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REINCARNATE

D3.2 – Methods for BIM Supported Dismantling

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Disclaimer

Acronyms and definitions

Acronym	Meaning
ATA	Assemble Them All
BIM	Building Information Management
CDW	Construction and Demolition Waste
CP-IM	Circular Potential Information Management
CSV	Comma-Separated Value
DfD	Design for Deconstruction
DG	Disassembly Graph
E-BAMB	Existing Buildings as Material Banks
EoL	End of Life
HVAC	Heating, Ventilation, and Air Condition
IFC	Industry Foundation Classes
IoT	Internet of Things
JSON	JavaScript Object Notation
LCA	Life Cycle Analysis
LoD	Level of Detail
Pset	Property Set(s)
SDPB	Selective Disassembly Planning for Buildings
STEP	Standard for the Exchange of Product Data
TRL	Technology Readiness Level
UML	Unified Modelling Language
VPL	Visual Programming Language
WP	Work Package

XML	Extensible Markup Language

Reincarnate project

The average lifespan of a building is 39 years — in Europe, it is only 25-30 years — and the main reason for demolition is obsolescence. This is why there is a large amount of construction and demolition waste (CDW) — representing approximately 25-30% of all waste in Europe —, in addition to that generated in current construction works.

The recycling rate for CDW is relatively high (above 75%). This activity generated $126.89 billion in 2019 — Europe contributed the largest share, almost two-fifths of the total global market — and is projected to reach $149.19 billion by 2027. Unfortunately, many of the most valuable materials in CDW cannot be meaningfully separated and end up in landfills.

This helps to get an idea of the efficiency potential for climate neutrality that exists in construction.

Reincarnate aims at advancing circular economy practices within the European construction industry and enabling to significantly maximise the life cycle of buildings, construction products and materials, reduce CDW by 80%, increase the reusability of buildings, construction products and materials and, as a result, lower the sector's emissions by 70%.

As a result of these actions, Reincarnate will significantly advance circular economy practices within the European construction industry.

First, it will create a Circular Potential Information Management (CP-IM) platform and a set of innovations to use it. These solutions will draw upon emerging digital technologies, such as digital twin representation, artificial intelligence, and robotic automation.

3 empirically proven social science insights will allow fostering widespread adoption of reused high-quality construction products and materials, and business eco-system development frameworks to combine actors within sustainable value chains. All innovations will be demonstrated on eleven selected real-world projects and value chains. Furthermore, business process guidelines and an e-learning platform will be developed to drive the dissemination and exploitation of the Reincarnate results.

Contents

1. Introduction

1.1. Introduction and Objectives

The construction industry is on the brink of a significant paradigm shift, driven by the need for sustainability and the evolution of digital technologies. This report for Deliverable 3.2 in the Reincarnate project introduces a forward-thinking project that aims to present a new way for building products and components to be reused across construction projects.[1]

This report was created in collaboration with the Technical University of Berlin who are responsible for Deliverable 3.3 and who utilize Autodesk's parametric modelling tool, Dynamo, for effective parameter configuration. The collaboration under the Reincarnate umbrella enables the creation of a systematic approach for the de-installation and subsequent reuse of building elements in a manner that maintains high product quality and contributes to environmental conservation. Deliverables 3.2 and 3.3 together aim to form the concept at a Technology Readiness Level (TRL) of 4-6 which responds to Task 3.2 in the Reincarnate project which have the objective to enable architects and product owners to exchange reusable products and components on a conceptual level utilizing the Circular Potential Information Management (CP-IM) platform.

This report includes a comprehensive framework that marries theoretical knowledge with practical application, emphasizing the role of sustainable construction practices in the digital age. By effectively leveraging BIM for dismantling and reuse, this study not only adheres to environmental priorities but also addresses economic and operational challenges, marking a significant step towards the sustainable transformation of the construction industry.

The result of this report introduces a concept which through process maps illustrate how a designer can use the CP-IM platform to find reusable products and components and incorporate these into new buildings. It additionally illustrates how the product owners

[1] The task will develop the required concept to allow for de-installing product and components of buildings and to re-use them in other buildings at high product quality. The task will develop solutions for BIM informed deinstallation planning methods (BIM supported modular dismantling planning methods) and parametric design methods (based on the Autodesk parametric modelling tool Dynamo) for enabling architects and designers to integrate dismantled construction products into the design of new and to be refurbished buildings (Architectural design methods accounting for availability of reusable building components and recyclables). Part of this integration will make use of the embodied carbon estimation methods developed in T2.1 and integrated within the CP-IM to prioritize components for reuse based on carbon saving potential. A focus will be on the most common building components, starting with windows, façade elements, and HVAC components. The approaches will be validated by a user group of architects, construction and demolition contractors that will be established as part of this task. (Grant Agreement).

can obtain disassembly plans for the deconstruction of buildings and successfully upload disassembled components to the CP-IM platform to be reused. The results also present the structure of information attached to the reusable products and components through a UML class diagram based on the IFC (Industry Foundation Classes) ontology (further explained in Deliverable 1.1 in the Reincarnate project). It finally presents suggestions for additional Property Sets (Psets) for a seamless flow of information between actors in the construction industry.

This report suggests the incorporation of embodied carbon estimation methods (developed in task 2.1 by Mostostal) into the project, allowing stakeholders to select components for reuse based on their potential to reduce carbon emissions through decision-making. Initially focusing on commonly used elements like windows, façade systems, and HVAC units, this approach prioritizes materials with significant environmental impact benefits.

The project incorporates a collaborative framework, involving a dedicated user group of architects, construction experts, and demolition contractors. This group plays a crucial role in testing and refining the developed methodologies, ensuring they are not only theoretically robust but also practically applicable and user-friendly.

1.2. Relation to Other Work Packages

Within the project Reincarnate, Work package (WP) 3 holds a pivotal position alongside WP1 and WP2, each contributing essential tasks towards overarching goals. Task 3.2, focusing on methods for BIM-supported dismantling planning and the reuse of building components, stands as a key component of this phase. The outcomes of Task 3.2 were developed in collaboration with WP2 and WP3, facilitating the identification of circular design principles and the cataloging of reusable building components. Moreover, the insights gained from Task 3.2 will feed into WP5, where analysis of the ontology's effectiveness will inform strategies to enhance its role in fostering a circular economy within the built environment and business impact. This task is built upon the ontology developed in WP1 and takes those results as a basis. Finally, the practical application of these methodologies will be tested and refined in the project's demo cases.

1.3. Delimitations

This report delineates the scope and limitations of the research conducted under the current project, which has been developed to a Technology Readiness Level (TRL) of 4-6. At this stage, the methodologies and concepts presented are primarily theoretical and remain at a conceptual level. Consequently, the results discussed have not undergone practical testing as of the publication of this report. However, future testing is planned in various demo cases, including the Tiny House project conducted by 3L, The Water Treatment Plant conducted by VIAS, and the Ragn-Sells demo projects, which will provide empirical data to validate the findings and methodologies discussed herein.

The focus of this research is deliberately narrowed to three primary types of building components: windows, HVAC systems, and façade elements, with a particular emphasis on windows. This specific focus was chosen because windows were a central element of investigation in WP1, which provided foundational insights that are further explored in this report.

Moreover, the IFC ontology was chosen as the main ontology based on the work that has been done in WP1. This decision was based on a comprehensive evaluation of available options, where IFC ontology was deemed the most suitable given the current objectives and constraints of the project.
These delimitations are crucial for understanding the context in which the research findings should be interpreted and the potential implications for future studies and applications within the field.

2. Theory

2.1. Introduction to Theory

The theory chapter serves as the foundation upon which the results and analysis of this report are built upon. It delves into the conceptual framework and theoretical constructs relevant to the subject matter, providing a comprehensive understanding of the key concepts and principles guiding the study. Through a review of existing literature and theoretical perspectives, this chapter aims to contextualize the research, providing the theoretical underpinnings that inform the investigation and contribute to the advancement of knowledge in the field.

2.2. Reuse

2.2.1. Reuse in the Building Industry

The reuse of buildings is an important aspect of sustainable development, mainly because of its many environmental and economic benefits.

Environmentally, the reusing of buildings contributes to reducing the amount of waste sent to landfills as well as conserving natural resources. The construction industry contributes to a significant amount of waste and pollution, by reusing building products and components this impact shall be reduced. Additionally, reusing building materials can also reduce energy consumption and greenhouse gas emissions associated with the production of new building materials.

Economically, the reusing of buildings can assist with the creation of new jobs in sales of reused products, as well as reduce costs of building demolition and construction (Zhao, Leeftink, & Rotter, 2010).

To help promote reuse of buildings, Roper (2006) has found a few different strategies which can be implemented. These are improving the design of buildings for disassembly for more efficient removal and reimplementation, encouraging and promoting the use of reused products in construction projects as well as increasing public awareness about the benefits of reused products, further collaborations and partnerships between industry groups promoting the cause, and finally the implementations of incentive programs such as tax credits and subsidies.

Furthermore, in the study “Recycling concepts and the index of recyclability for building material” conducted by Vefago & Avellaneda (2013) the authors propose a method to evaluate the recyclability of building materials, which is also applicable for the reuse of products, named the *index of recyclability*. The index considered three main factors when evaluating the recyclability of building material, these were: material composition, processing requirements and the market demand for recycled materials.

The first factor of material composition refers to the material’s type and quality, such as its chemical composition, purity, and contaminants. The second factor of processing requirements refers to the possible cost and complexity of processing the material into a new product. And finally, the third factor, market demand, refers to the availability and demand for recycled and reused materials currently in the market.

The index of recyclability is a tool which can be used for comparing different building materials as well as for guiding material selection decisions in construction projects. The index can be used in such a way which could promote the use of recyclable materials and reusable products (Vefago & Avellaneda, 2013).

2.2.2. Material Banks

A concept to enable reuse of products and components is “existing buildings as material banks” (E-BAMB), referring to still operating existing buildings viewed as stock until integration into future constructions. This with the aim to enable shorter lead times and less financial resources that go towards storing components and materials for reuse, as they can be extracted directly from an old building ready for demolition into a new construction (Debacker & Manshoven, 2016). To be able to utilize existing buildings as material banks, a BIM model must be established correctly, and the contained data needs to be put into a database as well as be capitalized. The database will work as a catalogue of components to enable efficient and direct reuse for future buildings (Bertin et al, 2020).

For the database to be able to be utilized for the purpose of reuse, it needs to contain a substantial amount of data for designers to be able to integrate the old components into the new buildings. Old buildings are often lacking in terms of the amount of information available in this department. One of the ways to obtain needed information is to execute a scanning of the existing buildings to be able to gather the as-is information of the facilities in question regarding their components and materials (Mohamed, Abdallah, & Marzouk, 2020).

2.3. BIM

2.3.1. Introduction to BIM

BIM (Building Information Modelling) is at its core a digital representation of physical and functional characteristics of places/buildings and is a transformative approach to architectural and construction design. It offers a collaborative way of working, enabling stakeholders such as architects, engineers, contractors, and facility managers to work together on a single platform, sharing information and insights throughout the entire lifecycle of a building project.

BIM emphasizes not only on geometrical information but also metadata such as material properties, cost estimations and time schedules, enabling better decision-making from initial design to construction and maintenance. It also improves coordination among stakeholders and enhances overall project efficiency through the seamless exchange of information, coordination of tasks, and resolving conflicts in real-time (National Institute of Building Sciences, n.d.).

2.3.2. BIM for waste management

BIM-based tools and technologies today mostly focus its research on the design and construction phase, whilst research concerning the construction and demolition waste in post-construction stages has received much less attention. Nikmehr et al (2021) found that BIM-based technologies should be applied to support the theoretical foundations of managing waste beyond the design and construction stages and should be adaptable across various stages of a project's life cycle as well as focus on the smooth transition of data and information throughout all phases of delivering a project. Additional studies conducted by Ge et al (2017) found that to successfully identify hazardous materials such as asbestos and lead paint, deconstruction should be applied to manage the waste properly. In the study they used 3D reconstruction and BIM, and their results indicated that it could provide a visual environment that ensures accuracy of deconstruction materials, ultimately making waste management plans more accurate and timelier. Accurate identifications and estimations of deconstruction materials assists in formulating tailor made demolition waste management strategies which improves rates of reuse and recycles, saving costs of deconstruction and logistics as well as avoids mismanagements.

A study conducted by Guerra, Leite & Faust (2020) wanted to investigate whether 4D-BIM could enhance construction waste reuse and recycle planning in comparison to construction waste management planning by conducting a case study on concrete and drywall waste streams. The 4D-BIM strategy enables construction waste generation to be visualized at the same time as construction activities are performed, thereby facilitating the planning of construction waste reuse on-site, as well as construction waste recycling off-site. Strengths of the study relied on streamlining estimates of construction waste for reuse and recycle with the use of data commonly available and easily retrievable construction projects, therefore facilitating detailed construction waste management planning. Specifically, the application of the proposed approach is dependent on the availability of: (1) BIM with the 3D geometry of elements generating concrete and drywall waste (i.e. structural elements, and drywall partitions); (2) construction schedule; and (3) contractors' purchasing records of concrete and drywall materials. On the other hand, one limitation of the proposed approach is its dependency on the accuracy of purchasing records and BIM provided by the project management teams. Discrepancies between the elements build on-site and BIM may cause variations in the construction waste estimates, differences may also arise due to purchasing strategies adopted for each project, or significant rework activities that are not reflected in the construction schedule (Guerra, Leite & Faust, 2020).

However, an appropriate level of detail (LoD) for the required BIM-based parametric disassembly models as well as a methodology to automatically extract the corresponding parameters from a BIM model are often unknown. These knowledge gaps were addressed by Sanchez, Rausch, Haas, and Hartmann (2021) who developed a method to determine a appropriate LoD. The study aimed to describe and validate a methodology for determining parameters for BIM-based disassembly models to support the reuse of building components towards a circular economy in the construction industry. The BIM tools developed in the study demonstrated that it was possible to complete the information necessary for a disassembly model in a mostly automated and efficient way (Sanchez et al 2021).

2.3.3. BIM – Design for Deconstruction

Design for Deconstruction (DfD) is an approach that considers the ease and efficiency of disassembling structures at the end of their lifecycle. By integrating principles of DfD into the design phase, structures can be optimized for future disassembly, reuse, and recycling, thus minimizing environmental impact and promoting circular economy principles.

A literature review conducted by Akbarieh et al (2020) found that DfD was a part of BIM-based End of Life (EoL) decision making and digital deconstruction, identifying seven main research directions. These were: BIM based DfD (as already stated), social and cultural factors, BIM-based deconstruction, BIM-based EoL within LCA, BIM-aided waste management, Material and Component Banks, off-site construction, interoperability, and Industry Foundation Classes (IFC). The analysis found research gaps in the path of raw materials to reusable materials, i.e., from the deconstruction to Material and Component banks to DfD-based designs and then again to deconstruction. BIM helps with more transparency, which increases the collaborative spirit in a construction project and helps with clearly defining the EoL responsibilities in decision-making and execution. Additionally, the automation of tasks through BIM reduces waste due to design-errors and can offer a useful comparison between EoL alternatives (Akbarieh et al 2020).

Another study carried out by Akinade et al (2017) wanted to discuss the future direction of effective DfD by the usage of a BIM-based approach to design coordination by conducting focus group interviews. The results indicated three key functionalities of BIM-based DfD tools. These included; (i) improved collaboration among stakeholders, (ii) visualisation of deconstruction process, (iii) identification of recoverable materials, (iv) deconstruction plan development, (v) performance analysis and simulation of end-of-life alternatives, (vi) improved building lifecycle management, and (vii) interoperability with existing BIM software.

2.4. State of the Art

2.4.1. Introduction to State of the Art

To add onto the theoretic background, in this chapter a short introduction into state of the art is given. Specifically, two pieces, one project report and one paper, have been identified as relevant for the task and report at hand. The concepts that have been developed in this Task 3.2 as part of the Reincarnate project and enable the dismantling of products and components in buildings. These concepts are based on previous research projects and represent a further development of two articles written by Gutsche & Hartmann (2017) 'BIM parametric modeller, Deliverable Report D2.2' and 'A framework for BIM-based disassembly models to support reuse of building components, Resources, Conservation and Recycling' by Sanchez et al (2021). The summary of the for this project relevant parts can be found in the following two chapters.

2.4.2. P2Endure Project

P2ENDURE was an EU-funded research project for deep renovation and promotes evidence-based innovation solutions based on prefabricated Plug-and-Play systems to an e-Marketplace in combination with on-site robotic 3D-printing and Building Information Modelling (BIM) (Van Delft, 2017a).

One of the results from the P2ENDURE project is "The BIM Parametric Modeller," a tool that enables the user to design their building for energy-efficient renovation before the project starts. This is done by the user uploading their *as is BIM* to the P2ENDURE e-Marketplace and testing various products available on that platform (Gutsche & Hartmann, 2017).

The P2ENDURE e-Marketplace has an interface to a BIM-oriented procurement/tendering platform that facilitates multi-criteria decision, e.g. cost, time and quality, for optimizing the different options depending on the selected product (Van Delft, 2017b).

The prerequisite for this functionality is that the manufacturers describe their products in the e-Marketplace as detailed as possible, i.e. as IFC parameters. The authors of the article (from Technical University Berlin) have developed a UML diagram for the orientation of the product description in which the necessary attributes of the respective product group can be found. The parameterized description of the data is stored in a

Comma Separated Value-format (.csv) in a product catalogue and is loaded from the back end via an interface.

Consequently, the user can replace the parameters, i.e. the existing products, in their *as is BIM* so that it is updated with the alternative products with better energy-efficiency (Gutsche & Hartmann, 2017).

The P2Endure parametric modeller consists of several subsystems that operate as microservices and are interconnected via interfaces.

The architecture of microservices as subsystems facilitates maintenance, scalability, and expandability, making the parametric modeller flexible and enabling users to predict the building's performance based on BIM model data and products from the e-Marketplace.

To visualize the BIM model on the website, it is necessary for the IFC file to be converted into JavaScript Object Notation (JSON) format, and the diagrams that display the building's performance based on calculations from the various microservices are visualized through the JavaScript library d3.js, which can read data in the formats JSON and Comma Separated Values (CSV) (Gutsche & Hartmann, 2017).

The description of IFC parameters, UML-diagrams, an E-marketplace and microservices in the P2Endure report are used as the basis for the concept of enabling architects to design with reused products and components as a development in the task 3.2.

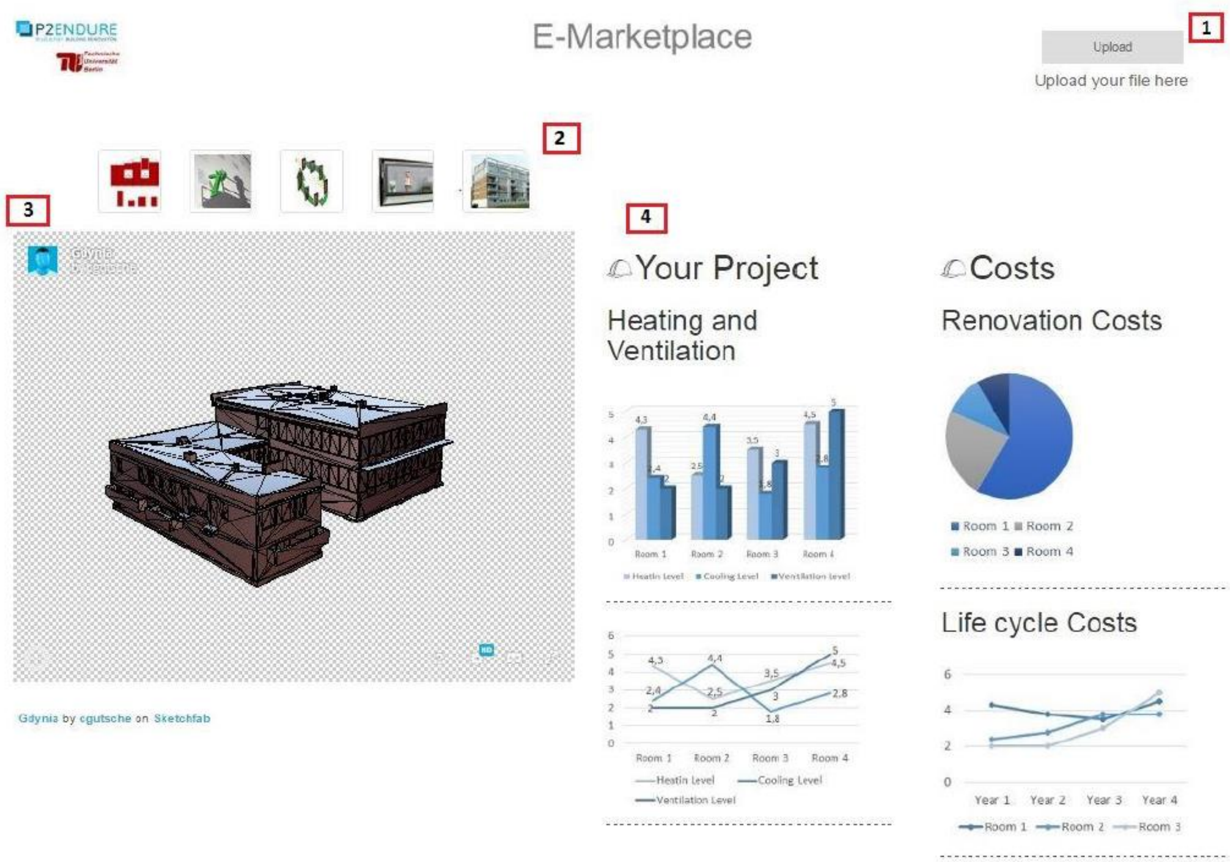

Figure 1: P2Endure front end (Gutsche & Hartmann, 2017).

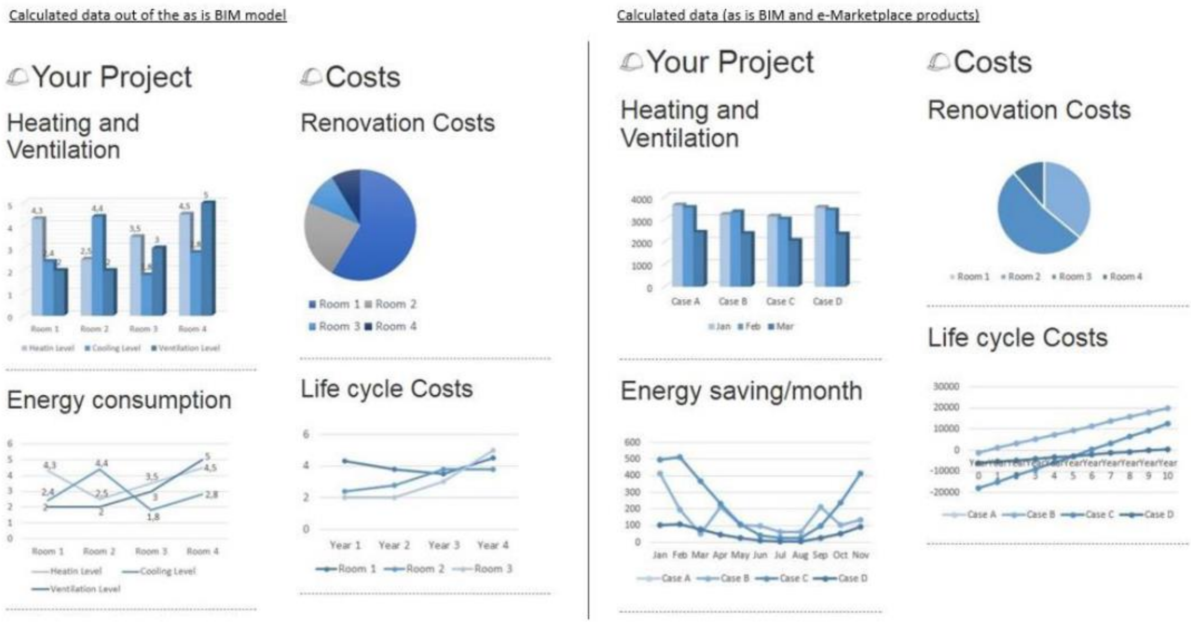

Figure 2: Representation of the simulated data using d3.js (Gutsche & Hartmann, 2017).

2.4.3. BIM for Disassembly

The article "A framework for BIM-based disassembly models to support reuse of building components" by Benjamin Sanchez et al (2021) presents a methodology for integrating Building Information Modelling (BIM) into selective disassembly planning for buildings, aiming to support the reuse of building components. It addresses the lack of a detailed level of detail (LoD) and a method for automatically extracting disassembly parameters from BIM. The methodology involves developing a framework for determining parameters for BIM-based disassembly models, proposing principles for multi-LoD disassembly models, and identifying necessary BIM parameters. Case studies validate the approach, demonstrating its effectiveness in creating disassembly models that facilitate the reuse of building components, contributing to a circular economy in the construction industry (Sanchez et al, 2021).

The methodology described in the article for integrating Building Information Modelling (BIM) into selective disassembly planning involves several key steps:

1. Definition of BIM Elements' Parameters for Selective Disassembly: This step involves establishing hosting relationships and adding corresponding parameter values to the BIM data structures. It focuses on developing parameters that define the physical and topological relationships between building components to support selective disassembly planning.

2. Generation of Parameters for Disassembly Models: This involves topological analysis of the disassembly model to determine specific constraint values for each BIM element, focusing on physical constraint parameters. This step is critical for creating accurate and functional disassembly models that can be used to guide the disassembly process efficiently.

3. Construction of Disassembly Graph (DG) Models: Based on the parameters defined in the previous steps, DG models are constructed to represent the disassembly planning process. These models are used to identify the optimal sequence of disassembly steps, considering various constraints and the interdependence of building components.

4. Information Taxonomy for Disassembly Models: The methodology also includes the development of an information taxonomy to organize and classify the necessary data

for disassembly models. This taxonomy helps in identifying, sorting, and defining the information required for effective disassembly planning, ensuring that all relevant parameters are considered.

5. Integration with Industry Foundation Classes (IFC): The methodology proposes extending the IFC schema to include new attributes and entities relevant to disassembly planning. This integration is aimed at facilitating the extraction and management of disassembly-related data from BIM models, making the information more accessible and usable for disassembly planning purposes.

6. Implementation through Visual Programming Languages (VPL): The methodology utilizes VPL environments, such as Dynamo, to preprocess the data and implement the proposed IFC extensions. This approach allows for the automation of data extraction and parameter definition processes, enhancing the efficiency and accuracy of disassembly planning.

This methodology aims to provide a comprehensive framework for utilizing BIM in the selective disassembly of buildings, facilitating the reuse of building components and contributing to sustainable construction practices (Sanchez et al, 2021).

The parameters for disassembly as outlined in the article serve as crucial data inputs for selective disassembly planning. These parameters are divided into categories, each with specific roles in the disassembly process:

- Classification: Includes parameters like Type Name, Unique Type ID, Part Type, and Disassembly Part ID. These parameters provide basic identification and classification of BIM elements, distinguishing between components and fasteners for effective disassembly planning.
- Building Element's Membership: This category consists of parameters related to the physical interdependence and connectivity between elements, including Hosted Components and Connection Hosted. These parameters help in understanding how components and fasteners are related and interconnected, which is essential for planning the disassembly sequence.
- Spatial Characterization: Encompasses parameters that define the three-dimensional location and physical constraints of elements within the disassembly model, such as Motion Constraints (in various directions), Working Space,

Assembly Openings, and Element's Location. These spatial parameters are crucial for understanding the physical layout and potential movement restrictions of elements during disassembly.

- Deconstruction Specifications: Include parameters such as Deconstruction Method, Deconstruction Cost, and Deconstruction Life Cycle Assessment (LCA). These parameters are used for evaluating the disassembly process from economic and environmental perspectives, allowing for the optimization of disassembly sequences based on cost, environmental impact, or a combination of factors.

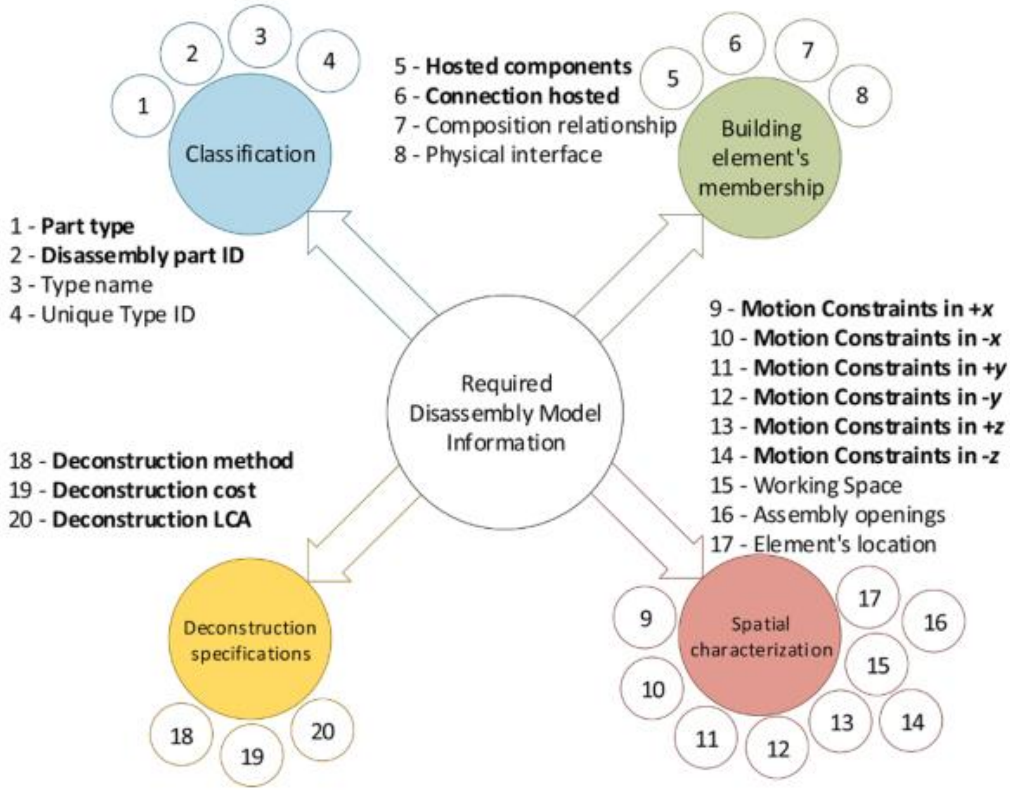

Figure 3: Required information for disassembly models (Sanchez et al, 2021)

These parameters are utilized in the SDPB (Selective Disassembly Planning for Buildings) approach to develop a multi-objective optimization analysis of the disassembly planning. They enable the assessment of disassembly sequences, helping to minimize deconstruction costs or environmental impacts, and make informed decisions about the disassembly process. This comprehensive set of parameters, collected from BIM models during the planning and design stage, forms the foundation for effective disassembly planning that aligns with sustainable construction and deconstruction practices (Sanchez et al, 2021).

The figure below visualizes the process of extracting data from IFC to disassembly models in the SDPB. The IFC parameters are combined to enable disassembly.

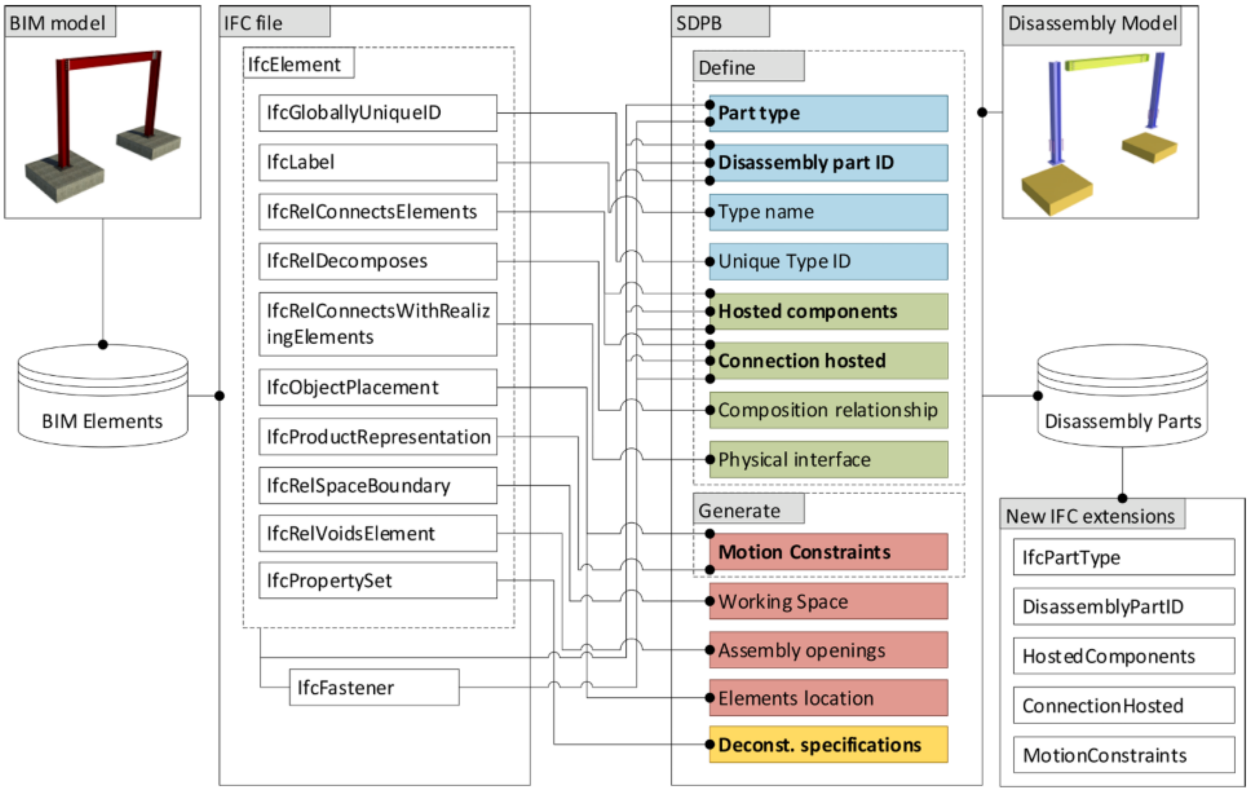

Figure 4: Overall process for SDPB (Sanchez et al, 2021)

These parameters for disassembly defined by Sanchez et al (2021) are used as the basis for the concepts for reuse and disassembly in the concept development of this report.

The research conducted by Sanchez et al (2021) also recognizes the critical role played by Selective Disassembly Planning, which is introduced as a concept whereby certain components are disassembled in a predetermined sequence in a BIM environment. While searching for literature on the subject of geometric sampling and physics-based methods, few studies where to be found. However, among these studies the method Assemble Them All (ATA); Physics- Based Planning for Generalizable Assembly by Disassembly conducted by Tian et al (2022) was found, which is an open-source repository that introduces an automated and digitalized approach to assembly planning by leveraging physics-based simulation to navigate the complexities of assembly tasks, particularly focusing on small scale products. They generated a large digital repository of the varied product models. The scope of their methodology is based on the product design for handling the intricacies of a variety of assemblies (single and multi-part) due to their need for a physics-based foundation. Their method utilizes the assembly-by-disassembly principle through physics-based simulation to efficiently explore disassembly path planning. Because geometric sampling methods rely on spatial relationships and deterministic movements, physics-based methods simulate the nuanced physical interactions between parts, offering a richer, more comprehensive understanding of assembly challenges. Also, geometric-based approaches cannot handle deformable objects since they cannot model the physical deformation (Tian et al, 2022). They formulate the disassembly path planning as in the form of a tree search, a concept starting from the root and exploring nodes containing the desired condition. In this case, initiating the search from the assembled state and searching for a sequence of actions until a disassembled state has been found or some time/depth limitation of the search has been reached (Tian et al, 2022). Their method, in the digital environment through a custom simulation approach, enables the possibility to simulate real-world assembly scenarios accurately through assembly-by-disassembly for products. They solve the assembly problem in reverse, starting from the assembled state and searching for a disassembly solution to reduce the overall search cost (Tian et al, 2022). Following the assembly-by-disassembly approach, disassembly path planning and disassembly sequence planning are illustrated.

Additionally, their assembly-by-disassembly approach primarily serves assembly-focused tasks, subtly sidelining the nuances of selective disassembly that this research aims to delve into. The open-source GitHub repository established by Tian et al (2022), which includes baseline path planning methods and simulations pivotal to their study, serves as a beacon for further exploration into physics-based disassembly planning of a custom assembly. Since ATA methodology is based on product models, which are basic mesh models, not BIM models, it is done through an iterative process with a pre-processing script (process_mesh.py).

2.5. Reuse Based on Carbon Saving Potential

Estimating embodied carbon footprint is an important step in measuring and subsequently optimising the environmental impact of a construction project as well as work as a basis for decision-making. Though, utilising secondary construction materials or elements is a common concept to reduce environmental impact of a building, measuring the exact carbon footprint savings poses challenges.

The current methodology for estimating the carbon footprint of buildings is based on Life Cycle Assessment (LCA) and standards - EN 15978 (methodology for the environmental evaluation of buildings) and EN 15804 (methodology for the environmental evaluation of construction products). The LCA methodology divides the calculation into several LCA modules, corresponding to the phases of the building life – extraction and transport of raw materials and production (modules A1-A3), product transport and construction (modules A4-A5), operation, maintenance and repair (modules B1-B3), replacement and refurbishment (B4-B5), energy and water consumption (modules B6-B7), demolition and transport of waste and its disposal or treatment (modules C1-C4), benefits and loads beyond the building life cycle (module D). Life cycle analysis (LCA) allows to quantify the impact of a product or building over its entire life cycle, taking into consideration multiple environmental issues, and thus avoiding pollution transfers. Though, depending on the selected LCA method large differences in results can occur (Douguet, 2022).

The end-of-life allocation significantly impacts products using secondary resources or materials. In LCA, two main strategies assess the use of secondary materials: the 'recycled content approach' (cut-off or 100:0 approach), which credits the use of secondary materials in the production stage and the 'end-of-life approach' (0:100 approach), which credits the recycling rate or use of secondary materials at the end-of-life stage. End-of-life approach focuses on the potential benefits related to the reuse of products at End-of-life so it will value products that are reusable. Whereas the cut-off (100:0 approach) focuses on the use a reused product, where the benefit is certain. This is in line with the “polluter pays” principle (Douguet, 2022).

Here it is important to distinguish between certain and potential savings.

- Certain Savings: Emissions reductions that can be directly and unequivocally attributed to a specific action or change in practice. For instance, in case when a secondary element is reused on a new site then the element does not end up on a landfill and consequently the waste disposal emissions are avoided.
- Potential Savings: Emissions reductions that are theoretically possible if certain conditions are met, however, may not be realized due to various factors. For

example, avoided emissions from not producing new materials assume that these materials would indeed have been produced if the reused materials were not available.

2.6. Industry Foundation Classes

2.6.1. Introduction to Industry Foundation Classes

Industry Foundation Classes, or "IFC", is a standardized, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard (ISO 16739-1:2018) usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases. IFC can define physical components of buildings, manufactured products, mechanical/electrical systems, and furthermore abstract structural analysis models, energy analysis models, cost breakdowns, work schedules, and more.

BuildingSMART is the international authority of the standard and have developed an IFC scheme that is a standardized data model that codifies, in a logical way, different aspects such as:

- The identity and semantics – name, machine-readable unique identifier, object type or function
- The characteristics or attributes – such as material, color, and thermal properties
- Relationships – including locations, connections, and ownership, of objects – like columns or slabs
- Abstract concepts – performance, costing
- Processes – installation, operations
- People – owners, designers, contractors, suppliers, etc

The schema specification can be used to describe how a facility or installation is used, how it is constructed and how it is operated (BuildingSMART, n.d.).

2.6.2. How IFC is used

IFC can be used to exchange information from one party to another but also as a means of archiving project information during different phases of a project, for example the design and construction or as an "as-built" collection of information for preservation and operations purposes.

A typical procedure where IFC is used is when an architect provides an owner with a model of a building design. The owner then sends the building model to a contractor to request a bid. When the building is built, the contractor can provide the owner an "as-built" model with details describing installed equipment and manufacturer information.

For the users to export, import and transmit data in IFC format, there are several software vendors of building information modelling tools that will provide an interface to do so and the IFC data can be encoded in various formats, such as JSON, XML, and STEP (BuildingSMART, n.d.).

2.7. Process Management and Maps for Visualisation

2.7.1. Introduction to Process Management and Visualisation

Process management involves the systematic identification, documentation, analysis, and improvement of workflows within an organization to achieve operational efficiency and effectiveness. One of the key tools used in process management is process mapping, which visually represents the sequence of activities, decision points, inputs, and outputs involved in a particular process. Developing process maps plays a crucial role in streamlining tasks and enhancing productivity by providing a clear understanding of the steps involved and potential areas for optimization (IBM, n.d.).

2.7.2. UML Diagrams

Different sorts of process mapping tools exist, including flowcharts, swimlane diagrams, and Unified Modelling Language (UML) diagrams to name a few (IBM, n.d.). UML diagrams are particularly advantageous for process mapping due to their versatility and standardized notation, they are graphical representations used to visualize and communicate the structure and behavior of systems and processes. They serve as a standardized language for various stakeholders involved in system design and development (Visual Paradigm, n.d.-a.).

UML diagrams come in various types, such as class diagrams, sequence diagrams, and use case diagrams, each with a specific purpose. These diagrams are not limited to software but can also depict business and system processes. They help clarify system requirements, design system architecture, and facilitate communication among team members and stakeholders.

Beyond software development, UML diagrams are instrumental in illustrating how business and system processes work, making them valuable tools for business analysts, process designers, and project managers. By providing a visual representation of complex processes, UML diagrams enhance understanding, streamline communication, and improve overall efficiency in both software development and broader business contexts.

UML diagrams can be categorized into two main types: structural and behavioural diagrams (see Figure x). Structural diagrams focus on illustrating the static elements and relationships within a system, such as classes and objects. In contrast, behavioural diagrams emphasize the dynamic aspects, showcasing how components interact and behave over time, including processes and workflows. Both types of diagrams serve distinct purposes in system modelling and design (Visual Paradigm, n.d.-a.).

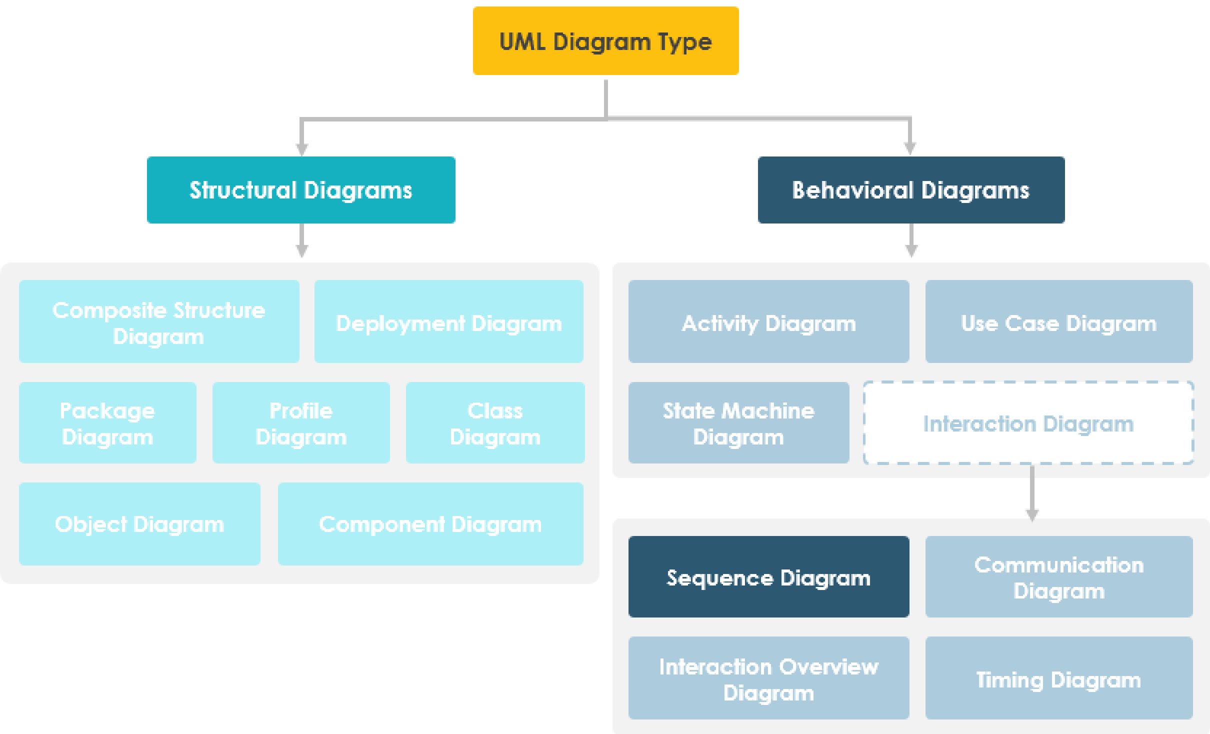

Figure 5. The structure of different UML diagram types.

2.7.2.1 Sequence Diagram

A sequence diagram is a type of interaction diagram, as seen in figure 6, that details how a system operates. The diagram visualizes the interactions between users of a system and the system or the interactions between different systems, this to provide a visualization of how objects interact with each other over time. The actions/messages are illustrated in the form of horizontal arrows, which are sent between the users and systems as sequences read from the top down (Visual Paradigm, n.d.-b).

The diagram consists of different objects which are illustrated as vertical lines with a box at the top stating which object the diagram is referring to, these are called lifelines. Each lifeline has an activation bar that shows during which time period an object is active. This is represented with a rectangle that goes from the first activity to the last of each lifeline (Visual Paradigm, n.d.-b).

The activities or communications between the lifelines is called a message. There are six common message types, they are synchronous, asynchronous, asynchronous return, asynchronous create, reply, and delete message (IBM, 2021). The synchronous message is represented by a solid arrowhead and line, this is used when a lifeline asks or needs something from another lifeline and is made to wait for a response before, they can continue. An asynchronous message does not require a response and is shown by a solid line and a lined arrowhead (Lucidcharts, n.d.-a). The return and create message to the synchronous message is represented by a dashed line and a lined arrowhead. A reply message is also represented by the same type of arrow as the return message and is used as a reply to either a synchronous or an asynchronous message (Lucidcharts, n.d.-a). The last message is the deleted message, this message destroys an object and is shown by a solid line with a solid arrowhead and an “X”.

When a message or several messages are recurring, they can be put into a box stating “loop” in the top left corner. There can also be an alternative set of messages within the loop, then the box states “alt.”. An example of this can be if a particular thing needs to be tested every day to see if the response is negative or positive where not until it is positive it should still be checked every day, but as soon as the response is positive the outcome is different. When this happens, the “alt.” stated messages occur instead of the messages inside the “loop” and another set of messages or activities are sent out.

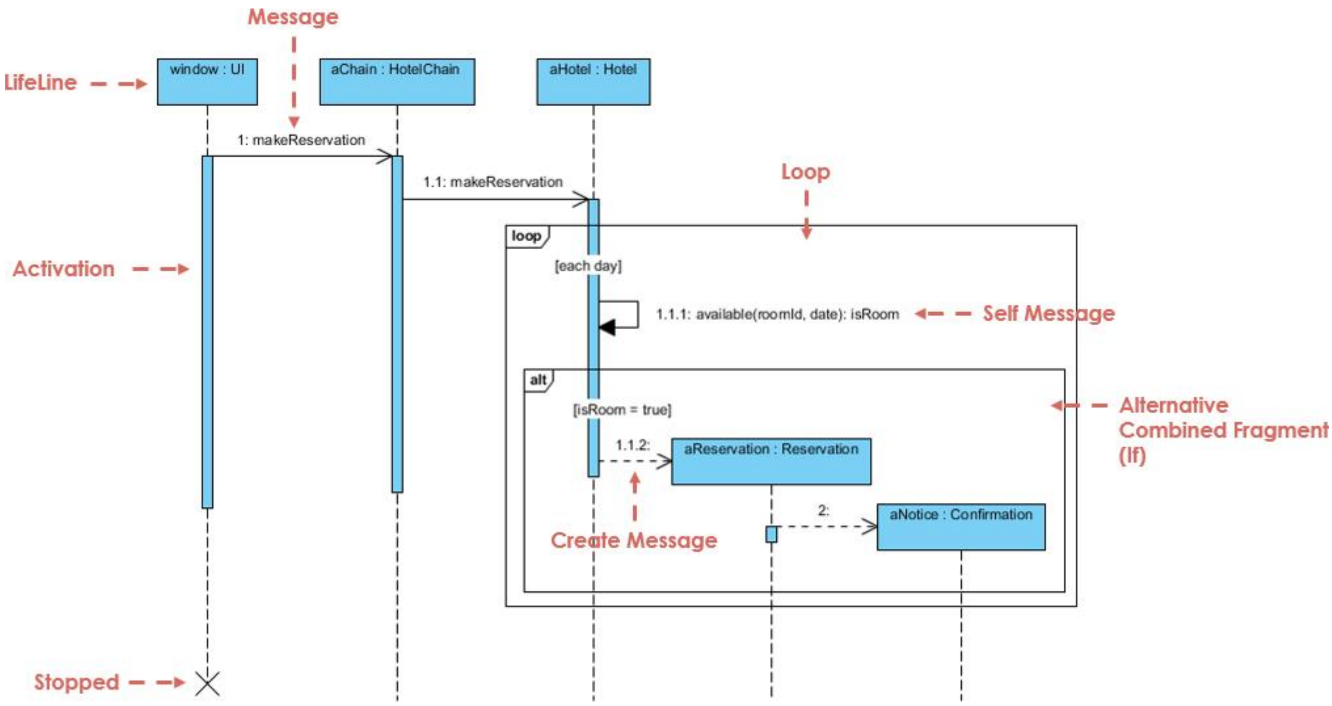

Figure 6. Visualization of the structure of a UML Sequence diagram.

2.7.2.2 Use Case Diagram

A UML Use Case Diagram serves as a behavioral diagram in systems analysis and design, as depicted in Figure 7. It offers a visual representation of how an actor, typically a user, interacts with a system, shown in Figure 7, elucidating the sequence of use cases (actions) within the system from the actor's perspective (Visual Paradigm, n.d.-c). This diagram effectively encapsulates the relationships between various activities termed "use cases", actors, and the system itself. It provides a concise portrayal of an actor's objectives and the sequential steps required to achieve specific goals. Moreover, use cases articulate the functionalities within the system, delineating the processes in which the system engages. The delineation of the "system boundary" visually outlines the system and the encompassed use cases (Usability, n.d.).

In essence, a use case summarizes a specific function within the system, initiated with a verb and establishing the necessary connections with actors. While each actor needs to be connected to a use case, a use case might not need to be connected to an actor. The actor, serving as the primary initiator of the process, provides input to the system and expects corresponding output. Use cases can be categorized into base use cases and child use cases, where the base use cases represent a fundamental, standalone functionality whilst in the child use cases more specialized or detailed behaviors can be shown. Child use cases also inherit the functions from the base use cases which they are connected to. (Visual Paradigm, n.d.-c).

The interplay between actors and use cases, as well as amongst different use cases, is facilitated through connection links. One type of link is symbolized by a solid line, to elucidate the interconnections (Lucidcharts, n.d.-b). They depict the manner in which actors and use cases interact. Furthermore, three distinct use case relationships are utilized to describe these connections. The first, known as 'extend,' signifies optional occurrences and is illustrated by a directed arrow with a dotted line, with the arrowhead pointing towards the base use case (Visual Paradigm, n.d.-c).

In a UML Use Case Diagram, several types of lines illustrate the relationships between actors, use cases, and systems. Association lines, depicted as solid lines, signify interactions between actors and use cases, or amongst different use cases. Extend relationships, represented by dotted lines with arrowheads, indicate optional functionalities that extend a base use case. Include relationships, also shown with dotted lines and arrowheads, signify essential functionalities included within a use case. Generalization relationships, depicted with dotted lines, arrowheads, and triangles, represent inheritance between use cases, where a child use case inherits behaviours from a parent use case (Visual Paradigm, n.d.-c).

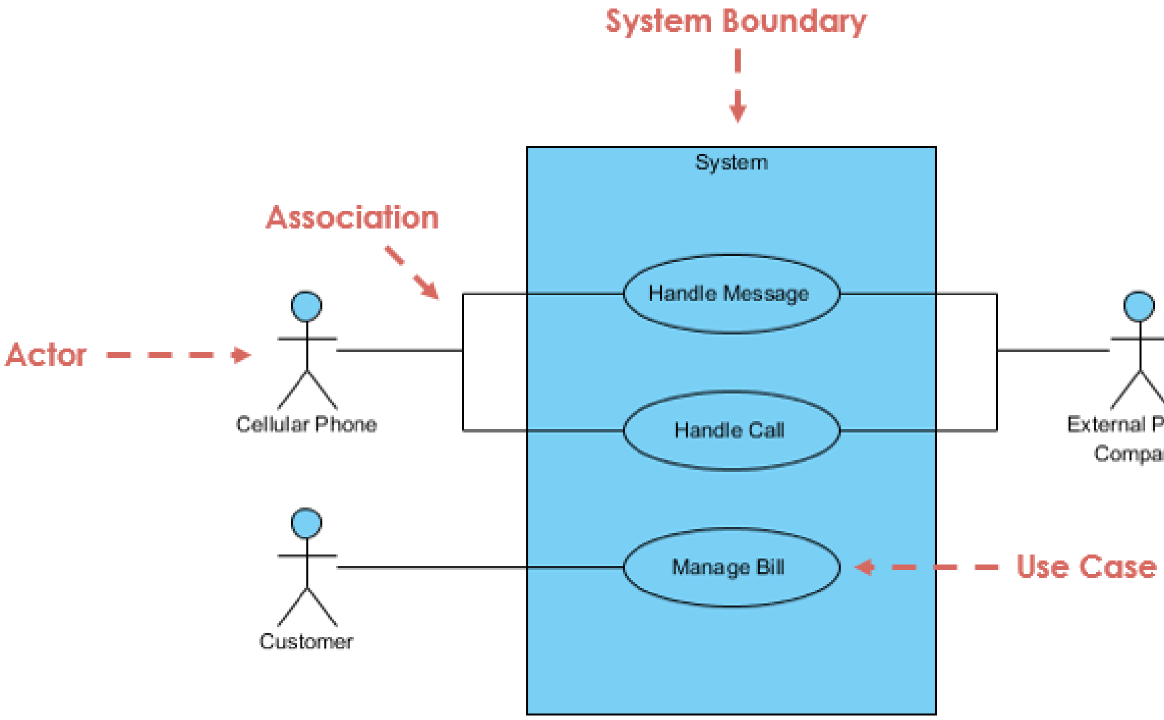

Figure 7. Visualization of the structure of a UML Use case diagram.

2.7.2.3 Class Diagram

A UML class diagram is a type of structure diagram that describes the structure of a system by illustrating the system's: classes and the classes' attributes and operations, as well as their relationship to one another. The class diagram is a graphical notation used to construct and visualize object-oriented systems. A class is a blueprint for an object, a class describes what an object will be but is not the object itself. The classes are illustrated as a box with the class name in the first partition (see figure 8), the classes' attributes in the second partition, and finally the classes' operation in the third partition. The attributes describe the classes' properties and the operation describe the classes' behaviour or method. What's stated for the attributes and operation starts with the symbols "+", "-" or "#" which denote the visibility of the attribute. The symbol "+" denotes that the information is public, "-" denotes that the information is private, and "#" denotes that the attribute or method is protected. What is stated for the attributes and operations section can either be with or without signatures, which informs the reader about what format the attribute or operation is stated in (Visual Paradigm, n.d.-d).

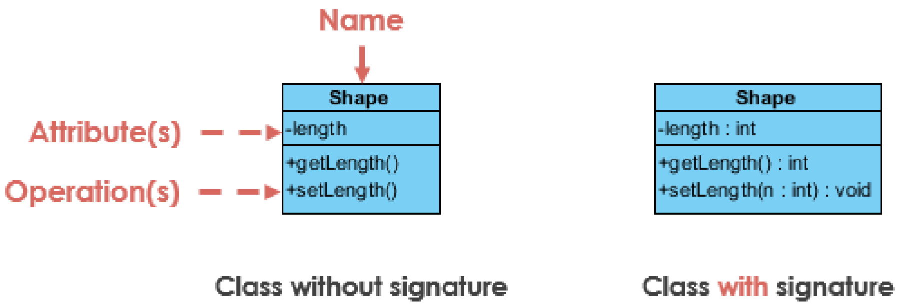

Figure 8. Visualization of the structure of the classes in a class diagram.

In the UML class diagram there are also different types of relationships between the classes which are illustrated with different arrows and symbols. The class diagram can exactly convey how code should be implemented just from looking at the diagrams. The figure below shows the different types of relationships the classes may have to one another (Visual Paradigm, n.d.-d).

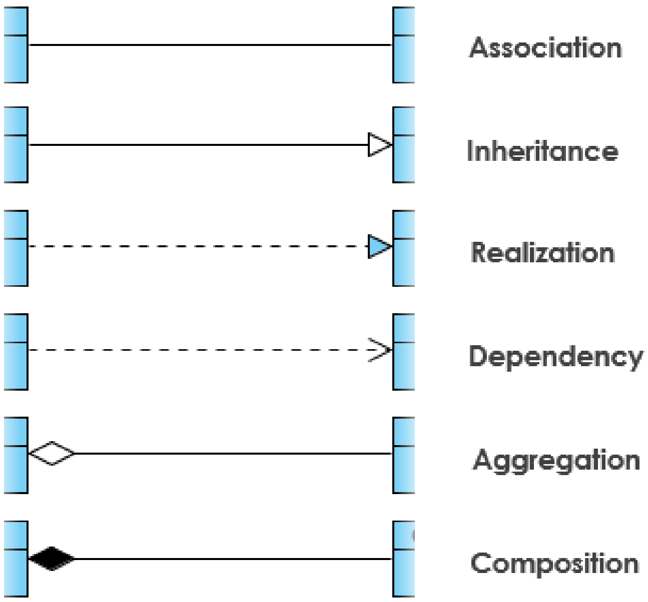

Figure 10. Visualization of how the different types of relationships are illustrated in a class diagram.

- Association: One class is associated with another class, e.g. a student class can be associated with a course class representing the courses that the students are taking.
- Inheritance: One class is a subclass of the other class and the subclass inherits the attributes and operations from another class, e.g. a dog class inherit attributes and operations from an animal class.
- Realization: The relationship between two classes where one class implements the behaviour specified by another class, e.g. a car class can realize the behaviour specified by an engine class which defines methods for starting and stopping etc.
- Dependency: Dependency is a relationship between two classes where one depends on the other, e.g. a student class is dependent on a teacher class providing the students with methods for lecturing and grading.
- Aggregation: Is a representation of a relationship between two or more classes where one class is a collection of other classes, e.g. a department class can have a collection of employee classes.
- Composition: Represents a relationship between two or more classes where one or more classes is a part of another class, e.g. a house class can have a window class which represents the windows of the house (Visual Paradigm, n.d.-d).

3. Method

Regarding the methodology of this study for gathering data, analysing, and ultimately bringing forth a result, approaches have been established which are illustrated in figure 11.

Initially, the philosophy of interpretivism was adopted. An interpretive philosophy recognizes that reality is socially constructed, subjective as well as context dependent. It emphasizes understanding the diverse meanings individuals attribute to their experiences within their natural social context. Interpretivism do not believe that there is a single objective reality but instead values the exploration of subjective perspectives (Bell et al, 2019).

Moreover, this study employs a deductive reasoning for its research design. Deductive reasoning entails moving away from general theories or hypotheses and instead views specific observations or predictions. In this study, the research establishes theories and hypotheses related to the phenomenon being studied and seeks to test these through the collected qualitative data, meaning that the collected data consists of non-numerical information and focuses on the depth and diversity of individual narratives. Additionally leading to the chosen way for data collection, which was conducted through semi-structured interviews. Semi-structured interviews implies that the researcher has a set of pre-determined questions or topics to guide the conversation, but there is flexibility during the interview to add follow-up questions or dig deeper into certain topics of interest.

The interviewees for the study were collected using a purposive sampling method. A purposive sampling method is a non-probability sampling technique in which researchers intentionally select participants based on specific characteristics or criteria relevant to the research question. This means that instead of randomly choosing participants from a larger group of participants, a deliberate and purposeful selection process has been conducted where the researchers have chosen participants based on relevant criteria matching the research objectives providing information-rich data.

Ultimately, a thematic analysis has been conducted as the data analysis method. This involves systematically identifying, analysing, and reporting patterns or themes within the qualitative data. The analysis begins with familiarization with the data, followed by coding, theme generation, and interpretation. Thematic analysis allows for the discovery and exploration of recurring patterns and meanings within the dataset (Bell et al, 2019).

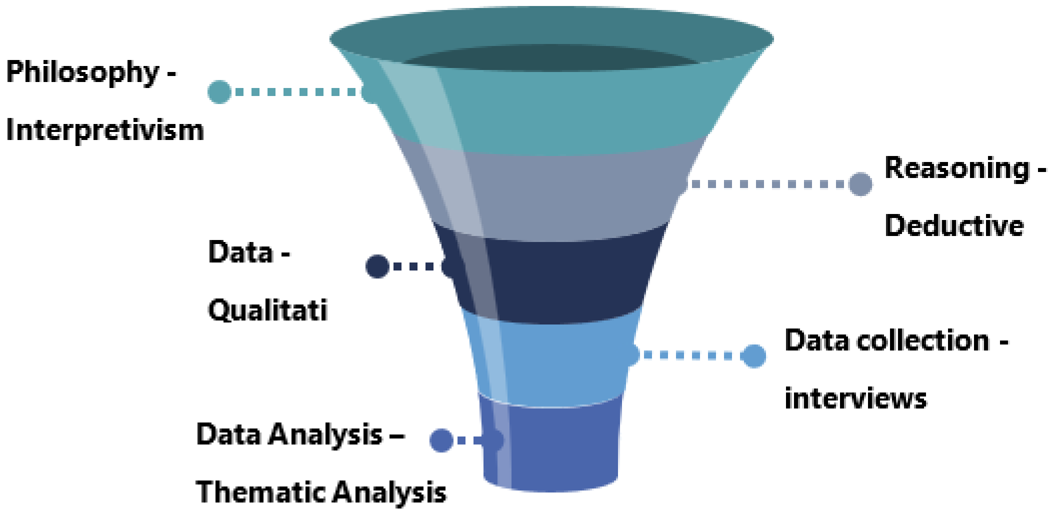

Figure 11. Visualization of method for gathering and analysing information.

4. Results and analysis

4.1. Introduction to results and analysis

The following chapter describes the practical process and the results developed in Task 3.2. The Task is focused on the development of a concept to use BIM for dismantling planning and to support the reuse of building components. The main components for the concept development are windows, facade elements and HVAC, and the users in focus are designers and architects.

As described in the theory and methodology chapter, the process has been iterative and practice oriented. The main input to the concepts is derived from industry and academic experts inside and outside the Reincarnate consortium. Interviews, prototyping, and feedback loops led to the concepts presented in chapter 4.2.

In the following chapter, first the initial steps in the concept development are described to showcase the iterative character of the research and development. In the second part, the UML diagrams are presented and described as the results and visualisation of the findings. Lastly, the feedback from the test groups is summarized and how it has impacted the concepts.

4.2. Iterative Concept Development

4.2.1. Parameter Definition for Dismantling and Reuse

The process of developing a concept for de-installing products from a building and to reuse them in another building started with a screening of the existing research. The main source and background for the dismantling part is described in chapter 2.4.3. It was quickly decided to build on the existing research and to focus on the reusability aspect which had not been considered in the context explicitly.

To evaluate the reusability automatically, similar to the dismantling process, it is crucial to have the necessary information and data for such an evaluation. Therefore, the first step in the concept development process was to define the data and information requirements: what information is needed to determine if a product can be reused. This type of information we refer to as “parameters”. Of course, these parameters vary substantially for each type of product (window, façade element and HVAC).

The first step in the process was to do interviews with experts from different disciplines to get the varying perspectives represented in the parameters. As expected, the required information differs widely between different actors. A dismantling company for example, is mostly interested in size and weight of components for transport, and an architect focuses more on the condition and aesthetic of a product. Based on the interviews, a first list of required parameters was created for each category. These lists were iterated with the Reincarnate consortium members and additional industry experts. The parameters were first collected in an excel file and iterated several times. All parameters are (where possible) defined in the IFC (Industry Foundation Classes) format, according to the Reincarnate ontology. The defined parameters almost all can easily be saved in a BIM model, but practically that is not yet done in most projects today, the level of detail is much lower. Therefore, it was then decided to differentiate between basic parameters and advanced parameters for dismantling and reusability to make the concept more accessible from the beginning. The dismantling parameters can be found for reference in appendix 1.

The evaluation of different methods and visualisations for the concepts from Excel lists, over texts and process maps, resulted in the use UML diagrams to visualize the actual concepts in the best way. The process and the final concepts are described in chapter 4.3. The parameters are visualised in a class diagram.

4.2.2. Processes for CP-IM users

After the first drafts of parameters for reusability were developed, the parameters had to be incorporated into a process to create a theoretically usable concept, instead of just a list of parameters. As one of the aspects of Task 3.2 the main actors were defined as architects and designers who want to incorporate used products in their buildings. The second actor or user which was identified is a property owner, because they can have a crucial and influential role in the reuse process.

In Work Package 1 of the Reincarnate project the CP-IM is developed. With the CP-IM as a starting point and interface to the user, two user journeys were developed for the two user groups: architects and property owners. The methodology used was similar to the one used for the parameters. Expert interviews were analysed and used to build the user journeys, answering questions like “what would an architect do first?”, “how would a property owner use the CP-IM if they wanted to support reuse of components?”. The user journeys and drafted process maps were discussed and tested with the consortium members and then iterated and adjusted.

As the most suitable methodology to visualize the process concepts UML diagrams were identified. Starting from Use Case Diagrams, additionally Sequence Diagrams, a Class Diagram were developed and iterated. The process and results in the UML diagrams is described in the following chapters (chapters within chapter 4.3). Because of the nature of the process concepts, it was decided to focus on Sequence and Use Case diagrams as visualisations, as well as a Class Diagram for the structuring of data. The content is the same, those visualisations seemed to illustrate the purpose in a better way.

4.3. Process Mapping Using UML Diagrams

4.3.1. Standard Format for Understanding the UML Diagram Results

In this chapter, the results developed and visualised as UML diagrams are presented. The UML diagrams help to describe how the innovation BIM modular dismantling planning methods (which is developed in the Reincarnate project and described further regarding what it entails in chapter 1) is to be accomplished by using the CP-IM platform. The first subchapter is illustrating the processes by using the Use-case diagram framework for the innovation, showing which actors are involved in each action and the actions that are being performed. The second subchapter explains the processes by using the Sequence diagram framework, this clarifies how the actions are sequenced to one another and how these are communicating between the systems enabling and supporting the innovation. Finally, the third subchapter explains how the data based on the developed parameters shall be structured using the format of a class diagram. This is essential to seamlessly exchange data between actors and to define clear data and information requirements.

To understand the Use Case diagram and the Sequence diagram, the different actors need to be explained. Those are defined as followed:

- **Property owner** - Signifies the actor wanting to make products in a building available for reuse. They use the CP-IM platform to assess the reusability of the components and to generate a disassembly plan to be able to disassemble a building or a specific part of a building in the easiest and best way possible.

- **Designer** - Signifies the actor wanting to reuse products for their new building which is to be constructed within approximately 1-4 years. This can be someone who works e.g., as an architect or a constructor.
- **CP-IM** – This actor (or lifeline in the sequence diagram) refers to the front-end of the CP-IM platform, which the property owner interacts with for the purpose of making products available for reuse, as well as the designer for the purpose of reusing products and components. The CP-IM stores and provides information through API solutions as a basis for decision-making to enable reuse at high product quality and low CO2 emission.
- **Microservices** – Regarding the Use-case diagram and the Sequence diagram for the process illustrating from the property owners perspective, the microservice is a BIM-modeller. The tool provides a disassembly plan and a reusability assessment to the property owner. In the Use-case diagram and Sequence diagram depicting from the designers point of view, microservices refer to a calculation tool calculating values for a dashboard to support decision making showed in the CP-IM.
- **Storage** – The storage is in the back-end of the CP-IM and stores all the data and information regarding the products and components for reuse. The information is structured according to the class diagram depicted in chapter. The storage can either be in the CP-IM back-end or at other independent initiatives (e.g. E-marketplace) which can connect to the CP-IM through an API solution.
- **Calculation tool** – The calculation tool provides calculations to support decision-making for designers. These calculations are to be illustrated in a dashboard shown in the CP-IM. However, the calculation tool is a microservice outside the CP-IM platform which is connected through an API solution.

4.3.2. UML Use-Case Diagram

4.3.2.1 Reuse from the property owner's perspective

In this section the process depicting how the property owners shall offer their reusable products at a high product quality by using Building Information Modelling (BIM), will be visualized using the framework of UML Use Case diagram. This process will work together with the outcome of deliverable 3.3, see appendix 2. The UML Use Case Diagram for reuse from the property owner's perspective illustrates the interactions between the property owner and various systems, delineating the functions of each system and the nature of information they furnish (see figure 12).

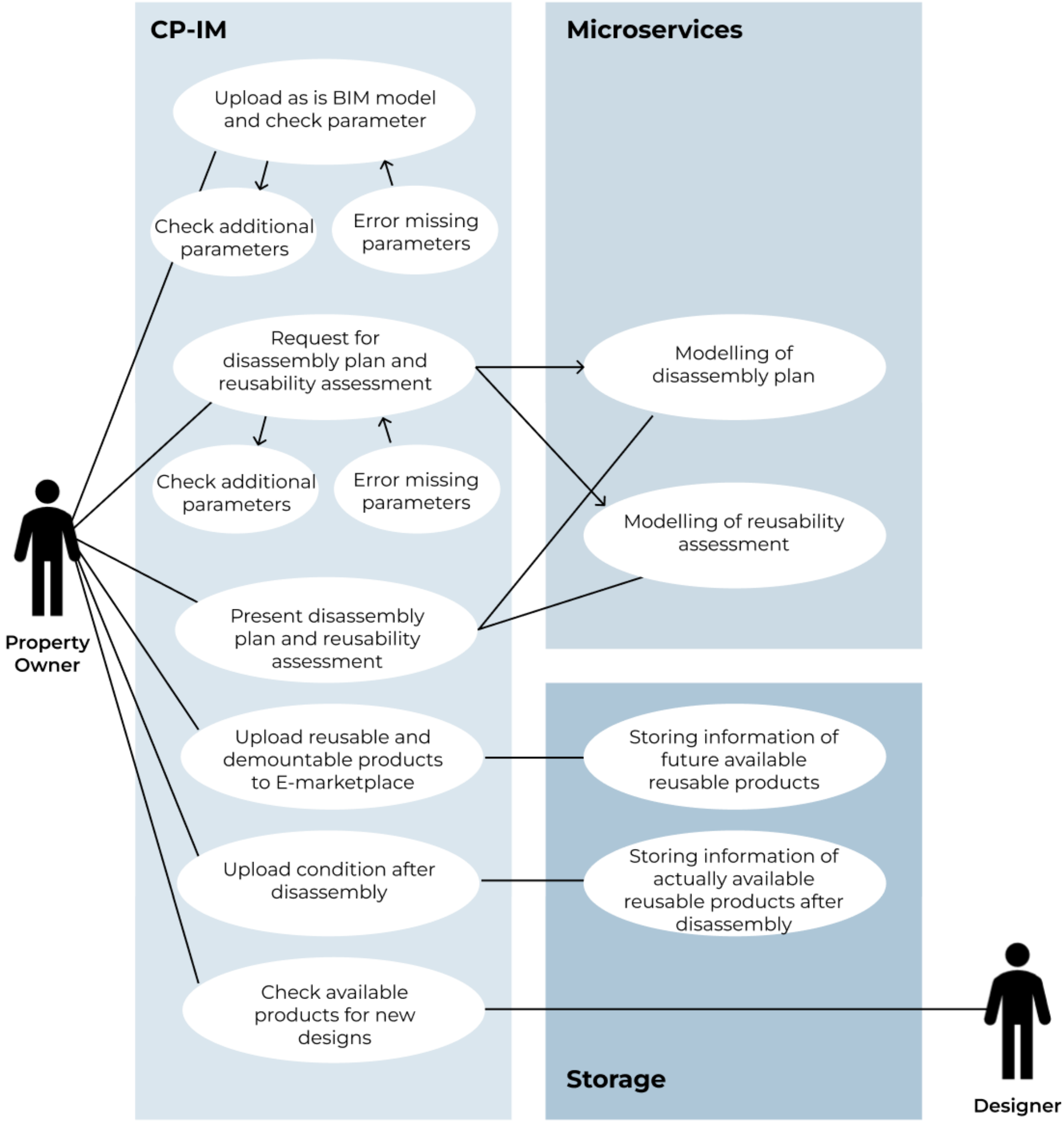

Figure 12: Use case-diagram for the innovation BIM modular dismantling planning methods, how the property owner upload reusable products.

Initially, the property owner starts the process by uploading the as-is BIM model, representing the current state of the building, onto the CP-IM platform. Subsequently, the CP-IM platform verifies the presence of required basic parameters for reusability (according to appendix 1), as stipulated within the platform's predetermined requirements.

Upon the property owner's request for a disassembly plan and reusability assessment, the CP-IM platform further reviews the as-is BIM model for additional parameters applicable for disassembly and reusability. If the model meets approval criteria, the CP-IM platform dispatches a request to a designated microservice, such as the disassembly modeler established within the study conducted by Sanchez et al (2021). The disassembly modeller then furnishes a disassembly plan and reusability assessment, transmitting product-related information back to the CP-IM platform, which subsequently presents and visualizes this information for the property owner. This enables the property owner to execute the disassembly of their building or property with a heightened level of precision and quality.

Moreover, within the CP-IM platform, users can request the uploading of reusable and demountable products to and online database or storage (e.g. E-marketplace), facilitating visibility of available products for users and designers. Post-disassembly, the property owner updates the physical condition and quantity of products, ensuring accurate information within the storage. Designers can then utilize the CP-IM platform to identify reusable products, a process elucidated within the sequential and use-case diagram for the designer's perspective depicted in the following chapter.

4.3.2.2 Reuse from the designer's perspective

To describe the concept in which designers can integrate high-quality recycled products into new buildings through Building Information Modelling (BIM), the process has been visualized by using the UML Use-case diagram framework. This process will work together with the outcome of deliverable 3.3, see appendix 3. The approach is employed to provide a comprehensive understanding of how designers can leverage Reincarnate's innovation platform, the CP-IM. Figure 13 illustrates how the designer, the primary user, and the property owner, a secondary user, will interact with the CP-IM platform. It also demonstrates how the platform interacts with additional systems, which in this case are storage and microservices.

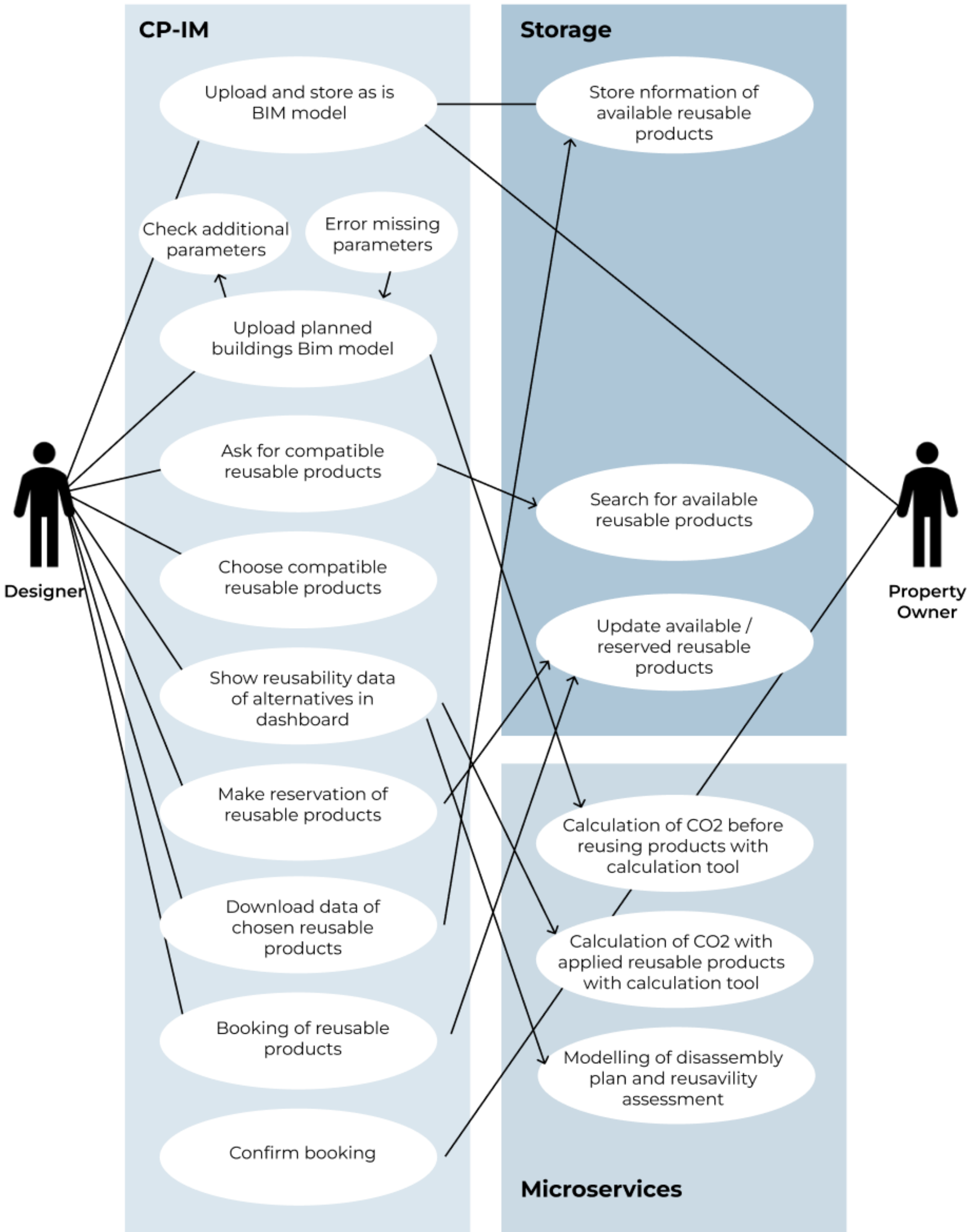

Figure 13: Use case-diagram for reuse from the designer's perspective.

The initial step for the designer involves uploading their BIM model of the intended new building into the CP-IM. It is important at this stage that the BIM model is in the IFC format, enabling the CP-IM to read the file. The CP-IM will then ensure that all necessary parameters for facilitating reuse are in place.

Once the BIM model is uploaded, an initial assessment of the building's environmental impact is calculated based on its data through a microservice. Simultaneously, the designer can search for recycled products that meet their specified requirements. The reusable products available for search within the CP-IM are those uploaded by the property owner through the CP-IM, and ultimately stored in the storage which for example is a national e-marketplace or simply a database within the CP-IM.

The designer can then choose reusable products from the different compatible alternatives suggested by the CP-IM. After choosing a product, a reusability assessment is calculated based on its information through a microservice and compared with the uploaded BIM model. The designer then makes a reservation on the chosen reusable product/-s and downloads the datasheets of information.

By using the downloaded datasheets, the designer can use the information in a parametric design tool (view deliverable 3.3 from the Reincarnate project) to evaluate the design of the building with the reused products.

When the designer is content with the product selection, these products are booked through the CP-IM. Information about the booking of products is sent to the storage, subsequently updating the status of available reusable products.

The integration between the CP-IM and the microservices is facilitated through APIs and is made possible by the CP-IM being an open-source platform.

4.3.3. UML Sequence Diagram

4.3.3.1 Reuse from the property owners perspective

To illustrate the process of the property owner and how they interact with the systems in order to get their products reused, the innovation has been applied to the UML Sequence diagram framework. The UML Sequence Diagram regarding the innovation BIM modular dismantling planning methods in the Reincarnate project consists of four lifelines, CP-IM, microservices and storage, which are described in chapter 2.6.2.1. In this case, the microservice is a disassembly modeller. The tool provides a disassembly plan and a reusability assessment to the property owner.

This diagram 14 below shows how the CP-IM will be involved in generating a disassembly plan and to also give the owner an assessment of the reusability of the products in the model.[2]

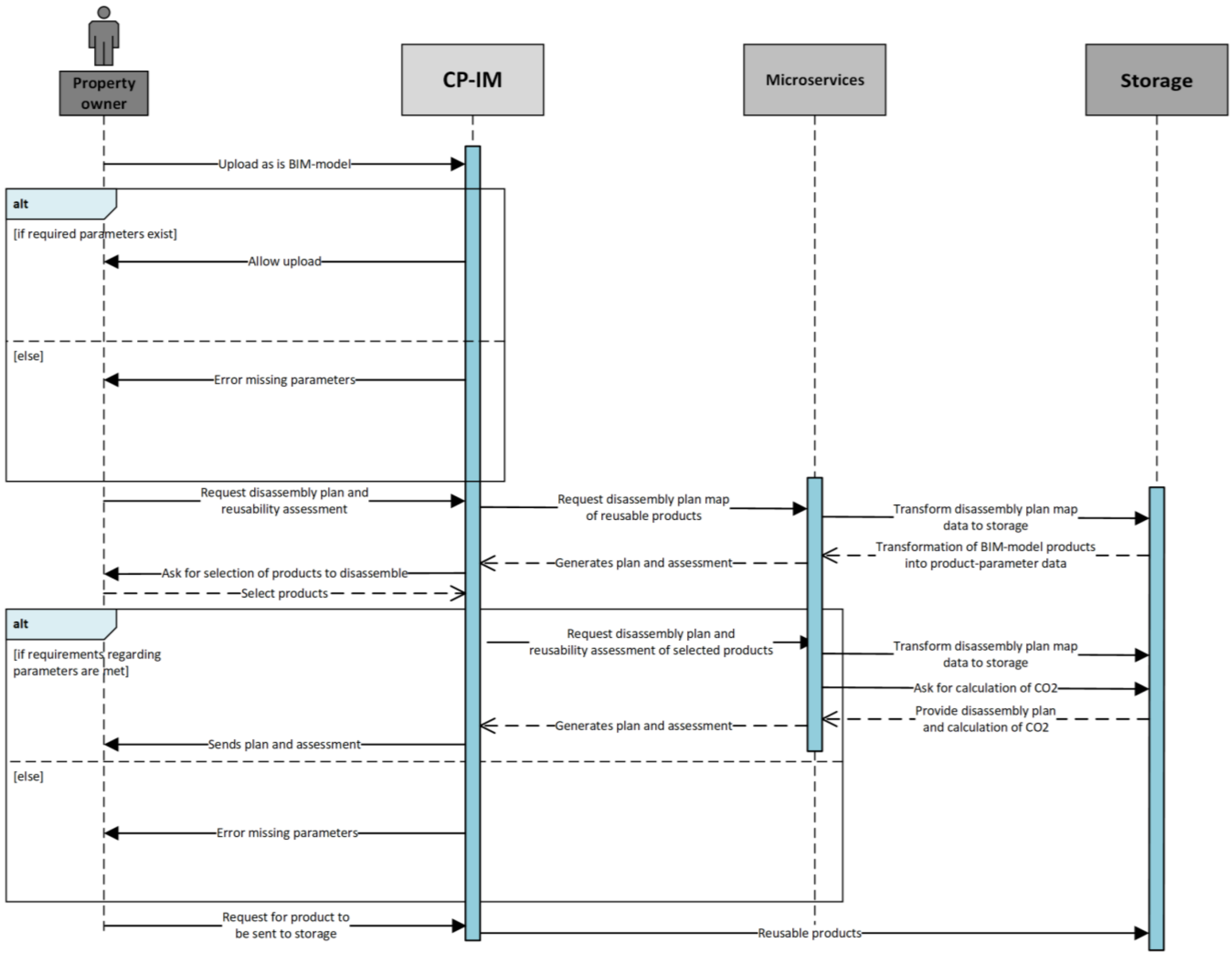

Figure 14: UML Sequence diagram for the innovation BIM modular dismantling planning methods, how the property owner upload reusable products.

The property owner or any user who has a building that is going to be disassembled start the process by uploading their *as is BIM*-model to the CP-IM, which is the BIM model in

[2] The process is the same as in the Use Case diagram figure 12.

its current state. First the platform checks that the IFC-model contains the required basic parameters. If the required parameters are not met, then the property owner will be sent an error message with information about the parameters missing.

The property owner then sends a request for a disassembly plan and reusability assessment. They can choose to check all or just some products in the model for disassembly. The CP-IM then checks if the chosen product meets the requirements regarding disassembly and reusability parameters. These requirements are already predefined in the CP-IM and are explained in chapter 4.3.4. If the requirements are met the CP-IM sends a request to the disassembly modeler (microservices) for a disassembly plan and reusability and mapping of reusable products. The microservice will then send a disassembly plan map through data to the storage which in return will transform the BIM model products into product- parameter data to the disassembly modeller. The disassembly modeller will thereby provide a disassembly plan and map the reusable products to which will be viewable in the CP-IM leading to the platform asking the property owner to make a selection of product that it wants to disassemble and answering by selecting products.

After a product/-s has been selected the CP-IM will request disassembly and reusability assessment of the selected products to the disassembly modeller. This later transform a disassembly plan map data to the storage and ask for calculation of CO2, which will be provided by the storage. The disassembly plan from the information provided generate a plan and assessment to the CP-IM. This is then sent back to the CP-IM that in turns sends it to the property owner. If the requirements are not met the CP-IM will message the property owner with an error message. The property owner can then choose to request for the reusable products to be sent and shown in the Storage.

4.3.3.2 Reuse from the designer’s perspective

The following UML Sequence Diagram demonstrates how a designer interacts with the CP-IM platform to reuse products and components while maintaining high product quality and minimizing CO2 emissions.

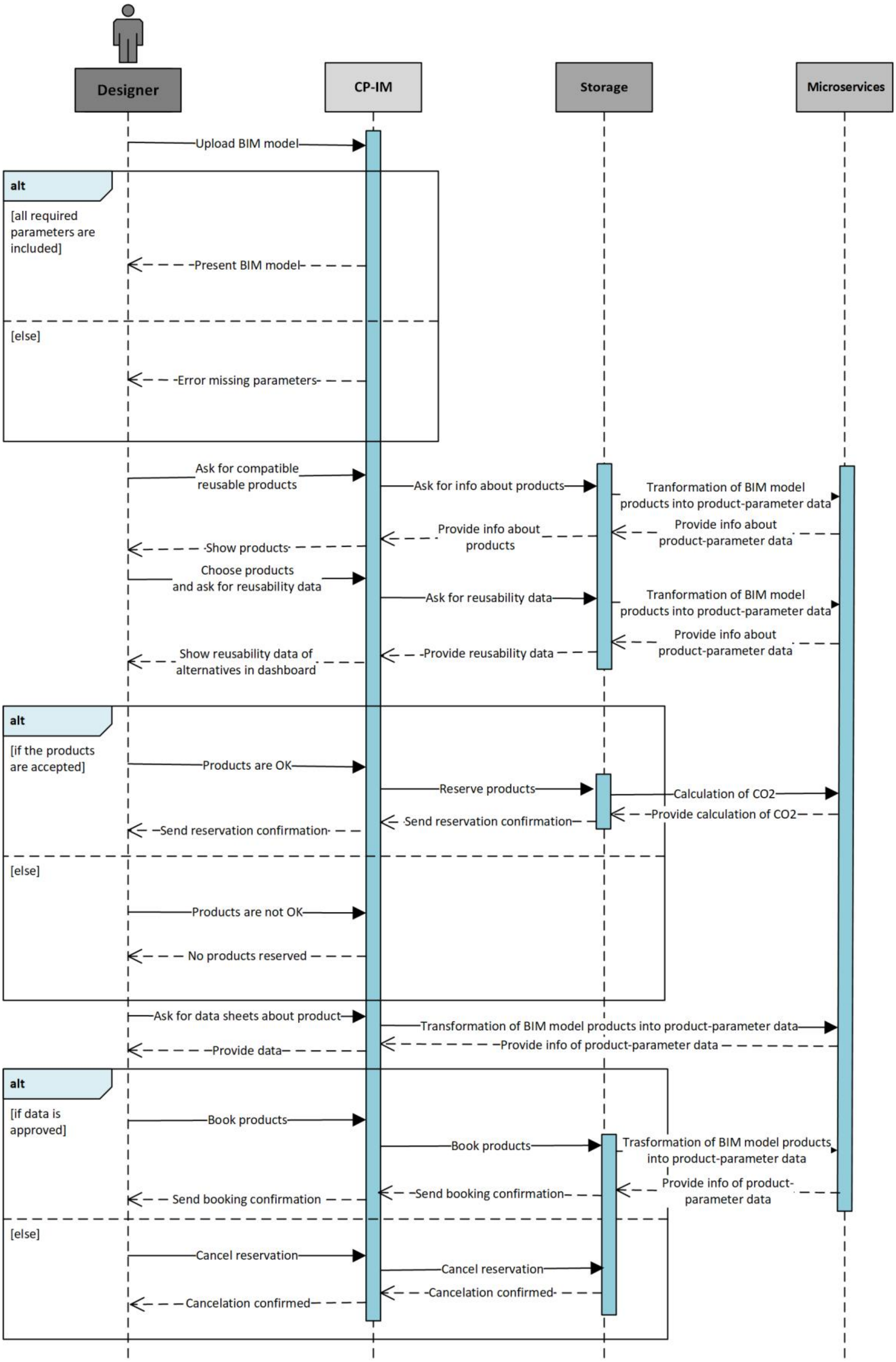

Figure 15: UML Sequence diagram for reuse from the designer's perspective.

The process visualised in diagram 15 starts with the designer uploading their current BIM model of the construction project, including the necessary parameters and format, to the CP-IM, as described in appendix 1.

For the CP-IM to effectively identify reusable products for the designer's BIM model, it's of importance that the information follows a consistent format and contains all the relevant data, as suggested in the appendix. This leads to two possible outcomes after uploading the BIM model. If the information is sufficient, the CP-IM displays the BIM model for the designer to review. If the information is insufficient, the CP-IM sends an error message, prompting the designer to improve their BIM model by adding the necessary information and adhering to the format, and then re-upload it.

After the BIM model presentation, the designer asks the CP-IM for compatible reusable products, which, in turn, requests information from the storage to transform BIM model products into product parameter data from the microservices which will be provided back to storage. The storage provides information about available reusable products to the CP-IM, which then shows these products to the designer. The designer can select products for potential reuse and request additional data about them which is possible by utilising the storage and the microservices.

The CP-IM sends a request to a calculation tool (microservice) to assess product quality and CO2 emissions. The results are presented in a user-friendly dashboard for the designer to make informed decisions. Subsequently, the designer can either accept the products, leading to a reservation by the CP-IM in the storage and a confirmation to the designer, or reject the products, resulting in no reservations. The designer can then either restart the product selection process or conclude it without reusing any products.

When a reservation is made, the products are held for a specific period to allow the designer and other stakeholders to decide whether to reuse them. If the reservation is not confirmed within the set timeframe, the reservation is cancelled, and the products become available for other designers. To make this decision, the designer requests data about the products, which is provided by the CP-IM.

In the next step, there are two possibilities. If the data is approved, the designer asks the CP-IM to book the products, which triggers the CP-IM to request the storage to make the booking. The Storage sends a booking confirmation to the CP-IM, and then to the designer if the reservation is still valid. If the data is not approved, the designer cancels the reservation through the CP-IM, which in turn cancels the reservation in the storage and sends a cancellation confirmation. Both scenarios mark the end of the process.

4.3.4. UML Class Diagram

In UML, a class diagram can serve as a blueprint to organize Industry Foundation Classes (IFC) parameters as explained in this chapter. Entities within the IFC schema, like walls or doors, are represented as classes in the diagram. These classes capture the essential characteristics of each entity. The connections between classes in the diagram illustrate relationships. Within each class, attributes specify the properties of the entity. These could be dimensions, materials, or any other relevant information. Overall, class diagrams provide a visual framework for understanding and implementing the IFC schema which is why it was used to visualise the reusability parameters.

The three component categories of the task 3.2 are windows, façade elements and HVAC. All of these categories belong to an IfcBuildung which in turn belongs to an IfcSite. Each aspects inherits the information from the previous category and the further it goes, the more detailed is the information. In this case the information and structure of the reusability parameters is structured in the class diagram to make it easy to understand. The information was divided into three categories: basic parameters, advanced parameters, and reuse parameters (structure visualised in figure 17, full class diagram in appendix). These levels of parameters are intended to make the use of the reusability and disassembly concepts easier. To access the CP-IM, only the basic parameters for one (or more) of the product categories are needed. Advanced and reuse parameters are only needed when an assessment needs to be made. The assessment is only possible if all required parameters are in place to secure an accurate result and a high quality. Therefor the completeness of parameters needs to be checked by the CP-IM before starting an assessment.

For the process concept of BIM for modular dismantling planning methods, the property owner uploads their BIM model to the CP-IM. In this step the basic parameters (shown generically in Figure 17 on the top) need to be checked for the model to be able to be used. When the property owner then wants to get a reusability assessment, the advanced and reusability parameters need to be checked if they are in the model. Only when all parameters are in place, a solid reusability assessment can be made. The advanced and reusability parameters are also shown in Figure 16 in the middle and on the bottom.

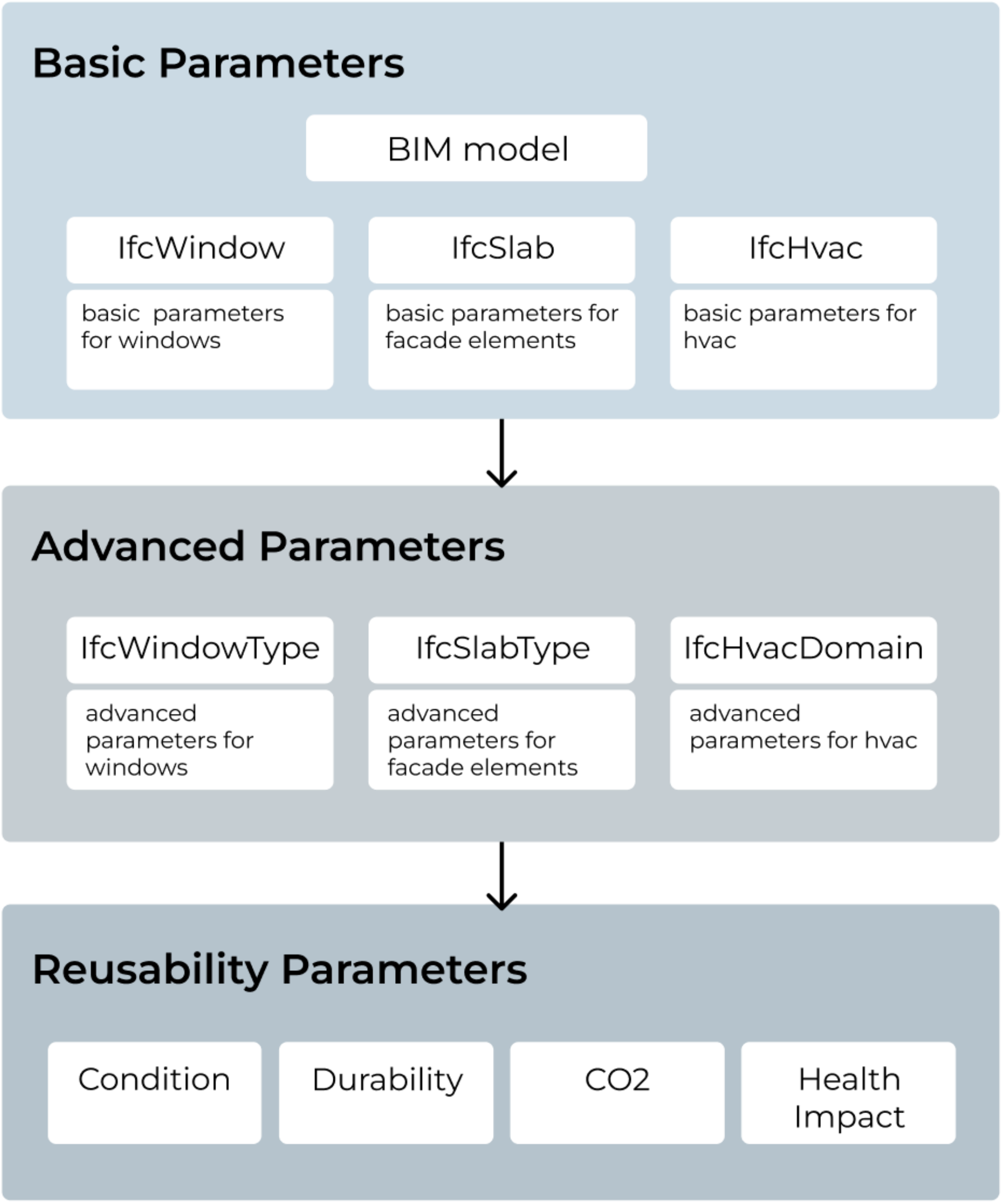

Figure 16: Class Diagram Generic Overview of Basic, Advanced and Reusability Parameters

The focus for the development of parameters lied on the category windows, as many other tasks and work packages focus on this category as well. In work package 1, an ontology for the recycling of windows has been developed and the findings of that are included in this class diagram.

Within the advanced parameters for windows (shown in Figure 17) the following property sets are included for windows (IfcWindowType): Pset_WindowCommon, Pset_DoorWindowGlazing and the properties: IfcWindowPanelProperties and IfcWindowLiningProperties.

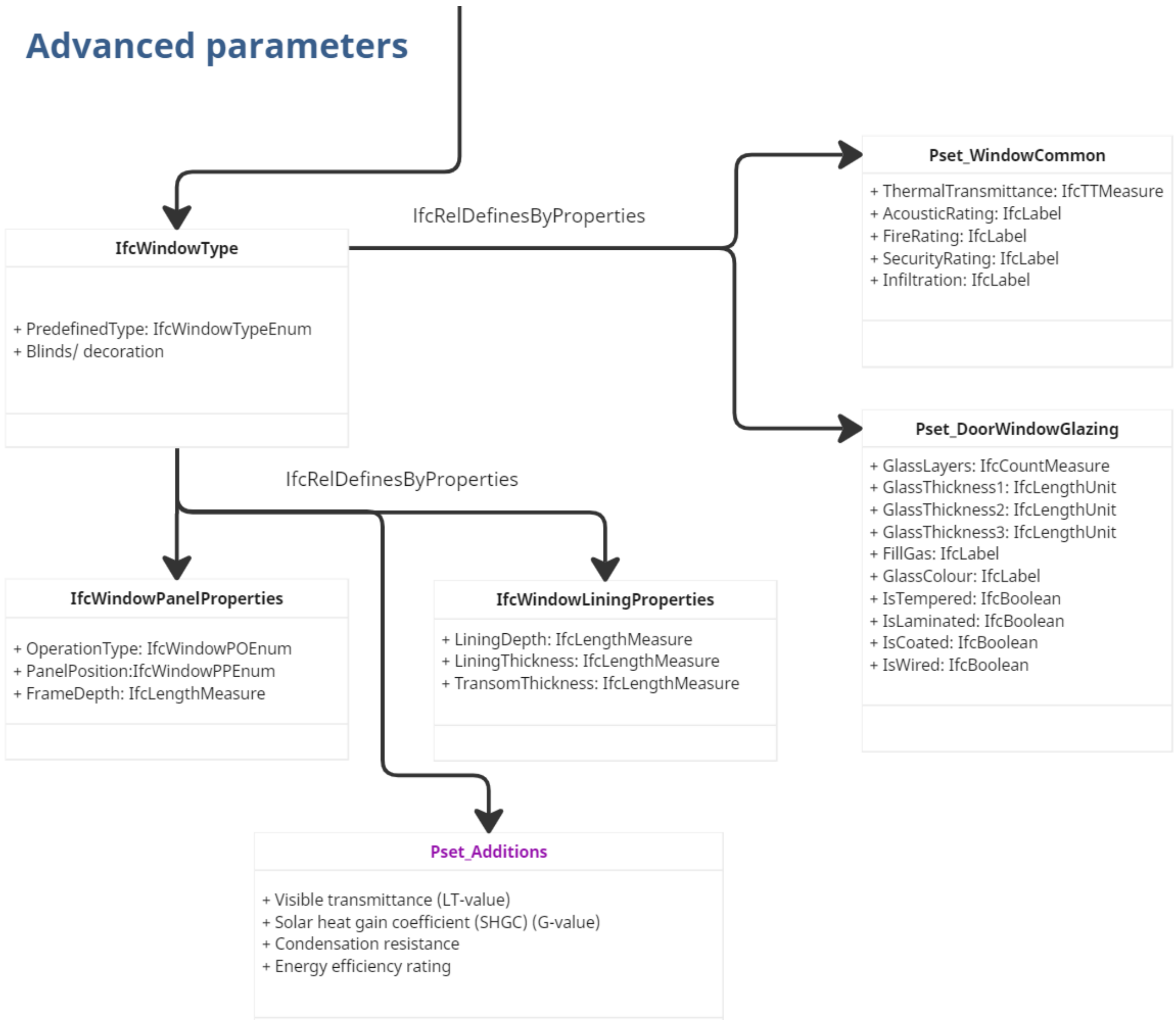

Figure 17: Advanced Parameters for Windows

Most of the parameters in the class diagram for the process concepts are based on the IFC format. However, several aspects that were defined as crucial to determine the reusability of a product are not yet defined in IFC. Some examples of these are Construction Method, Mounting Method, and Hazardous Materials. Furthermore, two new Property Sets are defined, combining parameters that have been defined as crucial in defining the reusability of products. Those two new Property Sets can be seen in figure 18.

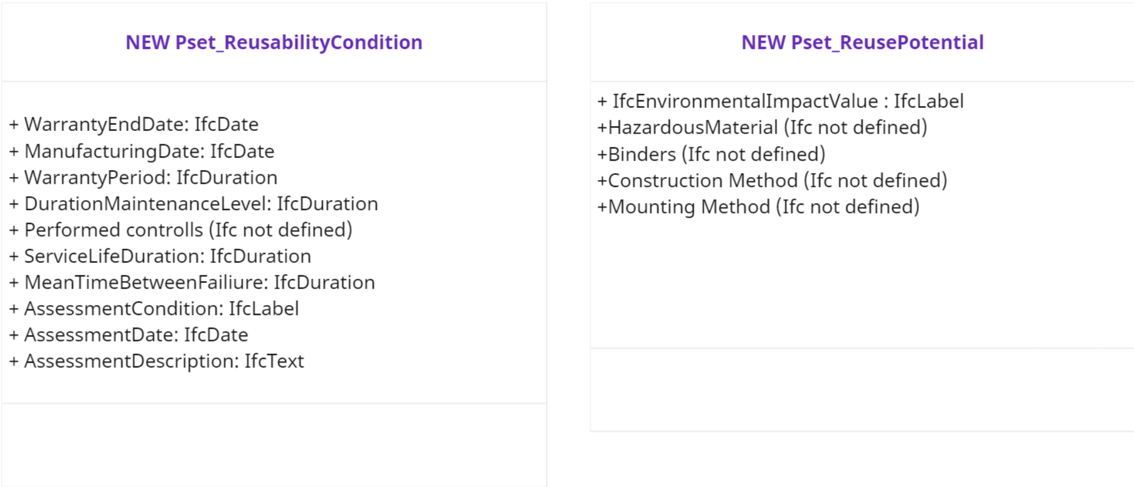

Figure 18: Proposed New Property Sets for Reusability

4.4. Dismantling Planning Methods

For the first step of extracting a component which is to be reused from a building, the process defined by Sanchez et al (2021) and described in chapter 2.4.3 can be followed. To then actually reuse a component like a window, to increase product repairability and consequently decreasing waste, is the Assembly Them All (ATA) methodology depicted by Tian et al 2022. ATA focuses on product assembly by disassembly through physic-based disassembly planning where they aim to develop an assembly method (described more in depth in chapter 2.4.3). In the scope of the Reincarnate project, an investigation on their methodology to explore the possibility of developing a disassembly graph, particularly a selective disassembly graph for building components. This methodology enables designers to get disassembly path planning and sequence planning, bringing relevant information to the disassembly plan which is stated in figures 12 and 14.

In Deliverable 3.3 in the Reincarnate project, which is a result from Task 3.2 developed by TU Berlin, a case study has been conducted. The case study focuses on the disassemble of aluminium-framed windows (however deliverable 3.2 also takes façade elements and HVAC into consideration but inspiration can be taken from the aluminium-framed windows case study for further development of the concept). The case study is intricately aligned with the Reincarnate project's objective of developing sustainable upgrading solutions for window frames, with a particular focus on the automation aspect of the process for selective disassembly (figure 19). Additionally, this methodology enables the researchers of Deliverable 3.3 to investigate the possibility of integrating digitally developed disassembly graph planning into robotic disassembly, which is also a new area to study. In this scope, the development of disassembly graph planning on windows was explored to leverage robotic disassembly systems to advance the upgrading of aluminium windows.

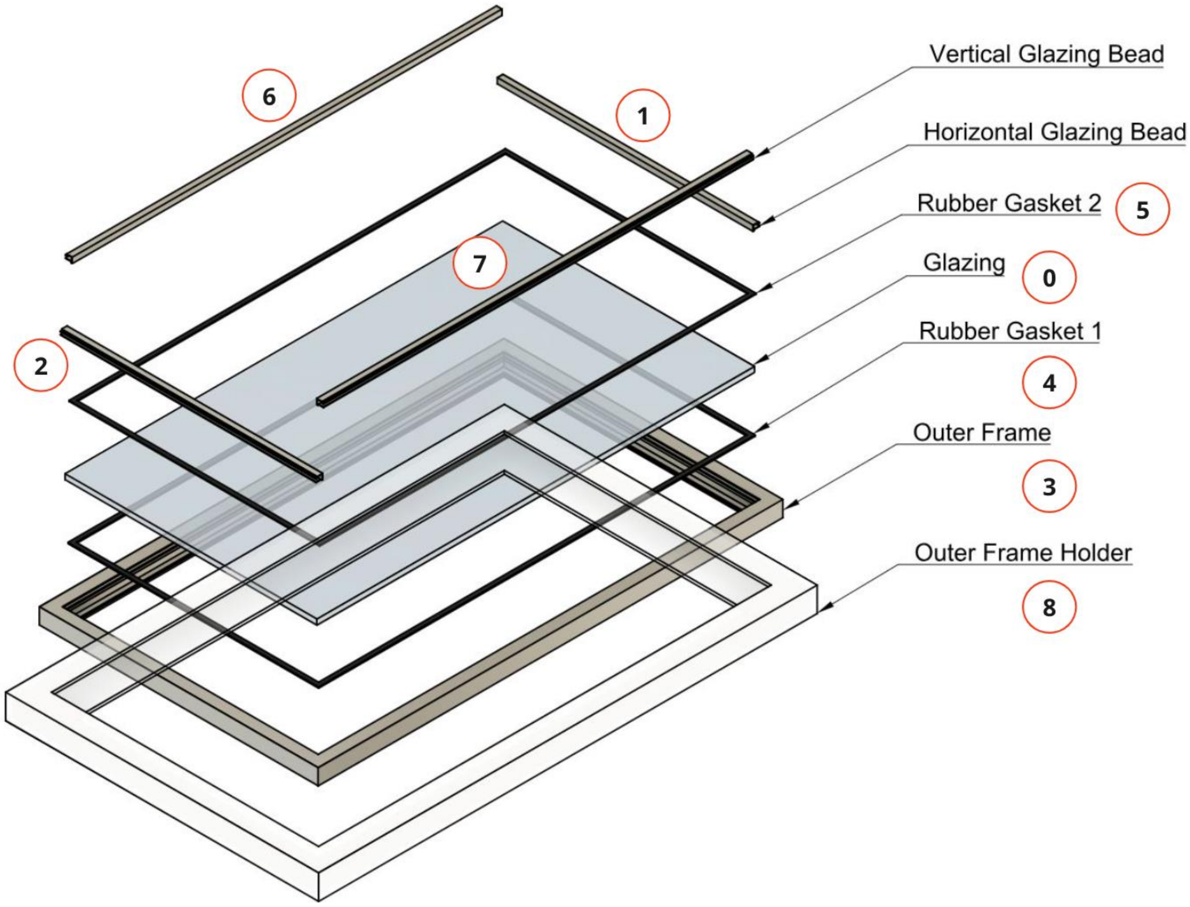

Figure 19: Axonometric decomposition of the parts, including the part IDs, aluminium window: Model I: Model I c

A case study of a 1.3 m x 1.3 m aluminium-framed single-glazed window unit was studied to develop efficient selective disassembly planning. Two different window models were prepared for the experiments: Models I and II. When considering the available physics-based method path planners, 40 physics-based experiments were conducted, excluding those that were not applicable. Moreover, four experiments were conducted using geometric-sampling-based experiments using default configurations. Thus, 44 experiments were conducted in total (Figure 20).

Approach	Model	ID	Disassembly Path
Physics-based Simulation	Model I	model_I_c	5→6→2→ 4→1→7→0→**3, 8**
			2→6→7→1→4→5→0→**3, 8**
			2→6→7→1→ 5→0→4→**3, 8**
			2→6→7→1→5→0→ 4→**3, 8**
			2→6→7→1→4→5→0→**3, 8**
			2→6→7→1→5→0→4→**3, 8**
		model_I	7→2→1→6→4→3→5→0
	Model II	model_II_c	5→6→8→2→0→1→4→3→7
			8→2→6→7→1→0→4→3→5
			2→6→7→1→5→0→4→**3, 8**
			8→2→6→7→1→0→ 4→3→5
			8→2→6→7→1→0→4→3→5
			2→6→7→1→5→0→4→3→8
		model_II	5→6→4→1→0→7→3→2
Geometric-sampling Based	Model I	model_I_c	2→6→7→1→5→0→4→**3, 8**
		model_I	7→2→1→ 6→3→5→0→4

Figure 20: Results of both Physics-based and Geometric-sampling Based Simulations.

In that sense, this case study has systematically enabled the researchers to explore the potential of automated disassembly within the context of the built environment, offering critical insights into the application of ATA methodologies. In addition, discovering further capabilities within the ATA repository extends its results from mere automation in obtaining disassembly graph to gaining an understanding of simulating physical motions for disassembly before experiments in robotic disassembly systems and the early phase of decision-making in its simulations (Cavusoglu, 2024). This approach shows a tangible impact of automated disassembly planning through the 3D model of the building components as automated disassembly planning, particularly within selective disassembly, and leveraging geometric information beyond physical feedback in disassembly planning (Figure 21). While this study confirms the significant promise of automation in enhancing the efficiency and sustainability of disassembly processes, it also opens a dialogue on the implications of such technologies. Results show a tangible impact on pre-robotic cell experimentation simulations, aligning with the main motivation of this research project. The findings of this research carry significant implications for the field of automated disassembly process planning, particularly within the context of selective disassembly. According to the researchers, these results could significantly contribute to automated disassembly process planning in the field of selective disassembly, both in the phase of robotic disassembly simulations and their application in real experiments by supporting early phase decision-making (Cavusoglu, 2024). The production and disposal of these systems themselves must adhere to sustainable practices to avoid undermining the environmental benefits they are designed to deliver.

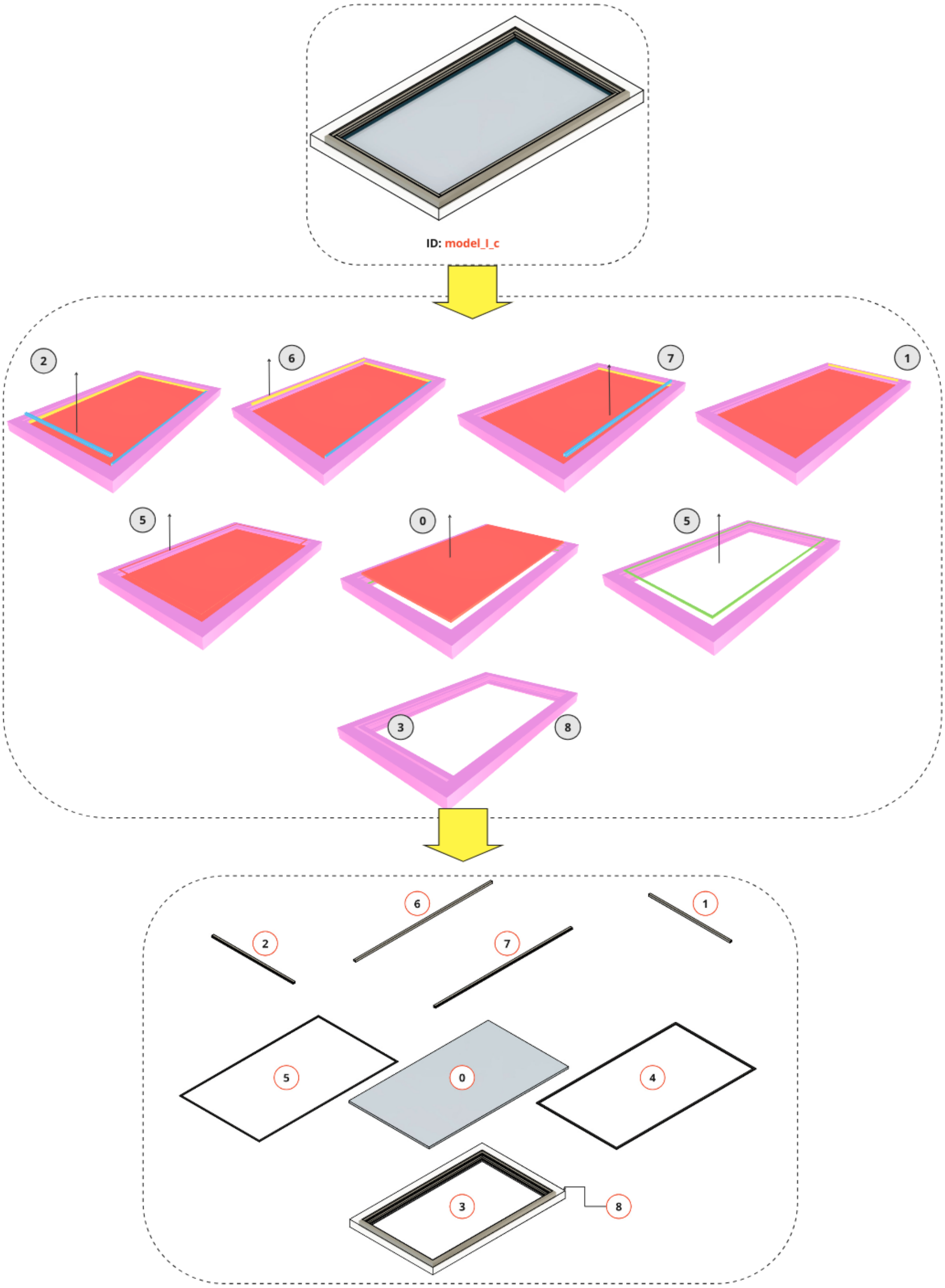

Figure 21: Demonstration of the input/output in the simulations.

4.5. Calculation of Carbon footprint

The objective in Task 2.1 of the Reincarnate project was to create a streamlined system for tracking carbon footprint during a construction of a building focusing on concrete. For Deliverable 3.2 the result of Task 2.1 can be applied for concrete façade elements. The results show parametrising the BIM model in real-time with data immediately after the material is delivered and embedded on site clearly shows construction site's environmental impact. It makes carbon footprint data more detailed as well as allows for better optimisation of that impact in the future projects. By saving carbon footprint information from all LCA modules in a structured way in a BIM model, the benefit of utilising secondary materials can be clearly outlined. It is the integration of the concepts developed within T2.1 and T3.2 in the CP-IM with the use of the ontology defined in WP1 that will allow a designer through decision-making prioritize secondary components for reuse based on carbon saving potential.

The results of task 2.1 and of task 3.2 will be integrated in the demo cases later on in the Reincarnate project. There is potential to develop the innovations further and to integrate them to support decision making for designers.

4.6. Feedback from Test Group

Validating the results through discussion meetings with a test group is a crucial aspect of the software development lifecycle, ensuring that the system's requirements are accurately represented and understood by all actors involved in the construction process. The test groups have consisted of participants from DEMO Consultants, TU Berlin, 3L, Vías y Construcciones and TU Delft, all partners of the Reincarnate consortium. Those partners are representing architects, designers, constructors, IT-consultants, and academics involved in the construction sector. During the discussion meetings, the test group collaborates with developers (the authors of this report) to review and validate the results, to ensure that they are applicable to real life and can be validated and tested in the demo cases in the other work packaged of the project.

In the second half of 2023, several meetings and workshops, partly online and partly in person in Sweden, were held with the previously named partners. In the first step the task and context were repeated to ensure the same starting point for discussions. Secondly, the concepts and UML diagrams as visualisations were presented. As a third and last step the concepts were discussed to gain valuable insides and feedback. The meetings were schedules one after the other so that the feedback from one partner could be incorporated, reported back and then the optimized version would be presented to the next partner. For example, the feedback given by TU Berlin included to add the step of reporting the condition after the actual disassembly to the property owner for the concept BIM modular dismantling planning methods. This step was added and then included in the updated version and presented to the other partners. The feedback from 3L contained a positive note on the practicality and approval for the validation of the demo case Tiny House from month 24 onwards.

In a next step the developed concepts will be further tested in practical cases and in construction projects. There are several projects identified which will test the developed concepts, one project is a "Tiny-House" in Germany with the architects 3L, a water-treatment plant in Spain by VIAS and other demo cases are hosted in Sweden by Ragn-Sells.

The task team even contacted Baukreisel in Germany for an external view and received positive feedback.

The feedback and validation from the test group is therefore extensive, consisting of consortium internal and external persons and professionals from different fields within the building and construction industry.

5. Discussion

5.1. Introduction to Discussion

The discussion bridging the theoretical foundations and the results as well as the analysis on leveraging Building Information Modelling (BIM) for dismantling planning and reuse of building elements underscores a thorough examination of sustainable construction methodologies and the digital transformation within the construction sector. Herein, we intertwine the insights and methodologies delineated in theory and the findings to construct a unified narrative on enhancing sustainable construction practices through technological advancements and process concept innovations.

5.2. The role of BIM and information processes for the reuse of products

The foundational theories presented in chapter 2 in this report highlight the significance of a conceptual schema that encapsulates sustainable development, with a special emphasis on the reuse of building elements as a means to accomplish environmental and economic benefits with the assistance of BIM.

The utilization of Unified Modelling Language (UML) diagrams within the task plays a crucial role in translating the theoretical frameworks of BIM application for sustainable building practices into detailed, actionable concepts. The developed diagrams in this report serve as a visual and structural representation of the processes, actors, and data flows involved in dismantling planning and the reuse of building products and components. By showing the interactions between property owners, designers, and the CP-IM platform, the UML diagrams facilitate a clear understanding of the methodology for assessing reusability, generating disassembly plans which is described in Deliverable 3.3 using the ATA method, helping with decision-making building on Task 2.1. results, and integrating reused products into new constructions. The next step is the conversion from these rather theoretical concepts described in chapter 2.4.3 and the process diagrams to practical cases, as for example the demo case Tiny House.

These visual models not only encapsulate the complexity of the processes but also highlight areas for potential enhancement and expansion, especially regarding the dismantling plans. Moving forward, the concepts described in the UML diagrams could be developed further by incorporating advanced analytics and machine learning algorithms to predict the lifespan and reusability potential of building components more accurately. Additionally, integrating real-time data from IoT devices in buildings could enhance the precision of the disassembly plans and the efficiency of material reuse. By expanding the scope of the UML diagrams to encompass these technological advancements, future research can continue to bridge the gap between theoretical sustainability principles and their practical application in the construction industry, driving further innovation in sustainable building practices. A much higher level of detail in the BIM models than what is usual today is necessary to implement and test the concepts.

The process concepts developed in this task and visualized in UML diagrams in chapter 4 show a practical application of BIM models for the reuse of building components. The interaction of the user and the CP-IM platform is described and explained, showing how different granularity levels of information in the model are needed for different use cases (basic, advanced and reusability parameters). The microservices in the CP-IM should show architects available and suitable products according to the search ranges. Property owners on the other hand should get an evaluation of the components in their buildings and assistance with a disassembly plan. These concepts describe clear use-cases that create value for the users and enable and support the reuse of building components. As the concepts have been discussed and tested with experts they have been approved on a conceptual level. As a next step the practicality needs to be assessed in the demo cases and tested in real building projects.

5.3. Exploiting BIM for Improved Management of Waste Products and Components

The discourse on BIM's efficacy in waste management and its utility in designing for deconstruction (DfD) offers a clear pathway from theoretical frameworks to practical executions. By analysing how BIM can facilitate waste minimization and endorse the reuse and recycling of construction products, this report underscores the practical application of theoretical concepts in addressing tangible issues. BIM's capacity to provide intricate digital representations of buildings aids in pinpointing reusable elements and formulating effective dismantling strategies, thus supporting the sustainability principles laid out in the theoretical discourse.

The theoretical underpinnings introduce the concept of "material banks," where existing buildings are viewed as repositories of valuable materials that can be reclaimed and reused in new construction projects. This approach not only reduces waste but also lessens the demand for virgin materials, thereby conserving natural resources and reducing the environmental footprint of building projects. In tandem with this concept, the reusability index is presented as a tool to evaluate the potential for reclaiming materials based on factors such as material composition, processing requirements, and market demand. This index provides a systematic method to assess and compare different materials for their recyclability and reusability, ensuring that the materials chosen for construction projects are aligned with sustainable practices.

Aiming to promote sustainable practices within the construction industry, the concept of material banks and the reusability index emerges as pivotal strategies that bridge the theoretical frameworks discussed in the introductory sections with the practical applications detailed in the results and analysis chapter. These ideas show how theory informs practice, guiding the development of systems that facilitate the reuse of building components, thereby advancing environmental sustainability and economic efficiency.

5.4. Adoption of IFC Ontology for Seamless Exchange of Information

Seamless information exchange among stakeholders is crucial in the construction industry, particularly as it moves towards more sustainable practices and greater efficiency. The importance of such fluid communication underpins the introduction of Industry Foundation Classes (IFC) ontology, which facilitates comprehensive and interoperable data sharing across various software used by different stakeholders involved in building projects. The Reincarnate specific ontology was developed in work package 1 and used as a basis for this task. This standardized data model ensures that architects, engineers, contractors, and facility managers can all access and utilize consistent and accurate information about building components throughout the lifecycle of a project.

However, as building practices evolve and the demand for more sustainable and customized solutions increases, the existing IFC ontology must be expanded. This expansion involves the addition of more Property Sets (Psets) which are essential for capturing and standardizing additional data that can support advanced functions such as the detailed assessment of product reusability, the environmental impacts of materials, and the integration of new technologies or products into existing building models. By enriching the IFC ontology with more comprehensive Psets, stakeholders can not only ensure better adherence to sustainability standards but also enhance the functionality, analysis capabilities, and overall value of the BIM models used in their projects. This enhancement is crucial for supporting the complex decision-making processes required in modern construction environments, where efficiency, sustainability, and innovation are at the forefront.

The inclusion of new Psets in the Industry Foundation Classes (IFC) ontology specifically for reusability is a strategic response to several critical gaps in the existing schema, particularly in the context of recycling and reuse of building components like windows. The current IFC schema is comprehensive for typical construction and architectural needs but lacks specific attributes crucial for assessing the reusability of products and components. For example, properties such as Construction Method, Mounting Method, and the presence of Hazardous Materials are directly influential in determining the ease and safety of dismantling, recycling, and reusing components, yet these are not typically covered in the standard IFC schema.

Including new Psets that capture these crucial reusability parameters enables stakeholders to determine the potential more effectively for reusing a product right at the design stage. This proactive assessment helps in planning for end-of-life processing, thereby aligning with circular economy principles where materials are kept in use for as long as possible. Furthermore, incorporating reusability-focused Psets enhances data management and interoperability among different software and stakeholders involved in building design, construction, and demolition. With a standardized set of parameters that include reusability metrics, data can be more consistently collected, analysed, and utilized across different projects and phases. This creates more transparency and accessibility for different actors of the industry to enable reuse of components.

Moreover, these enhancements support broader sustainability goals by promoting the reusing of products and components, reducing waste, conserving resources, and minimizing environmental impacts associated with the production of new materials and the disposal of old ones. As sustainability regulations become stricter and market demands shift towards more environmentally friendly practices, having a robust framework that includes reusability parameters becomes increasingly important. Companies can use these detailed classifications not only to ensure compliance but also to enhance their market competitiveness. Thus, the introduction of new Psets tailored to capture reusability aspects in the IFC ontology is not merely a technical update but a necessary evolution to meet the demands of sustainable construction practices.

5.5. Feedback and Iterative Development: Bridging Theory and Practice

The input from test groups, as elaborated in chapter 4 Results and Analysis, furnishes an essential connection to the theoretical foundations of the study. Through validating the practical BIM applications in the context of reuse, the feedback mechanism acts to refine the theoretical concepts based on empirical experiences and perceptions. One of the insights from the feedback from test groups was that BIM-based disassembly, particularly selective disassembly, requires a focus on the construction industry. According to experts, existing methodologies are studied on products such as product assembly and disassembly, in which the scale of the products is small compared to building components. On the other hand, product models are not BIM models; they are mostly 3D digital models. In that sense, BIM-based selective disassembly in the construction industries has become prominent in bridging the gap between theory and practice with the help of the product manufacturing and design industry.

The feedback from test groups, as detailed in the analysis, underscores the practical viability and user-friendliness of the UML concepts for the use of the CP-IM platform. This iterative feedback is crucial for refining the system to better meet the needs of the industry, ensuring that the theoretical advantages of material banks and the reusability index are fully realized in practice. The collaborative nature of the feedback process also reflects the overarching theme of the project—integrating diverse perspectives to foster innovations that support sustainable development in the building industry. The next step in the project is the practical testing of the developed concepts in different demo cases.

5.6. Further Suggestions for Development of the Concept

While this study has laid down a conceptual foundation for integrating product reuse and sustainability into building projects through the use of IFC and the CP-IM platform, there are several areas where further developments and improvements could significantly enhance the robustness and applicability of the concepts. As these suggestions are implemented, they can transform the initial concepts into more mature, practically applicable methodologies.

First, while the current conceptual model utilizes UML diagrams to map out the interactions within the BIM model and the CP-IM for reusability, the full integration of these diagrams into the platform should be operationalized and more automated. This could include developing plugins or tools within BIM software that can automatically generate and update these diagrams as project parameters change. This integration would provide real-time updates and insights to stakeholders, enhancing collaborative decision-making.

Secondly, the conceptual results could benefit from pilot testing in real-world scenarios, which is planned for the next step of the overarching project. Collaborations with ongoing construction projects will provide valuable insights and data, helping to refine and adjust the theoretical models based on practical experiences and challenges encountered in actual construction environments. This testing could also help identify any gaps in data requirements or functionality that may not be apparent in a theoretical setting. There are several projects identified which will test the developed concepts. One project is a “Tiny-House” in Germany with the architects 3L, a water-treatment plant in Spain by VIAS and other demo cases are hosted in Sweden by Ragn-Sells. The rather theoretical UML process concepts can be integrated with the work by Sanchez et al (2021) and Tian et al (2022) described in chapter 2.4.3 and applied in those demo cases. A crucial step is the integration to the CP-IM as described in the process maps.

Additionally, engaging even more deeply with stakeholders through workshops or feedback sessions could help tailor the IFC extensions and the CP-IM platform functionalities to the specific needs of different users, such as designers, engineers, and contractors. This engagement would ensure that the developed tools are not only theoretically sound but also user-friendly and directly relevant to the industry’s needs.

Finally, considering the rapid advancements in digital technologies, integrating emerging technologies such as artificial intelligence and machine learning could further enhance the capabilities of the CP-IM platform. These technologies could be used to predict the reusability of materials more accurately and optimize the disassembly and reuse processes based on historical data and predictive analytics.

These improvements, while conceptual at this stage, hold the potential to significantly advance the current state of practice in sustainable construction. By continuously refining these concepts and integrating stakeholder feedback and new technologies, the path towards more sustainable and efficient construction practices can be solidified.

6. Conclusion

In conclusion, the report outlines a comprehensive framework that bridges theoretical insights with practical applications, focusing on sustainable construction practices through the utilization of BIM. By effectively leveraging BIM for dismantling planning and the reuse of building elements, this study aligns with modern digital transformation trends in the construction industry and addresses crucial environmental and economic challenges.

The adoption of UML diagrams within the project illustrates a well-structured approach to translating theoretical concepts into actionable strategies. These diagrams have provided a clear visual and structural representation of the processes involved, enhancing the understanding and execution of sustainable dismantling and reuse practices. The potential integration of advanced analytics and Machine Learning algorithms, as well as real-time data from Internet of Things (IoT) devices, represents an exciting future direction that could significantly enhance the accuracy and efficiency of these processes.

Furthermore, the development of new IFC ontology with enhanced Psets tailored to capture crucial reusability parameters is a significant advancement. This adaptation facilitates a more effective and seamless information exchange among stakeholders, promoting the reuse of building components and advancing sustainability goals within the industry.

The task outlined in the project aims to develop concepts that enable high-quality de-installation and reuse of building products and components, utilizing BIM-supported modular dismantling planning methods and parametric design methods. The integration of embodied carbon estimation methods within these tools will prioritize components for reuse based on their carbon saving potential, focusing initially on commonly used building components like windows, façade elements, and HVAC systems. This approach not only adheres to sustainability standards but also enhances market competitiveness by aligning with the increasing demand for environmentally friendly practices.

The inclusion of a user group of architects, construction, and demolition contractors will ensure that these developed methodologies are not only theoretically sound but are also practical and user-friendly. This collaborative approach, coupled with the iterative development and testing in real-world scenarios, will enable continuous refinement of the methodologies, ensuring they meet industry needs and contribute to a more sustainable and efficient construction sector.

Connection to CP-IM platform

The concept developed in deliverable 3.2 is in need of a platform linking different actors in the construction industry together to be able to work at is full potential. Therefore, the results of this report have used the CP-IM platform as a vital system for the concept to be developed, expanding the innovation of the CP-IM. The concept is closely connected to the CP-IM platform which will act as a marketplace where the property owners, wanting to get their products and components reused, will meet the designers wanting to reuse products for their new building. The CP-IM platform is therefore an essential part of the outcome of this deliverable and the deliverable an important input to the CP-IM platform.

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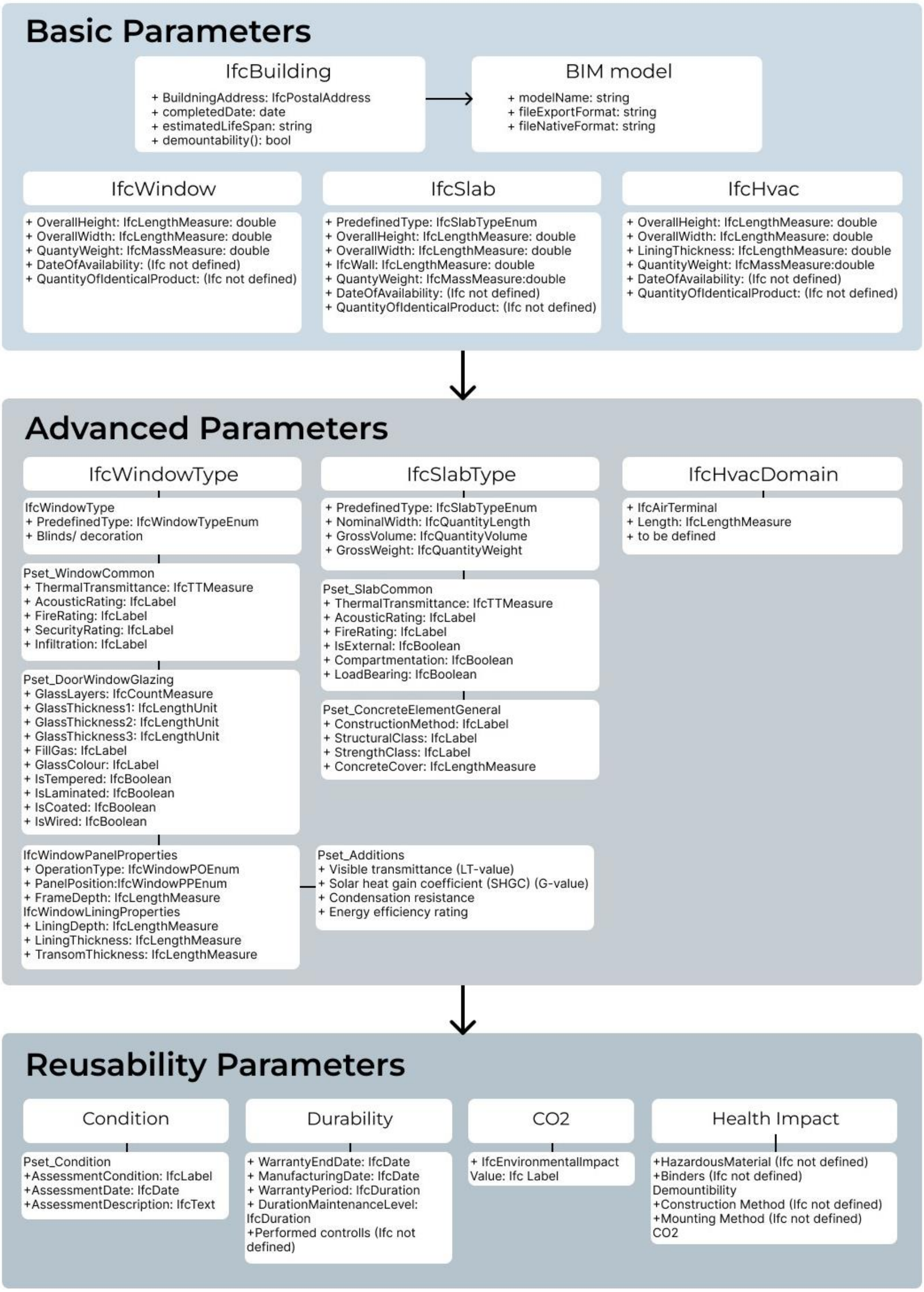
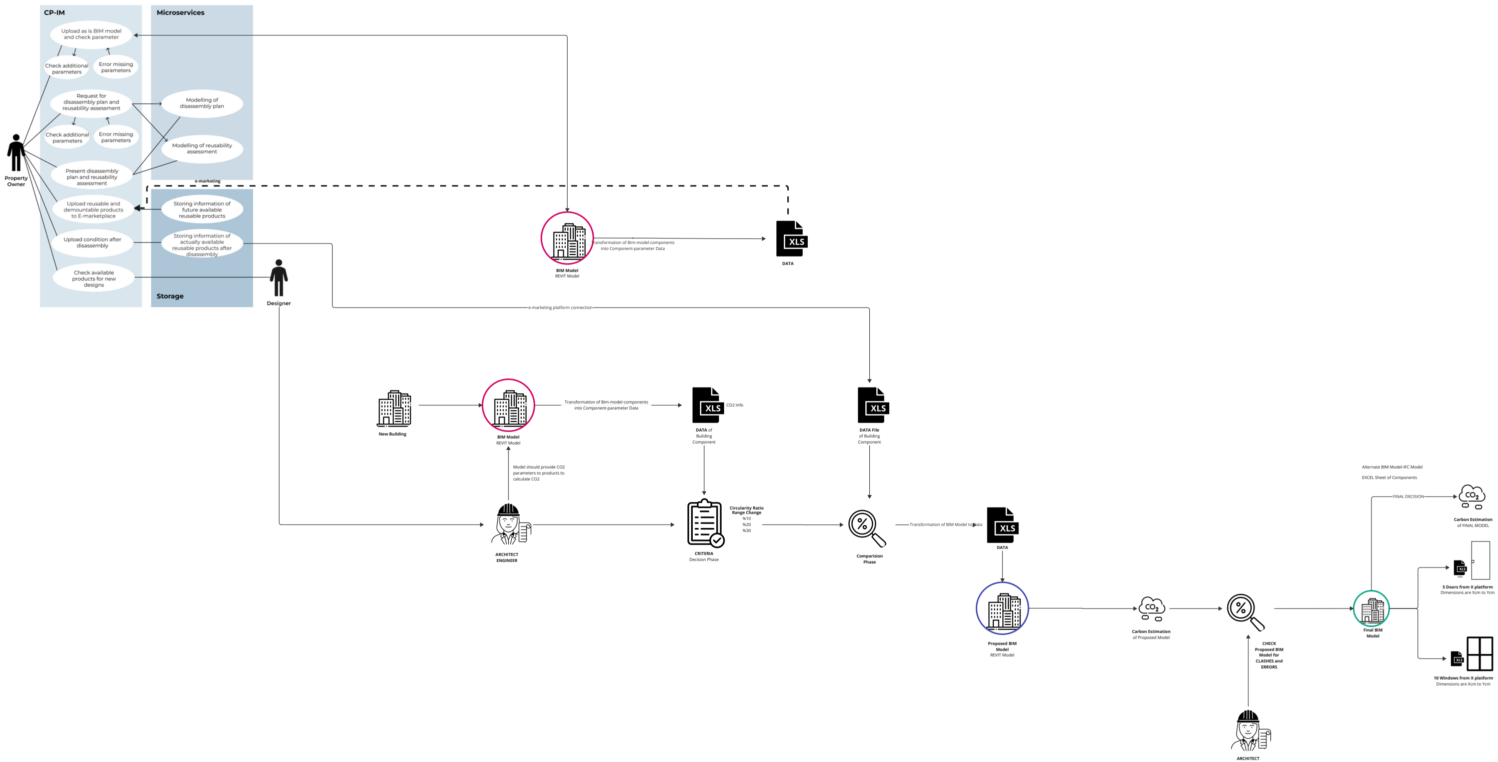
Appendix

Appendix 1 - parameters



Appendix 2 - WP3 - D3.3 DYNAMO Tool - Property owner



Appendix 3 - WP3 - D3.3 DYNAMO Tool - Designer