development. The most commonly implemented subschema of the industry foundation classes (IFC) schema, which is also a product of buildingSmart, has not resulted from an IDM (Sibenik and Kovacic 2020). IDMs can be regarded as a base for digitalization of processes during the design phase, but they are focused on data exchange and tightly coupled with the IFC-based data exchange. We find it necessary to investigate all activities during the design phase, focus on the standardization of activities that regularly occur and not focus on a single technological solution, since more appropriate solutions might be available.

Modularization

Modularization allows for efficient organizing of complex processes, where information is partitioned into visible design rules (or information) - consisting of architecture, interfaces and standards; and hidden design parameters (or information), which do not affect the design beyond the local module (Baldwin and Clark, 1997).

Designing modular processes is more difficult than creating comparable interconnected systems - because the essence and structure of the overall process needs to be known and understood in-depth for the creation of visible design rules required to make modules function as a whole. As rules for modularization have to be specified in advance, problems with incomplete or imperfect modularization tend to emerge exclusively when modules come together and work poorly as an integrated entity (Baldwin and Clark, 2002). Analyzing and deconstructing design workflows into sub-processes on the atomic level, which we call **activity**, is crucial for the exploration of suitable modular patterns for workflow standardization. Realizing these modular process patterns as digital assets in the design phase requires therefore in-depth understanding and documentation of workflows during the design phase. Figure 1 depicts the chain of single activities, where modules can be identified. A design workflow can then be described as a chain of modules instead as a chain of individual activities.

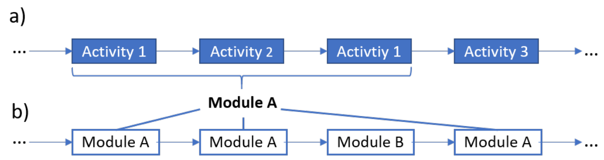


Figure 1 a) chain of activities; b) chain of modules

Design management solutions

Documentation of the design process has been performed with design protocols for decades. Document management platforms got popular with the digitization of documents and availability of internet. Common data environment (CDE) platforms evolved from document management systems primarily by providing ways to deal with 3D models, although the BIM-based approach is still generally file-based (Bucher and Hall, 2020).

A successful delivery of a construction project requires effective communication between the stakeholders (Bucher and Hall, 2020). Chen and Hou (2014) develop a framework and system architecture for an interdisciplinary collaboration platform focused on the integrated building model. Their approach involves domain-specific sub-models, related to access rules, revision notifications and version management, but the realized workflow is project specific and simplified compared to the processes found in practice.

CDEs are centralized cloud-based solutions to support project management, such as Dalux, Viewpoint, Trimble Connect and Bentley ProjectWise 365. The scope of services that CDEs provide is solution specific and not standardized (Stransky 2020). They offer document and model coordination during the design phase and provide automation and managing for exchange, review and approval of designs, with the possibility to define a design workflow. Workflow definition in the design phase is a cumbersome task, especially parts involving multiple SMEs and activities which take place without central authorities (e.g. general contractor). Larger companies often own intra-firm solutions which do not consider the interoperability with other CDE solutions. A centralized solution does not necessarily reflect the decentralized autonomous organizations which are commonly delivering a building project and suitable for the application of technologies such as BC (Sreckovic and Windsperger, 2019; Chen and Hou, 2014).

Blockchain and smart contract

In order to solve the problems in the industry, information and communication technology, which will support the organizational and management tasks, needs to be introduced (Turk and Klinc, 2020). Peer-to-peer (P2P) networks are recognized as a potential solution for online collaboration of stakeholders in the design process. Chen and Hou (2014) propose a hybrid P2P network for a collaboration platform. BC is a distributed ledger technology, which emerged hand in hand with cryptocurrencies, with the potential to be used in other businesses. Turk and Klinc (2017) recognize the solution to construction workflow problems in the BC technology due to the P2P relationship between participants; identifying the types of BC which are suitable for the AEC industry. They also state that BC technology is closely related to cryptocurrencies and therefore use the term blockchain 2.0 (BC2) in order to differentiate from the cryptocurrency BCs.

Nawari and Ravindran (2019) provide a thorough literature review regarding BC in the AEC industry, which involves the definition of a Smart Contract (SC). We emphasize the distinction between the SC in BC and in BC2, since SCs are often confused with the contract in their traditional legal and economic meaning. It might even be necessary to introduce Smart Contracts 2.0 (SC2) in order to distance it from its cryptocurrency-related meaning and bind it to BC2. Therefore, we refer to the definition by Clack et al. (2016) which is suitable for SC2: "A smart contract is an automatable and enforceable agreement, automatable by a computer, although some parts may require human input and control, enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code." This definition supports the use of SC2 within the design workflow without requiring the exchange of monetary transactions.

METHODOLOGY

The methodology follows three research design steps examining the design processes on three analysis levels:

Protocol analysis

The documentation of the design process is commonly realized through design protocols. The protocols are omnipresent and serve as a sort of do and done list during the design phase. They follow the contractual arrangements between the stakeholders with listings commonly referring to the building elements and the accompanying tasks, which are rarely individually addressed in the contracts.

This paper examines the protocols from a document management platform. The protocols consist of listings on particular topics, which are used to extract elements of a design workflow. We analyze protocols and existing design documentation in two one-time project team constellations. The first research step is the analysis of a use case, where multiple protocolized meetings are examined. The listings within the protocols are chosen randomly, and the ones which are relevant to the design phase are filtered. These protocol listings are further analyzed and described with the help of data-flow diagrams. The data-flow diagrams are useful since they can serve as a base for the automation of processes.

The whole design phase represents a complex arrangement of numerous elements and cannot be developed as a useful single data-flow diagram. Therefore, we develop multiple diagrams representing parts of a larger workflow, and by comparing them we identify the automation potential. The diagrams serve as a basis for statistical analysis of processes and identification of modular process patterns. They are created with unified modelling language (UML) and focused on the activities in the design process. Even though many listings were not straightforwardly convertible to a diagram, as will be discussed, they are defined to the best of the authors' knowledge. Statistical analysis is performed for two projects, which helps to discover specifics of a single project. An example of an anonymized listing and the corresponding UML activity diagram are represented in Figure 2.

a) Listing example

- Client instructed structural analysis to be performed
- Structural engineer delivered the modified plans
- General planner sent the plans to the client for approval

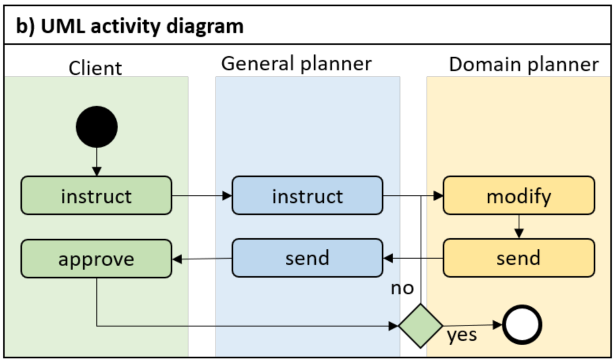


Figure 2 Example of a) protocol listing; b) corresponding UML activity diagram

"3A" process definition

A design workflow can usually be broken into smaller sub-processes, which might not be true for complex projects (Turk and Klinc, 2020). Triple "A" or "3A" analysis involves the analysis of **actor**, **action** and **asset** from a single sub-process.

We use the definition of an **actor** from ISO (2016) being a "person, organization or organizational unit involved in a construction process". Further on, ISO (2016) distinguishes two types of actors: initiator which makes a request and executor which responds to the request. These terms will be discussed for the implementation purposes.

Activity is used as an atomic sub-process of a design phase, required for digitalization purposes, since the term process is used on multiple scales. We consider the process a sequence of activities. In Zwikael (2009), the activity definition, relating to project management and significantly influencing project success, can be defined by breaking down the workflow into smaller packages. The activity definition for the digitalization purposes requires abstraction of terminology. Therefore, the terminology will be extracted from the literature for plans of work and services for building projects in Austria (HOAI, 2013; LM.VM, 2014) with the consideration of future digitalization and effects of the terms in the follow up.

Assets as in Succar and Poirier (2020) are addressing both digital and physical assets used in construction. They are interrelated, whereby the digital ones can be documents, models and data.

The approach used in this work examines the listings of protocols, extrapolates the 3A sequences of actors, activities and assets, and uses them for pattern recognition. The focus is set on the activities and they are atomized, meaning they cannot be complex; however, the actors and assets could possibly remain complex and are not brought to the atomic scale. For example: the activity *send* can address multiple assets such as plans and information, or the activity *discuss* involves multiple actors.

Pattern recognition

Turk and Klinc (2020) state that dynamic, spontaneous and informal communication patterns occur within unexpected events during the construction project, and are not supported by most of the available technological solutions. We aim to identify modular process patterns within the design phase, where, similarly to the construction phase, unexpected events occur on a regular basis; as design phase processes often merge with the construction phase (e.g. change order of design by client). The patterns are identified by statistical analysis of the 3As, where multiple sequences of actor, activity and asset were compared. The patterns are extrapolated as commonly occurring sequences, that provide a base for future automation of processes. Patterns are recognized by analyzing the actor, activity and asset sequences separately as well as their combinations.

RESULTS

Use cases

Two use cases were investigated in this research (Table 1).

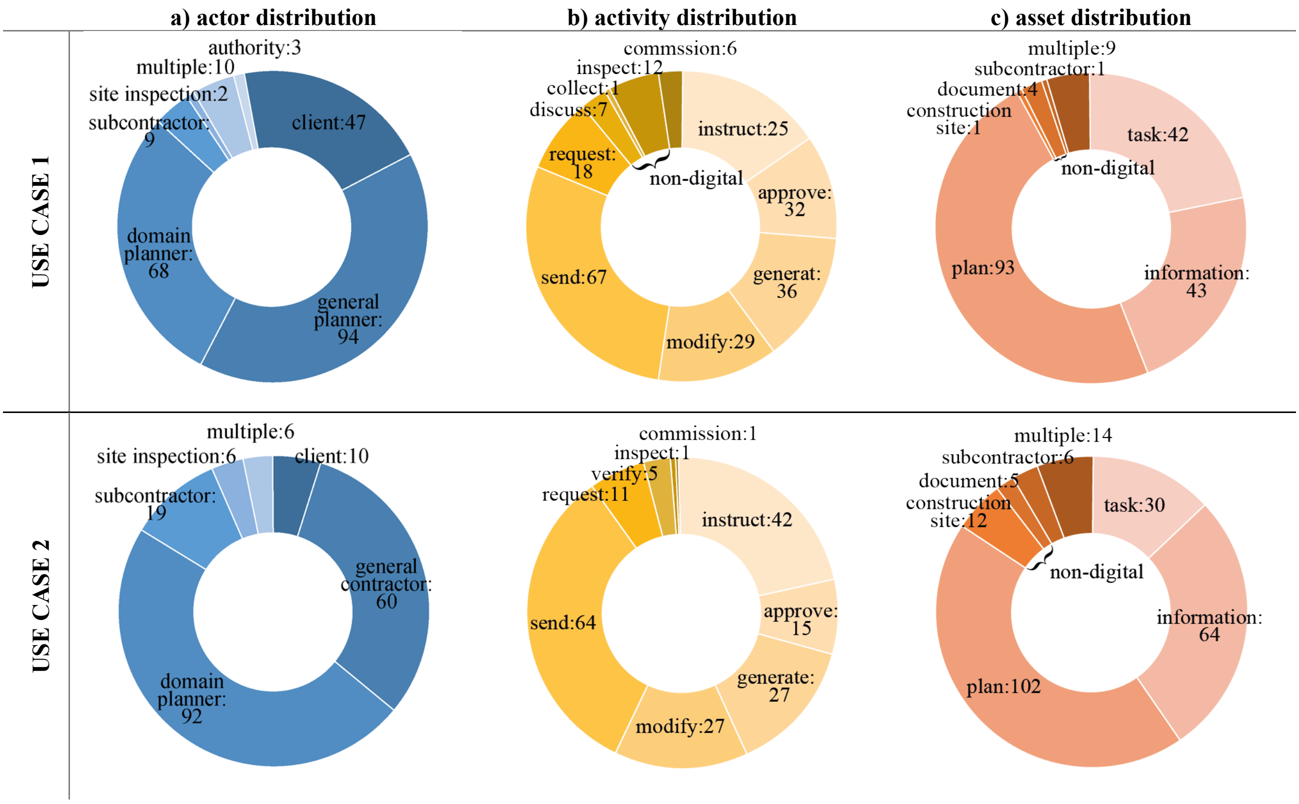
Table 1: Use cases overview

	Use case 1	Use case 2
Building type	Office	Residential
Project type	Renovation	New building
Size	5.000 m^2	25.000 m^2
Floors	6	7
Protocols existing / analyzed	113 / 80	95 / 25
Listings existing / analyzed	18.984 / 50	11.400 / 50

In total, 100 listings were analyzed, resulting with around 0,3% of the total number of listings. Same listings are repeated within multiple protocols, until a referring topic is closed, therefore the percentage of the unique listings analyzed is higher. Since the first use case is a renovation project, many listings focus on the construction site and do not involve design activities. In some listings, construction site was a physical design phase asset, as the design was highly dependent on the construction site conditions.

In the use cases, the documented activities lack clarity and uniformity, making it hard to achieve traceability or digitalize them as such. Therefore, a level of abstraction is introduced in the terminology, which is conform with the existing literature, to establish the relations between the actors, activities and asset. For instance, *information* is an abstraction of all digital non-geometrical terms; all digital information including geometry is *plan*. Activities similar to *modify* can be found such as *rework*, *adjust*, *revise* or *update*, however only the *modify* term was used. The terminology originates from the literature (LM.VM 2014, Lechner and Blasche, 2011), where the activities were filtered and the ones which do not have clear results or explanation such as organize or cooperate were excluded. The remaining ones are organized in groups. The identified activities can be found in the activity distribution diagram (Table 2–b).

Table 2 3A distribution graphs



Design activities

All analyzed processes, after comprehending and some patching, can be dissolved into subprocesses or activities, where patterns can be identified. The majority of resulting subprocesses (*send*, *approve*) can increase their value by digitalization, however some not (*discuss*). The majority of the identified and abstracted activities during the design process can be digitalized, such as *instruct*, *generate*, *modify*, *send*, *request*, *approve* or *commission*. *Inspect* and *collect* refer primarily to physical assets like the *construction site* or *document*, and hence are not possible to digitalize in that form. Another activity which is problematic for digitalization is *discuss* which normally involves multiple actors, and represents multiple iterations of information requests and instructing tasks. The term *discuss* is commonly misused when a new task is instructed. This can bring confusion during the abstraction of terms. In the literature, much more activities can be identified, many of them not being suitable for digitalization, such as when no clear result is defined since activity stretches over a longer time period (*monitor*), or complex tasks where multiple activities are incorporated into one (*cooperate*). In general, most of the terms can be considered vague and with tasks highly dependent on the specific project and the involved actors. The activities during the design phase mostly deal with digital assets, and represent a form of data management. On the other hand, in the software industry basic functions, which are generally sufficient for users to manage data, are defined as CRUD or *create*, *read*, *update* and *delete*. Nevertheless, our analysis shows that more than 100 activities focusing on the design phase (HOAI 2013; LM.VM 2014), have no clear distinction between different terms, where most of them dealing with digital assets (Table 2–c), which makes process automation or pattern identification difficult.

Modular patterns

Digital assets and activities which can be digitalized are identified as the majority of 3As in the previous step of this research; showing that during the design phase process elements can mostly be digitalized (Table 2). This step of the research finds the patterns within the 3A sequences. For that purpose, each element is analyzed for actor and activity sequences separately, and their combination in two and three sequence steps. As the activity was an atomized element, the sequential activities sometimes involve the same actor or asset. The results are represented through the graphs (Figure 3 & Figure 4).

The most common sequential activities are *generate/send* and *send/approve*, followed by *modify/send* and *send/modify* in the first use case. In the second use-case *modify/send* and *generate/send* are most common, followed by *instruct/modify* and *instruct/generate*. In both use cases domain-specific planners perform multiple activities most commonly. The organizational structure is reflected in the actor patterns: in the first use case there is commonly the client/general planner communication and the general planner/domain-specific planner sequence, while in the second use case the client is less present and the communication is taking place mainly between domain specific planners and the general contractor.

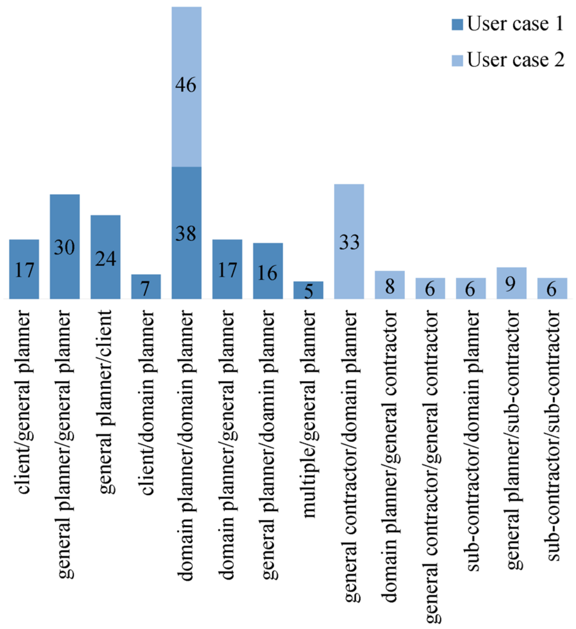


Figure 3 Actor sequences

Significant combination of actors and activities show in the first use case the following pattern: the general planner *sends* the asset to the client for *approval*, the domain-specific planner *modifies* and *sends* the asset, the general planner who performs the architectural design, *modifies* and *sends* the asset. In the second use case the domain-specific planner *modifies* and *sends* the asset, the general planner *instructs* the domain planner to *modify* or *generate* the asset, and the domain-specific planner *generates* and *sends* the asset.

Finally, the three-step analysis shows scenarios where the general planner *modifies* and *sends* the asset and the client *approves*. The second most common is a sequence of actions where the domain planner *inspects*, *generates* and *sends* the assets, and the general planner *generates* and *sends* the asset to the client for *approval*. In the second use case the most commonly occurring scenario is: the general planner *instructs* a task to the domain planner to *modify* and *send* the asset. The second sequence involves generating a new asset instead of modifying the existing one.

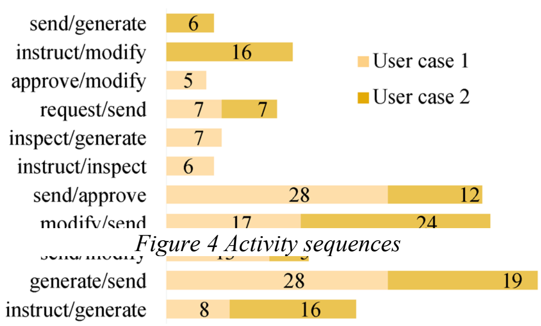


Figure 4 Activity sequences

Some tasks are modelled as loops and could be repeated multiple times, especially the ones containing the *approve* activity. Therefore, some patterns are even more present in practice until a loop is resolved.

These patterns show potential for communication automation with technologies such as SC and BC. Digitalizing process patterns can improve traceability and change management, eventually even bring additional innovation to the design phase.

DISCUSSION

This work tackled several problems when investigating the process patterns in the design phase. The first obstacle was the process documentation and the ambiguous terminology that describes it. The results are discussed after the documentation problems are explained.

Documentation problems

The creation of activity diagrams using UML language from the design protocols was not a smooth and easy process. The problems with design documentation affect the design process quality twofold: a) the documentation lacks sufficient clarity to be reliable and useful during the existing design process; b) it cannot be used for further process digitalization nor data analytics. The problems found during the analysis are listed here:

- two activities are started at the same time although one could exclude another one (e.g. a plan is sent for approval and at the same time as a basis for further activities)
- the activity initiator is unclear
- the activity executor is unclear
- some activities are missing, require imagination based on experience to recreate stories (e.g. if an asset is not approved it is returned with additional information)
- terminology is diverse, often different terms used with same meaning, sometimes unclear and misleading (e.g. “discussed” is common although there was no discussion, it often insinuates a request to the hierarchically upper actor in the process, or an approval of an asset)
- authorization of an asset not clearly described, not possible to conclude if it was required
- communication activities not happening directly between the initiator and executor, sometimes because of the hierarchical inter-organizational relations

Physical assets are part of the design process, whereby some of those, like physical documents, can be easily digitized and some such as the construction site not. For certain processes it is possible to perceive irregularities in the workflow by following activities: e.g. if an asset (plan) is not approved due to the lack of information on the construction site. It is possible to recognize the constant intersection between the digital and physical assets (as in

Succar and Portier 2020) such as physical documents, digital documents, work and material specifications, build environment, etc.

Modular patterns

Modular patterns can be found in both use cases, as well as similarities between the use cases. The greatest differences between them occur due to different constellations of actors in the project-specific organizations. Different actor involvement is visible in the actor distribution diagrams (Table 2-a). The activities listed in the diagram sufficed for converting the listings from protocols to the UML diagram, whereby *discuss* is complex as it involves multiple actors, and *collect* and *inspect* deal with physical aspects. *Verify* is used as a counterpart to *inspect* for digital assets. Assets *document* and *construction site* are physical, but they are present less than 8% of the 3As. Task is an asset which has enough information for establishing a new 3A, or more of them. *Instructing* a task carries a smart contract within its structure, which could be digitalized or automated. This property of tasks is potentially useful for the client or general contractor, depending on the organization type, while significant number of tasks could be digitalized.

The analysis shows that same actors most commonly perform multiple sequential activities, such as domain planners, but also the communication between the general and the domain-specific planner as well as the communication between the general contractor and the domain-specific planners occur frequently. Numerous patterns are found with the two-step analysis and a significant number with a three-step analysis. This implies the possibility to map the majority of processes and use them in their digital form. For instance, a general contractor *instructing* a modification of an asset, the domain-specific planner *editing* the asset and *sending* it back is a typical pattern where all the steps can be digitally documented, and a task is suitable to be realized as a smart contract. A significant digitalization potential is identified within the analysis and will be realized in the future steps.

CONCLUSION

Advantages and disadvantages of the existing protocols are recognized and compared to the requirements of various stakeholders. They are modelled as activity diagrams, which are analyzed in order to identify patterns in a 3A form, including actors, activities and assets. The analysis displays a significant digitalization potential in the design phase, which deals mainly with digital assets, where most of the activities can be digitalized and involve a single actor. The 3A approach is used to build activity blocks for technologies such as SC and BC.

Some of the limitations of the applied methodology is primarily the partly subjective process definition due to the lack of information in the existing protocols, and the activity diagrams which have not been validated so far. The 3A approach and the developed terminology is not yet implemented with any technology, and could expose unexpected problems. However, it was developed in consultation with and confirmed through BC experts.

Next steps include interviews with project stakeholders which should validate the results of the analysis. Activities, actors and assets will be digitalized in the form of 3A blocks or digital modules, with the aim to digitalize the design process. Besides the advantages that would be gained by digitalizing the workflow, a special attention will be given to the investigation of the automatic invoking and triggering of next steps based on the existing ones. This could further open the door for the use of AI and optimization of design workflows and corresponding processes.

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