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DICYCLE: RETHINKING THE BUILDINGS` END-OF-LIFE

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Abstract

The presented research project DiCYCLE aims at identifying, analyzing and mapping current End-of-Life processes in Architecture, Engineering and Construction, as well as optimizing these processes for digitalization, using Building Information Modeling, blockchain and smart contracts. The goal is to create new business models and enable sustainable digital design, construction and deconstruction workflows that facilitate the reuse and recycling of building materials and components along the building life cycle.

Introduction

The architecture, engineering, construction (AEC) industry is facing a number of challenges including the slow application of innovative technologies and digitalization. For the realization of digital technologies and methods in the building life cycle (LC), it is necessary to capture processes and workflows in design, construction, operation, as well as renovation and deconstruction (End-of-Life [EoL]), and to adapt those for the implementation of digital technologies. Currently available software tools still do not correspond to the practices and workflows of the end users, since building models, supported by Building Information Modeling (BIM-Models), are used mostly phase-based (in design, construction and operation) or domain-specific. For a BIM-based EoL phase, processes need to be defined, standardized and set up for digital tools.

The presented research project DiCYCLE aims at identifying, analyzing and mapping current EoL processes in AEC. Optimizing these processes should be achieved with the use of BIM, blockchain (BC) and smart contracts (SC). The goal is to create new business models and enable sustainable digital design, construction and deconstruction workflows that facilitate the reuse and recycling of building materials and components along the LC. Furthermore, identifying relevant stakeholders and defining their activities/roles/responsibilities concerning the development of the underlying BIM-Model for the EoL phase is essential. Ultimately, the goal is to enable a transparent, recycling-friendly collection and tracking of building materials and building components along the LC, thus minimizing and reducing waste materials during renovation, deconstruction and demolition.

On the one hand, DiCYCLE focuses on BIM-Models that correspond to the actual state of a building ("as-built"), and on the other, on processes and workflows that describe both data changes and the finished construction work. Therefore, identifying data structures for EoL-relevant information and linking this data with BIM is essential. BC-based technologies will enable the tracking and verification of this EoL-relevant data. Hence, SC need to be developed in order to track the reuse and recycling of building materials and components in an integrated digital building model thereby enabling even early EoL assessments. In this paper we aim at presenting the research project and the associated research question dealing with the exploration of necessary fundamentals for digital reuse and recycling in the E-o-L phase, specifically: *How can EoL processes be standardized and adapted for digitalization with BIM and Blockchain in order to enable optimized reuse and recycling?*

The grounding for the research project is further explained in the problem statement, methodology, innovative contribution and conclusion.

Problem statement

The construction industry is responsible for a significant proportion of raw material extraction, waste production, as well as CO2 emissions and energy consumption. Construction accounts for 40-60% of global resource demand (Bribián et al., 2011, Saghafi & Teshnizi, 2011), and it has tripled over the period 1970-2017 (Global Resource Outlook, 2019). The proportion of building and construction waste amounts to 17% in Austria (BAWP 2017) - including excavated soil even more than 70% of the total waste generation - and EU-wide to about 33% (Management of CDW in the EU, 2011). CO2 emissions from the construction and operation of structures account for around 40-50% of global CO2 emissions (WGBC 2016) and are responsible for around 40% of energy consumption (EU Green Deal, 2019), with 5-10% for building material production (Herczeg et al. 2014). Especially in urban areas, the building material balance is relatively even in terms of mass (Brunner 2011). Although building material is a finite, scarce commodity, material efficiency rarely finds its focus in design – the emphasis is more on energy efficiency, despite EU calls for the protection of natural capital (EU Green Deal, 2019). Considering the two terms sustainability and Circular Economy(CE)-sustainability: "A development that satisfies the needs of the present without jeopardizing the opportunities of future generations" (Brundtland, 1987); CE: "A regenerative system in which resource input and waste, emissions and energy losses are minimized by slowing down, closing and constricting material and energy cycles" (Geissdoerfer et al., 2017) - it is striking that when implementing CE measures, the resulting environmental impact must also be taken into account. However, the increased implementation of CE not only has ecological effects, such as resource conservation, reduction of transportation, energy requirements for material production and processing, as well as resulting emissions (EU RessEff 2014), but also economic advantages.

The construction sector in Austria is responsible for around 70% (44 million tons per year) of the total annual waste volume. This building and construction waste should be recycled if this is technically possible, ecologically sensible and not associated with disproportionately high costs (AWG, 2002). However, an adequate framework for assessment is lacking. Depending on the existing masses and volumes of the demolition objects, selective dismantling (ÖNORM B 3151) is to be carried out as the demolition method. However, recycling-oriented separation and collection of building and construction waste as well as the assessment which components are suitable for recycling or reuse, falls into the responsibility of the construction or demolition company. Hence, there is an urgent need to increase the reuse and recycling potential of building materials and components in the building LC and thus reduce the consumption of primary raw materials, caused on a large scale within AEC. As a result, new processes and business models are necessary for the final phase in the building LC which would enable 1) the tracking and implementation of a resource-saving and ecologically optimized value chain from design to demolition (and after demolition - in the new building life cycle), and 2) a clear definition of relevant models, data and stakeholders.

BIM for EoL

Business processes in the AEC industry follow established ways of working that are only partially suitable for digitalization. There are currently challenges in the implementation of BIM and digital technologies such as poor software interoperability, data exchange problems or loss of information. The main reasons for that are the lack of process descriptions, which are characterized by numerous different traditional ways of working, and as a result don´t allow for sufficiently useful and usable implementation.

While the BIM workflows are problematic for the reasons mentioned above, the EoL processes are not even defined or standardized in an analogue form and are therefore not adapted for digital processes. For example, an automated digital connection of LC assessments with BIM would enable ecologically and economically relevant parameters for resource-optimized building design and thus the EoL phase as well. However, this is currently still failing at the technical and procedural level (Potrč et al., 2020). Akbarieh et al (2020) have conducted an extensive bibliometric study on BIM in EoL. They argue that BIM-based EoL suffers from the lack of a global framework. They show problems that are also related to proprietary software solutions and thus have a strong influence on the degree of EoL digitization.

The required flexibility between disciplines in AEC is not supported in the current most used open exchange schema Industry Foundation Classes (IFC). The taxonomy model used to define exchange requirements has a very good extensive set of terms encompassing components and their attributes. However, this schema does not cover all necessary requirements of all participants in AEC, especially the LC experts - ecological parameters are not considered or only to a small extent (Santos et al. 2019). Akbarieh et al. (2020) come to the conclusion that the EoL phase is not sufficiently taken into account in any BIM software. The existing solutions are based on local waste management guidelines and the selection of case-specific sustainability criteria. This disconnect between BIM tools and EoL tools reportedly hinders holistic EoL considerations. The missing guidelines for material and component databases prevent conclusions from EoL considerations, which are already relevant in the design phase. An integral schema should be complete and support all product and project data from all involved disciplines. The focus must be placed on filter and interpretation processes, when implementing software solutions. This Software solutions should support well-defined integral model sub-schemas, like the concept of Model View Definition (MVD) in the IFC world, and provide a solution to the end-user needs.

Processes and data management

Standardized processes are required for BIM in EoL - which would also enable the implementation of digital tools, but currently they do not exist. In the digitalization analysis of the construction industry by Woodhead et al. (2018), new processes are expected to emerge in the future, especially in the manufacturing industry. The processes and the associated rules should be developed simultaneously in order to be able to exploit the maximum technical potential (Succar and Poirier 2020). The constant flow between the "assets", namely the digital and/or physical ones with the processes that happen in between, should be examined, whereby an "as-is" digital model is to be aimed for. For the implementation in the EoL phase, the BIM model should represent a Digital Twin as much as possible and reflect the last state of the physical building - we also use the term "as-is-BIM" where appropriate, where all changes made according to the "as-planned-BIM" and "as-built-BIM" are included. The "as-built" BIM represents a digital model of the built reality and the "as-planned BIM" is the resulting model of the design phase (Plandata, 2020). Thus, "as-is-BIM" is the model that should include all building changes during the LC, i.e. those that have taken place from design to operation and deconstruction. In practice, "as is" BIM models still pose a problem, since BIM models are usually no longer maintained after the design phase. "3D Imaging Technology" is a commonly used approach for recreating "as-is" BIM (e.g. O'Keffee and Bosche 2015), but it provides static models where the changes are not traceable. For the EoL phase, however, it is necessary to have a BIM model that corresponds to the latest data status, i.e. "as-built" including all structural changes that have occurred up to that point in the building LC. The two ongoing research projects at TU Wien, BIMd.sign and FMchain are pursuing this approach, where central BIM data management is being developed. Central data management means an open database that contains the building models and their changes, which are kept up to date dynamically, i.e. “as-is”. The DiCYCLE project aims at using "as-built" models, but there is also the possibility to use developed "as-is" models that were generated after the completion of the two projects.

BC and EoL

Giorgi et al. (2022) argue that future development and research of CE in the EU needs more practices, environmental assessment (LCA) and digital supporting tools (digital data, platforms, traceability), because of the currently fragmented CE strategies and legislative frameworks, which focus more on waste management than recycling, reuse or resource management strategies. Furthermore, in-dept analysis of the EoL phase have not been included in many of the performed LCA studies, mainly due to the existing lack of information about respective data and processes (Giorgi et al., 2018). In addition conversation about using blockchain to resolve problems in the implementation of BIM (Liu et al., 2021), still remain mainly on the conceptual level (Figueiredo et al., 2022).

Figueiredo et al. (2022) name challenges when creating sustainable building projects, including management of large amounts of data, reconciliation of diverse domain-specific disciplines, communication failures due to numerous project stakeholders and information loss during the building LC. They suggest the use of Distributed Ledger Technology (DLT) as the plausible solution for dealing with such obstacles.

Blockchain (BC) technology, often referred to as DLT was founded by Bitcoin (Nakamoto, 2008) and has since become widespread in many industries. While the term originally only describes the chained data structure of Bitcoin, it is now used for the background technology. In the technical sense, DLT enables the decentralized synchronization of states. This can be account balances, as in the case of Bitcoin, but also other data, where it is important for all participants to know the current status. The DLT can additionally be used to control state changes supported through the use of Smart Contracts (SC) (Szabo, 1997). The Ethereum BC (Buterin et al., 2013) was specifically designed to run SC and has now become the de facto standard.

In their original form (Bitcoin, Ethereum), BC are open networks in which anyone can participate, but where all data is also publicly visible. Private BCs, in which all participants are usually known (permissioned), stored data can only be accessed by these participants, which es therefore better suited for use in companies (Wüst et al., 2017). Unfortunately, many of these deployments have not been successful, which may be due to the lack of the "network effect" in private BCs. A hybrid solution of SC in public networks and private databases that exchange data via standardized interfaces can solve this problem.

There are several examples of how BC can support the life cycle approach in AEC (Scott et al. 2021): BC can provide full material and energy traceability, enabling the user to make predictions for the recycling and reuse of materials and goods used in the built environment (Shojaei et al., 2021); there is usability of BC to increase transparency and reliability of data in an Environmental Product Declaration (EPD) (Rangelov et al., 2021); end-to-end lifecycle assessment availability through the recorded metadata of raw materials for the proof of provenance from source to construction (Shojaei, 2019); Copeland and Bilec (2020) applied RFID, BIM, and BC to provide components with an evidentiary trail of data throughout its lifecycle, including the potential to integrate with a crypto-economic incentive scheme for the recycling of assets, with data verified by blockchain; BC for post-occupancy evaluation, employing BIM as the data repository for the built environment asset and BC as its corresponding data validator (Di Giuda et al., 2020).

Research design and methodology

Grounded in the problem statement, at this initial stage of the research project, we pose the following research questions: *How can EoL processes be standardized and adapted for digitalization with BIM and Blockchain in order to enable optimized reuse and recycling?*

Figure 1 shows the research design in which the two aspects, the procedural and the technical are brought together to create the DiCYCLE framework (platform), in a later step, which will be further evaluated and optimized with regards to both relevant aspects.

To answer the research question, the focus in this first step is on the documentation and investigation of the existing value chains in E-o-L and the common business models for recycling/use of building materials and building components based on case studies (from participating partners in the project). Consideration of the legal framework/regulations, as well as the roles/responsibilities of those involved in the process. For this purpose, use cases are examined, compared with each other and obstacles and potentials of the future are identified.

In a further step, the DiCYCLE framework will be developed as a proof-of-concept (prototyping), that would demonstrate the implementation of BIM, BC and SC in EoL The project thus represents the continuation of the framework developed in the research projects BIMd.sign and FMChain for the implementation of BC & SC in BIM-supported design (BIMd.sign) and operation (FMChain). The innovation of the project lies therefore in the integrated perspective of EoL data and processes, their coupling with BIM and the verifying / tracking with BC and SC along the LC.

Scenarios for the realization of BC and SC of the different business models will be tested and evaluated with test use cases from relevant and participating stakeholders in EoL. The relevant data for the BIM and SC-supported EoL processes (e.g. key performance indicators) will be coupled to the design phase (BIM "as-planned") in order to enable EoL predictions in the early stages of design. This way, EoL strategies can be derived and can serve as design and decision-making tools for building owners/investors, strengthening the "circular economy" in the construction industry.

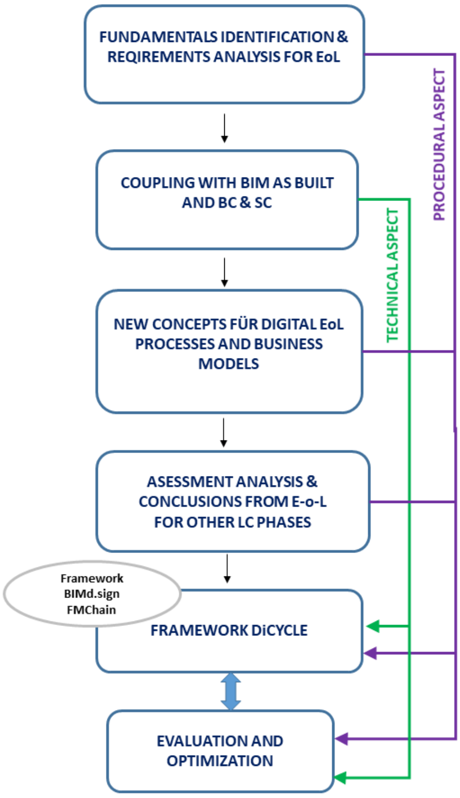

Figure 1: Research Design DiCYCLE

Innovative contribution

The business model examined in this research project is intended to use BC technology for the EoL phase. The BC technology requires a rethinking of the existing workflows and can help to use the potential of a BIM workflow. BC-supported workflows can increase transparency, speed up processes and simplify communication by providing real-time insight into data changes and facilitating query capabilities for each process step or phase. BC and SC can document the progress of the processes and the changes in the BIM models. The responsibilities and rights of intervention of the individual participants are managed by SCs and hence the compliance with these process steps is ensured. Furthermore, the current BIM model is anchored in the BC with a fingerprint. The storage takes place "off-chain" in a decentralized data storage (IPFS) - this implementation is being researched currently in the projects BIMd.sign and FMChain and should also be extended to DiCYCLE. In a BIM and BC&SC-supported business model for EoL, several advantages over the existing workflows can therefore be expected. In addition to seamless data and information exchange and automated communication steps, the new model will provide all users with the most up-to-date data version, track changes during building LC and enable faster and verifiable data flow. Thus, an optimized EoL value chain would be created that would show updated possibilities for recycling and reuse in the EoL phase.

The innovation of DiCYCLE lies in the following
1) the research of new E-o-L processes (business models) with BIM, BC and SC and thus the investigation of coupling possibilities of different digital technologies. New processes and services are being developed for the digital design, construction and operation of buildings.
2) the integration of various relevant E-o-L data with BIM, with a focus on data interoperability; striving for open data storage in order to cover a broader field of application. Common principles and standards for data management are observed. Interoperability between proprietary and open software solutions and BC is created to enable dynamic connection of models and EoL data.
3) the feedback loop from BIM "as-built" or "as-is" to BIM "as-planned", creating a decision support in the early design phases for the assessment of EoL value chains in the building LC. Ultimately, it serves for reliable life cycle calculation and sustainability assessment of buildings for sustainable energy and resource management.
4) a LC-wide framework solution in which the DiCYCLE framework is coupled with the ongoing projects BIMd.sign, FMChain. A continuous digital data chain is ensured through dynamic BIM models that combine static building models with processes. All project participants are assessed for their model responsibilities and roles.
5) In order to enable digital working methods for EoL, innovative BIM-based approaches, processes, interfaces and tools are being developed.
6) Striving for open solutions and documentation of existing processes opens up new possibilities for SMEs in the project consortium. On the other hand, the EoL process documentation can be used for standardization, possibly to support official digital procedures (digital approvals or permits, material passports, tendering, awards, contract and billing procedures).

Conclusion

The research gap that is addressed with DiCYCLE lies in the integrative view of E-o-L data and processes as well as their coupling to existing BIM databases and verifiable processes with BC and SC.
The research goal is the development of a framework and a proof-of-concept for the use of BIM and BC in the EoL phase, through the definition of new EoL business models, the connection with BIM, and based on this the design of SC with BC. The project aims herewith to contribute to the CE, by creating new digital business models which allow sustainable digitalized construction and design processes enabling reuse and recycling of building materials and components at the end of the life cycle, and furthermore clearly defining those responsible

for the model and their roles. The expected results include in this first step, referring to the posed research question:
1: Documentation of the value chain in EoL
The documentation is carried out by identifying typical processes in deconstruction and in the reuse and recycling of building materials and components, as well as waste management (disposal), with the help of case studies and ongoing projects of the project partners in the consortium. The identification of the EoL relevant parameters is also part of this goal, and from this the derivation of requirements for data management, data structures and software tools for EoL processes.
In the further steps in the project, the following results are expected:
2: New business models (BM) and scenarios for EoL
New BMs are developed and an implementation of these with BIM and SC is examined. The existing value chain of building materials/components in the building life cycle and the impact on the EoL phase are taken into account. Various scenarios for digitizing the EoL processes are formed from the designed BMs. Necessary adjustments of BMs are identified to enable later implementation. Processes, data flows and interactions are developed and formulated as BPMN (Business Process Modeling Notation).
3: Definition of an integral framework for EoL processes
The potential for standardization and automatization of existing workflows/processes is reviewed and, in conclusion, the requirements and implementations for SC application in EoL are identified, which would enable a more efficient and transparent value chain in the buildings´ LC (CE). The goal is to embed identified EoL parameters and data structures/databases in BIM as well as enable accessibility from the BC and SC side. The possibilities of referencing BIM models and/or individual information in BC and SC are thus reconciled and the optimal approach is determined. Based on the formulated BMs, the defined SCs and the BIM-EoL-based data management, test cases (prototyping) are to be formulated, evaluated and optimized in terms of feasibility, usability, functionality and scalability. At the necessary points, the DiCYCLE framework will also be expanded and improved with the findings from the BIMd.sign and FMChain projects in order to be able to better map and optimize the framework of the EoL relevant processes
It has be to mentioned, that the effects of a more efficient and qualitatively better BIM-supported EoL process, which is coupled with SC and BC, is currently difficult to quantify. New technologies and tools require greater integration of the processes and participants in a building`s LC, but design and construction processes, for example, are still sequential and very fragmented. Renovation and deconstruction processes are not yet standardized or adapted for digitalization. Currently existing poor software interoperability, missing links or integration of data for EoL with BIM are also difficult to quantify. The integral overall optimization intended with this research project, through the application of digital technologies in EoL, through testing, evaluation and optimization based on use cases and the proof-of-concept, promises an empirical recording of the potentials that can be achieved with these technologies in the LC of a building. Hence, DiCYCLE aims at offering promising solutions such as transparency, tracking of process steps (protocol), real-time communication; and thus creates a scientifically sound contribution to the digitalization of the value-added processes of the circular economy in the AEC industry.

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