A Digital Structure for Circular Reuse in the AEC Industry

A study to restructure the digital processes in the AEC industry to enable building component reuse

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2. PREFACE

This report completes the last step of my master Architecture, Urbanism and Building Sciences, track Management in the Build Environment, at the Technical University Delft. The initial steps towards this report were made in September 2021, after which full time work has been conducted since February 2022. During this final research I wanted to increase my knowledge about the most promising developments of the coming years in the construction industry: Circularity and further implementation of the Building Information Model (BIM). With this main goal printed in my head, started with this journey and the result is presented in this document. Constructing this report was a roller-coaster in terms of research goals and possibilities, motivations, and interests. Therefore, I would like to thank several people of the support and guidance during the construction of this report.

First and foremost, I want to express my gratitude to my first mentor Dr. Tong Wang for the positive encouragement and helpful discussions over the past moths. Her positive and enthusiastic review during our, unfortunately online, sessions really motivated me to improve and refine the report as much as possible. Furthermore, the constructive criticism helped me enormously to recognize the weaker sections to improve the quality of the report. I would further like to express my gratitude to Dr.ir. Sander van Nederveen, who functioned as my second supervisor the past half year. The open and encouraging feedback helped me to work harder and open my thoughts further. His additional support helped me to strive for a higher quality and more elaborate report.

Further, I would like all respondents and other participants of this research. The interesting and eye-opening discussions we had, helped me to construct the current report and to research the wider context than described here. It helped me to improve my understanding about the workflows and motives in the built environment and gave me insight to the current developments of the sector.

And finally, I want to thank my family, with special attention to my mom. The motivational speeches and support helped me to strive for the best and complete this study. I will always be grateful of the opportunities been given to me and thereby help me to develop myself to the way I am today.

Enjoy reading my report!

Anton van den Oudenrijn
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3. ABSTRACT

The current built environment is facing a transition from a linear economy towards a circular economy. In this new system, the building parts of today are used to construct the buildings of tomorrow. Reusing building parts requires knowing the qualities of those materials. However, the current AEC (Architecture, Engineering, and Construction) industry does not know what data is required to reuse building components and how this influences processes of modelling and decommissioning parties. Therefore, this research aims to answer the following question: “Which data is needed for circular component reuse and how does this data requirement influence the management of a BIM in new construction projects?” The goal of this report is to construct an ILS (Information Delivery System. Original Dutch name: Informatie Leverings Specificatie) that provides data requirements for reuse of building components.

To answer this question two organisation types are interviewed: linear building organisations and modular building organisations. The linear companies construct projects with a permeant aim whereby building parts are not redeployed in subsequent lifecycles. Modular organisations, on the other hand, construct high-quality modular assets whereby building components and elements are reused a lifecycle. By interviewing both typologies the data requirements and process could be described and compared to construct a new ILS and process.

The interviews expressed the data requirements and structures of both organisations. These inputs are processed and the “Circular Reuse ILS+” and “Circular Reuse ILS+” are constructed. These documents describe data requirements of digital models to ensure that building components could be reused. Implementation of these documents increases the length, complexity, and costs of the design phases since more properties and digital models should be created and stored during these phases. The disassembly phase, contrastingly, benefits from the data and documents prescribed by the ILS+ given that more information is available for the construction of redeployment plans and analysis of the qualities of the released components. During the use phase of an asset, data should be maintained to ensure that it could be reused in future lifecycles. However, the qualities, requirements, definition, and responsibilities of this data maintenance are still unknow. Future research could focus on data maintenance to ensure that all data could be used in a perfect circular world.

Key words

Circular decommissioning, Circular economy (CE), Industry foundation classes (IFC), Building information model (BIM), ILS (Information Delivery System)

4. LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
BIM	Building Information Model
CAD	Computer-Aided Design
CDE	Common Data Environment
CE	Circular Economy
DFD	Design for Disassembling
IFC	Industry Foundation Classes
ILS	Information Delivery System (Original Dutch name: Informatie Leverings Specificatie)
IT	Information Technology
LOD	Level of Development
NAA.K.T.	Name_Characterisic_Application (Original Dutch name: NAAm_Kenmerk_Toepassing)
NME	Native Model Environment
ODF	Open Data Format
RAL	Reich Committee for Delivery Conditions (Original German name: ReichsAusschuss für Lieferbedingungen)
2D	2-dimensional
3D	3-dimensional

5. TERMS AND DEFINITIONS

Aspect model	An fragment model of the main digital model modelled in higher LOD
Attribute	An information and data unit within an IFC entity
Building information model (BIM)	A virtual 3D model of an asset in which information and data of an AEC project is saved and processed
Building layer	A collection of building parts with a specific level of composition and detail
Circular Economy (CE)	An economical system that aims close loops by using R- Strategies
Circularity	Reusing material streams by using R-strategies
Data	Values, symbols, or descriptions. Data needs information to be interpreted
Digital model	A BIM or an IFC model
Entity	An information class defined by attributes and constraints.
IFC model	A virtual 3D model of an asset in which information and data of an AEC project is stored
Industry foundation classes (IFC)	An open standard information schema that structures BIM data to enable interoperational usage.
Information	The context of the data
NAA.K.T. method	A standardized material naming list for BIM purposes
Object	A digital representation of a building part modelled in a digital model
Placeholder	An object linked with a database that defines the appearance,

	characteristics, and qualities of the object in reality
Property	An information unit that provides a value of an attribute
Property set	A set of properties serving a common aim
R-Strategies	A hierarchical structure of methods to close circular loops
RAL Code	A colour coding system.
Relationship	An entity that describes information how objects relate to each other
Technical specification	One or more documents with information and data that define the characteristics of an object

6. TABLE CONTENTS

PART 3: RESEARCH METHOD 42

PART 4: RESEARCH FINDINGS 58

PART 5: SOLUTION IMPLEMENTATION 84

7. LIST OF FIGURES

8. LIST OF TABLES

Part 1
Introduction

In this part the problem addressed in this research is presented together with the research questions and the structure. It starts with an overall description of the environmental problems and the developments in the construction sector. Thereafter the research questions are presented with substantiation. Furthermore, the relevance and scope are further highlighted. The chapter ends with a reading guide, in where the structure of this report is outlined.

9. PROBLEM DEFINITION

This chapter addresses the problems in the construction industry which are researched in this thesis. The need of implementing the circular economy in the built environment is highlighted and how BIM (Building Information Model) could contribute to this economy. The main problem addressed in this thesis becomes clear after reading this chapter.

Architecture, Engineering and Construction (AEC) sector plays an important role in the transition towards the circular economy (CE), considering the enormous use of materials and associated emissions of the sector (Chan et al., 2021; Sparrevik, et al., 2021; Ajayabi et al., 2019). In total, the sector is responsible for 39% of the global greenhouse gas emissions and 40% of all material resources (Eberhardt & Birgisdottir, 2020; Ness & Xing, 2017; World Green Building Council, 2019b). In the CE building parts are reutilized in subsequent lifecycles without extraction of new commodities, which leads to a reduction of emissions and waste. The construction industry should redeploy building parts of current buildings in future buildings to implement the CE. However, new constructed assets are still not designed for this (van den Berg et al., 2020a; Debacker et al., 2017). Proper decommissioning and redeploying building parts becomes thereby almost impossible, and the intrinsic material value is lost (Durmisevic et al., 2021; Dams, et al., 2021). Design for Disassembling (DFD) is thereby crucial in implementation of the CE in the AEC sector (van den Berg et al., 2020a; Debacker et al., 2017). Furthermore, data of building parts is essential for redeployment of building parts (Durmisevic, 2006; Charef & Emmitt, 2021; Davila Delgado & Oyedele, 2020; Chan et al., 2021; Akinade, et al., 2017a; Adams et al., 2017; Ajayabi, et al., 2019; Durmisevic et al., 2021), because it enables qualifying and quantifying the recoverable materials and make performance analysis for redeployment of the parts in subsequent lifecycles (Akinade, et al., 2017b). Aspects that should be known include environmental, technical, and geometrical data of parts (Luscuere, 2017).

The Building Information Model (BIM) could help with storing this circular data (Adams et al., 2017; Akinade, et al., 2017a; Hart et al., 2019; Charef & Emmitt, 2021). A BIM is a virtual 3D representation of a built asset in which all data is structured to support construction, manufacturing, procurement, and maintenance activities (Eastman et al., 2011). This means that the BIM could contain information about, geometry, finances, construction methods, and building performance. However, current BIMs could not be used to decommission assets and analyse building parts after decommissioning (Akinade, et al., 2017a; Charef & Emmitt, 2021; Davila Delgado & Oyedele, 2020; Hart et al., 2019), whereas this is often viewed as a significant enabler for the circularity since it already contains the circular aspects (Adams et al., 2017; Akinade, et al., 2017a; Hart et al., 2019; Charef & Emmitt, 2021). To share and archive data the IFC format is used. The Industry Foundation Classes (IFC) is the leading standard open data format in the AEC industry and provides capabilities to exchange building data inter-operational over the whole building lifecycle (Davila Delgado & Oyedele, 2020). According to literature, the current IFC files could be used to store and analyse information and data for decommissioning (Davila Delgado & Oyedele, 2020; Akinade, et al., 2017a; Akbarieh et al., 2020; Volk et al., 2014; Durmisevic et al., 2021). However, since the IFC is exported from a BIM, the current IFC could not be used in the CE (Akinade, et al., 2017a).

One of the reasons in that data is missing or unclear for future users (Akinade, et al., 2017b; Becker, et al., 2018; Durmisevic et al., 2021; Chan et al., 2021). A decommissioning party highlighted this during exploratory interviews: “I simply need more information; I currently don’t know how to disassemble buildings [with a circular aim]” This emphasises that missing data is also recognized in practice and that the current data supply is incomplete for redeploying buildings. A second exploratory interview with a window frame interviewee mentioned: “The current material passport is not complete for us to reuse our window frames” This shows that this problem is not only recognized to the decommissioning side of the project, but also to in the manufacturing area.

One of the reasons for this is missing guidelines that help modelers to structure their digital model (Akinade, et al., 2017a; Chan et al., 2021). During a preliminary interview with a material passport platform the following was stated: “You may have consulted [Platform] CB’23, […] that describes what data is required in the passport” The organisation of the material passport argues that the circular data requirements are clear, but the private organisations mention that the requirements are insufficient for them. Platform CB’23 (2020) states the following: In order to achieve good data management, data must be able to be compiled according to specific guidelines and must be easy to find. In addition, data must be stored according to a certain standard. All this is guaranteed by setting up an Information Delivery Specification (ILS). The passport must become a part of this ILS. This also makes it clear which data must be included in a passport” An ILS is thereby used to set the requirements of the data in the material passport. However, which ILS should be used or requirements to that specific ILS is not specified by the platform. Thereby, the confusion of the market parties could be clarified. This means that the data in the material passport is undefined and could miss data, whereas this is key for implementing circularity in the built environment.

The previous sections highlight those digital models could help with the implementation of circularity in the AEC industry, since it already contains some technical, geometrical, and environmental data. However, it is unclear what data should be stored to enable circularity. Therefore, further research is needed to identify what data should be stored digitally to enable circular reuse.

10. RESEARCH QUESTIONS

The previous sections highlight the need of implementing the CE in the AEC industry, and thereby the need for decommissioning of built assets. However, data that is needed to define decommissioning possibilities is not added in digital models and thereby forms a hinderance in reusing building parts. This research aims to construct an ILS to check and improve the data storage for circular reuse of building components. To reach this goal the following main research question is formulated:

“Which data is needed for circular component reuse and how does this data requirement influenSce the management of a BIM in new construction projects?”

Building components is an agglomeration level in the hierarchical structure of a building. Paragraph 6.3.2. will elaborate the complete hierarchical structure of a building. Building components are chosen because these are the biggest building parts that could be assembled on a construction site and, according to the definition of van Buren et al. (2016), thereby the most circular strategy in the “Extend lifespan of products and its parts” division. This makes the choice for building components the most circular use in a subsequent lifecycle and should thereby be the first choice in redeploying building parts in the circular AEC sector.

Kirchherr et al. (2017) conducted a literature review to identify a comprehensive CE concept. They identified that CE and circularity consists of multiple layers of implementation. In this report the layer “Reuse” is chosen because this is the first step in the redeployment of parts. Thereby the most waste and emissions are saved.

10.1. Sub-research questions

To structure this report, sub-research questions are formulated. These sub-research questions aim to develop constituents for answering the main question. Answering the main question requires research to data storing capabilities, data requirements and data structures. Modular building companies are already storing data for reuse purposes and are therefore used to compare with the current linear organisations. This results in the following research questions:

1. *What are the capabilities of the IFC scheme?*

2. *What data saves a linear building organisation about their new constructed assets during the phases of a project, and why?*

3. *What data saves a modular building organisation about their new constructed assets during the phases of a project, and why?*

4. What process changes are caused by Circular Reuse ILS in the first project lifecycle?

The IFC is used to store BIM data for a longer period and, as described in the problem statement, current IFCs could not be used in the CE. Therefore, it is important to fully understand the mechanisms and the capabilities of the format to be able to recognize the boundaries of the scheme. Answering this research question will identify what data could be stored in the scheme and what could not. All these aspects will be addressed in the first sub-question.

In the second sub-question the data structure and data demands per phase of linear building organisations is examined. What data do they process during the phases of a project? and why are they storing such data? how is the data structured among their documents? are the most important questions that need to be answered. Answering this sub-question will give further insight what Level of Development (LOD) is required at each phase of the project for buildings designed for a linear economy.

In the third sub-question the same analysis is done for modular building organisations, because these organisations are already storing data for reuse

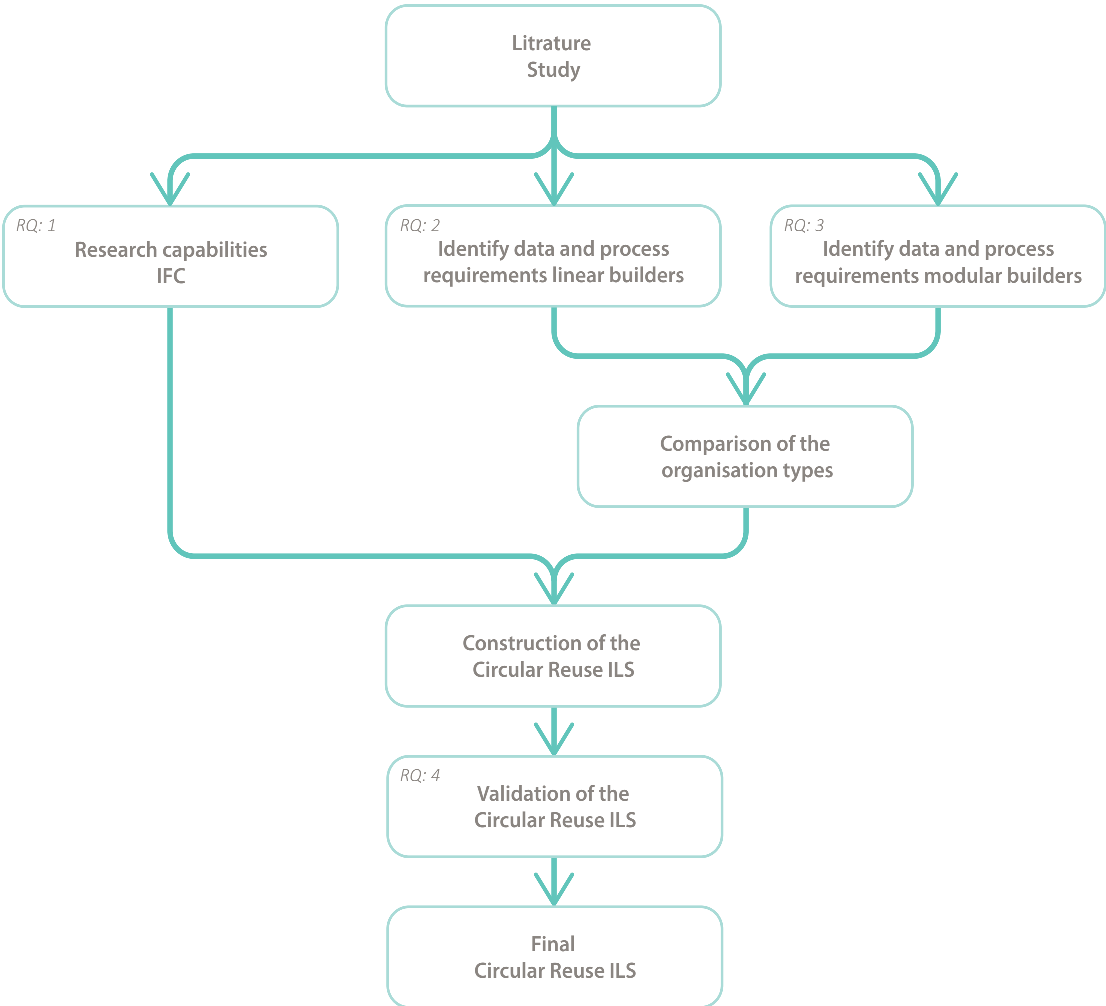

Figure 1: Research structure (Source: Own Illustration)

purposes. Answering this question will generate insight in the LOD of their model and how this enables reuse in ensuing projects.

The answer of sub-research two and three will provide an overview of the data management characteristics of both types of organisations. The types of data management could be compared, and data requirements could be analysed to identify the required data for reusing building components. Thereby lessons could be learned from both data structures for implementation in the Circular Reuse ILS. Implementing the Circular Reuse ILS in a model expresses the changes in workflows and could be further defined and verified by validation interviews. Thereby answer could be given to research question four. The changes in the process after implementation of the tool could be described and compared with the researched organisational processes of the linear and modular organisation.

11. RELEVANCE OF THE STUDY

Conducting research could have multiple purposes. In this section the relevance of this study is briefly highlighted. Creating new scientific knowledge is important for generating new solutions of the problems of today (UNESCO, 2021). Shawm & Elger (2013) stated that there are two types of study relevance: social relevance and scientific relevance. A social relevant study directly contributes to generate one or multiple solutions which are directly applicable in society. Scientific relevance, on the other hand, increases the knowledge and understanding of a process or disease.

Societal relevance

One aspect of scientific relevance is social relevance (Wilbertz, 2013). During exploratory interviews, conducted during the beginning of this research, it became clear that organisations are facing problems storing decommissioning data of their constructed buildings, because the data requirements are unclear and incomplete. Decommissioning parties do not know how they should disassemble buildings due to missing information and data and unknown building part characteristics. Modelling parties in the design phase, on the other hand, do not know what data should be available for the decommissioner to disassemble the building parts and redeploy these in further buildings. Thereby standards and requirements are missing to help these parties to structure their data, or, in other words, the current structure is not sufficient for implementation of the CE in the AEC industry.

Generating circular data requirements will simplify the implementation of circularity to the building industry, since the data requirements are known and validated. Thereby decommissioning parties could use this data to disassemble the building and make analysis of the redeployment possibilities of released building parts. Knowing the data requirements will results in simpler, complete, uniform, and structured data requirements. Thereby parties could check and manage the data in the digital model and ensure circular reuse of the building components in their building without testing of the materials. How data could be saved more efficiently and what data should be stored could be beneficial for a variation of parties, such as deconstruction companies, building owners, public authorities, and architects (Durmisevic et al., 2021). These organisations will have less work during the construction of the circular digital model because data requirements are clear and complete. This will decrease the complexity of their processes and thereby contribute to the adoption of the CE in the built environment.

Scientific relevance

How and what decommissioning data could be stored is still unknown (Davila Delgado & Oyedele, 2020; Akinade, et al., 2017a; Akbarieh et al., 2020; Volk et al., 2014), while literature highlights the need for disassembling data of an asset (Durmisevic, 2006; Charef & Emmitt, 2021; Davila Delgado & Oyedele, 2020; Chan et al., 2021; Akinade, et al., 2017a; Adams et al., 2017; Ajayabi et al., 2019). This research makes explicit what data is needed for circular decommissioning and adds thereby an extra layer of information to the research of Davila Delgado & Oyedele (2020), Akinade, et al., (2017a), Akbarieh, et al. (2020) and Volk, et al. (2014).

Furthermore, this research validates and discusses the circular data requirements of the ILS. The generation of circular data has influence on the modelling parties during the design and use phase. Thereby this research provides an interesting view on modelling processes in a circular built environment. Also, the new processes for decommissioning will be researched. Thereby the digital process of circular decommissioning is researched and validated.

12. DEMARCATION

As all research, certain boundaries should be set to keep the process and report manageable. Therefore, this chapter briefly describes the demarcation of this research.

- This research focuses on reusing of building components. Direct reuse of the building components is the most circular step, therein the assumption is made that the data remains available and does not change during the whole lifecycle;
- The agglomeration level “Building Components” is used. Thereby data needed for smaller agglomeration levels is not included in the research;
- Current requirements of the building degree 2012, as inventoried in May 2022 apply. Future extra regulations could not be guessed and are therefore excluded from this study;
- The work processes and data requirements of modular

organisations are assumed to be suitable for longer periods of data storage;
- This report focuses on the first building component lifecycle;
- The constructed building components are newly constructed components

13. STRUCTURE OF THIS REPORT

This report is structured among seven parts which encompass the following Theoretical Background, Research design and methodology, Research findings, Solution implementation, Conclusions, and it finalizes with a Reflection.

To improve the understanding of the used concepts presented in the introduction, literature research is needed. In the theoretical Background the three main used concepts are described in detail to ensure that a complete understanding is created about the main concepts: Circularity, Building Information Model (BIM) and the Industry Foundation Classes (IFC). These concepts form the basis of the researched topic and are used as input for the following report parts. Furthermore, a literature study to the concepts will contribute by generating a complete questionnaire for the interviews.

In part three the Research Design and Methodology is presented. This part informs about the research method, and the research deliverables after finalising the report. The steps which are taken for a complete report will be elaborated and structure is further highlighted. Also, the ethical considerations and analysing methods are described.

The research findings is the fourth part of this report. This part elaborates the results of the conducted interviews by the IFC-specialist, and the modular and linear building organisations. The needs and important issues are described of both organisations. In this chapter the data requirements of both organisations are further compared to identify the differences and the needs in every stage of the project. The goal is to identify which data should be in the ILS for component reuse. Thereby the boundaries are set for the Circular Reuse ILS.

In the fifth part of this research the new constructed “Circular reuse ILS+” is presented. The data generated from the research findings is presented in this new type of ILS. In this part the mechanisms, exportation structure and the new process of the ILS+ are described and visualized. Furthermore, the new process and data structure is validated and compared, to see how this could be implemented in current processes and what pitfalls could be recognized during the execution of this new tool.

Part six presents the conclusions and results of this report. In this part the answer on the main question and sub-questions could be found. The advantages and disadvantages of the designed tool are further highlighted and elaborated in a discussion chapter. Additional, recommendations for further research and improvements of the research methodology are further elaborate.

The final part will present a reflection of the whole report. Extra attention will be given to the research processes and the formation of the research gap.

Part 2
Theoretical Background

In this part the theoretical background is presented and contains a description of the key concepts. This part addresses three concepts: Circularity, BIM and the IFC. The first chapter elaborates the concept and the characteristics of circularity. Attention is paid to the definition and structure of the concept and how this concept is currently applied in the built environment. This chapter is followed with a BIM chapter whereby the principles and workflow of BIM are highlighted. The part concludes with an elaborate presentation of the characteristics of the IFC. The characteristics explains the structure of the schema and usability in practice.

14. CIRCULARITY

In this chapter the concept circularity is further elaborated. The paragraph starts with the history of circularity and the presentation of the R-strategies. These strategies form the basis of the concept circularity and are different approaches to reach circular construction. Thereafter, circularity in the built environment is discussed. The different layers of a building and the connection between the layers are highlighted and explained.

14.1. History of circularity

The origin of the concept “Circular economy” (CE) is widely debated by researchers, despite that the origin and initiator of the CE are still unknown (Murray et al., 2015; Winans et al., 2017). The idea behind the concept has been around for a period of time and evolved over the past decades (Winans et al., 2017). One of the first ideas arose in 1848 by first President of The Royal College of Chemistry R.W. Hofmann (Murray et al., 2015). He stated that a factory should only produce products without generating any waste. In his statement he primarily focused on the economic benefits that this could bring to firms, because removing waste could increase the profits of an organisation. In 1966 the English economist Kenneth Boulding developed the idea further by writing: “Man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy” (Murray et al., 2015). He acknowledges that the current economic system was not ecological sustainable over the long term and changes in the economic system should be made. Furthermore, Boulding was one of the first persons who mentioned that a cyclical system could be an option (Geissdoerver et al., 2017). Nowadays, the Ellen MacArthur (2013) constructed the most renowned definition for the CE. They define the CE as: “an industrial economy that is restorative or regenerative by intention and design”. They lay emphasis on the design for reuse and recycling and are less focused on the economic structure behind it (Kirchherr et al., 2017). Even though the the Ellen MacArthur (2013) is the most used definition, not all researchers acknowledge this as a comprehensive and complete definition. Lewandowski (2016), for instance, mentioned that circular business models are the driving force behind the CE and therefore should be included in the definition. On the other hand, Ghisellini, Cialani, & Ulgiat (2016) argue that consumer responsibility is key and should therefore be included. Still, a common accepted definition is lacking, which hinders in the implementation of the system in practice (Kirchherr et al., 2020).

The United Nation Climate officials calls the transition to CE key to compile with the goals of the Paris agreement (United Nations Climate Change, 2021b). United Nations Secretary Patricia Espinosa underlined this with the following statement: “The circular economy plays a definitive role here [meeting the goals of the Paris agreement]. It must expand if we are to reduce emissions across sectors as it is an essential component to achieving climate neutrality". Cantzler et al. (2020) and Stefanakis et al. (2021) mentioned that research agrees with Ms. Espinosa and that a CE alone is just a start. Jyki Katainen, President of the Finish Innovation Fund Sitra, highlighted the need for a CE in April 2021 during the World Circular Economy Forum by saying: "Overuse of natural resources is a major source of climate emissions. The circular economy provides us with a tool to tackle the climate crisis, to address the loss of biodiversity and to reduce our material consumption in an economically viable way" (Ministry of Infrastructure and Water Management, 2021). Therefore, national, and international goals are set to implement the CE in the nearby future. Realizing a CE in the Netherlands could lead to a reduction of seventeen megatons of carbon dioxide annually and thereby making serious steps in meeting the Paris agreement (Ministerie van Infrastructuur en Waterstaat, 2016). Despite the lofty ambitions and interests of the governments and researchers the level of circularity in the current economy is low (Clube & Tennant, 2020; United Nations Environment Programme, 2021). De Wit et al. (2020, p. 23) reported that the current degree of circularity in the global economy is lower than 9%, and that major steps needs to be made to a global implemented CE.

14.2. Definition of circularity

Kirchherr et al. (2017) conducted literature research among 114 definitions to identify the most important aspects of a CE aspects. They concluded that the definition should have three important aspects. First, the CE should primary be seen as an alternative economical system that aims to replace the "end-of-life" concept. In this new economic system, old parts are seen as the ingredients of tomorrow and thereby a closed-loop system is created (Eberhardt & Birgisdottir, 2020; Niero & Schmidt Rivera, 2018; Kirchherr et al., 2017; Ellen MacArthur Foundation, 2013). Furthermore, the definition should be operationally for micro, mesto and macro level and contribute to sustainable development (Kirchherr et al., 2017). Sustainable development means that future generations should benefit of the environmental quality, economic prosperity and social equity created today. Finally, the definition should point out a hierarchy. The hierarchy stimulates organisations to optimize their operations towards a higher level of circularity. The definitions of van Buren et al. (2016, p. 3) includes all these aspects and is easy understandable (Kirchherr et al., 2017). Therefore, this definition is used to describe the CE, which is as follows: "Reducing the consumption of raw materials, designing products in such a manner that they can easily be taken apart and reused after use (eco-design), prolonging the lifespan of products through maintenance and repair, and the use of recyclables in products and recovering raw materials from waste flows. A circular economy aims for the creation of economic value (the economic value of materials or products increases), the creation of social value (minimization of social value destruction throughout the entire system, such as the prevention of unhealthy working conditions in the extraction of raw materials and reuse) as well as value creation in terms of the environment (resilience of natural resources)." (van Buren et al., 2016, p. 3).

R-strategies

The definition of van Buren et al. (2016) could be simplified and structured to a hierarchy with 9-Rs. The strategies in the hierarchy are based on the “Ladder van Lansink”, in which a ranking illustrates how waste should be managed (Potting et al., 2016). The higher in the hierarchy the R is positioned, the more circular it is (Potting et al., 2016; Morseletto, 2020), due to larger material, labour, energy, capital, and emission savings (van Vliet, 2018; Ellen MacArthur Foundation, 2013). The strategies are structured among three distinct division, named: Smarter product use and manufacture, Extended lifespan and its parts, and Useful applications of materials (Morseletto, 2020). The divisions tell something about the function and goal of the used strategy and is stretched in the following sections. The R1 Refuse strategy is the highest ranked in the hierarchy and is therefore defined as the most circular strategy. R9 Recovery, on the other hand, is lowest ranked and thereby the least circular in this definition. The following sections the divisions and related strategies are further explained.

The smarter product use and manufacture division takes place during the mining, designing and development of materials. This division is closely related to design of goods and products and aims to decrease the usage of natural resources (Potting et al., 2016). Because the division is closely related to the design, the strategies have precursory, enabling, and transformative character. These aspects make “Smarter product use and manufacture” strategies in favour of the other divisions (Morseletto, 2020). The “Smarter product use and manufacture” division encompasses the Refuse (R1) and the Reduce (R2) strategy. The Refuse strategy makes products and components redundant by eliminating one or multiple functions. Furthermore, it is possible to abandon the product by offering a different product with the same function. Overall, applying this strategy will decrease the overall material usage and emission by refusing functions and products. The Reduce strategy aims to minimize the usage of natural resources by reducing quantities, such as square meters or overdimensioning products. Thereby, the products become more use-intensive, and less energy and waste are produced.

The “Extend lifespan of product and its parts” is the second division and aims to retain materials and goods in the economy by maintaining and improving their material and use value (Morseletto, 2020; Rijksdienst voor Ondernemend Nederland, 2021). This requires proper functioning reverse logistics, market receptivity, and a variation of business models (Morseletto, 2020). Often the quality and quantity of the materials and products face higher uncertainty levels compared to other strategies, due to adjustments in socio-economical patterns. The Reuse (R3), Repair (R4), Refurbish (R5), Remanufacture (R6), and Repurpose (R7) strategies are covered in this division. In the Reuse (R3) strategy products in a good condition are used by another owner without changing function and identity. This means that the product is used directly in an extra lifecycle without modifications. In the strategies Repair (R4), Refurbish (R5), and Remanufacture (R6), products are modified by a person or organisation to extend their lifespan to overcome

Smarter product use and manufacture	R0	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	Reduce	Increase efficiency in product manufacture or use by fewer natural resources
Extend lifespan of products and its parts	R2	Reuse	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R3	Repair	Repair and maintenance of defective product so it can be used with its original function
	R4	Refurbish	Restore an old product and bring it up to date
	R5	Remanufacture	Use parts of discarded product in new product with the same function
	R6	Repurpose	Use discarded products or its parts in a new product with different function
Useful application of materials	R7	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R8	Recovery	Incineration of materials with energy recovery

Table 1: R-strategies (Source: Own table, based on Morseletto, 2020)

obsolesce. Repair encompasses maintaining of inadequate functioning product, so it can be used within its original function. This could mean that components of the product are replaced to keep the product in a proper working condition. Refurbishing (R5) improves the use-value by replacing components of the product. Refurbishing differs from Repairing because it modernises the product, whereas in Repairing the use-value does not change. In Remanufacturing (R6) the components of a discarded product are used in defective products to create a new product within the same function. Contrastingly, Repurpose (R7) is the process of deploying discarded products into new products with another function. Important in the applicability of these strategies are the disassembly possibilities of the products, without disassembly options, these strategies cannot be executed (Morseletto, 2020).

The final division is “Useful application of materials”. This group of strategies covers material and component streams which would otherwise be landfill or incarnated without heat recovery (Morseletto, 2020). The Recycle (R8) and Recover (R9) strategies are in this division and are two lowest ranked strategies, this is due to low yield rates, expensive treatments, and the disposal of intrinsic material value of the strategies. Morseletto (2020)

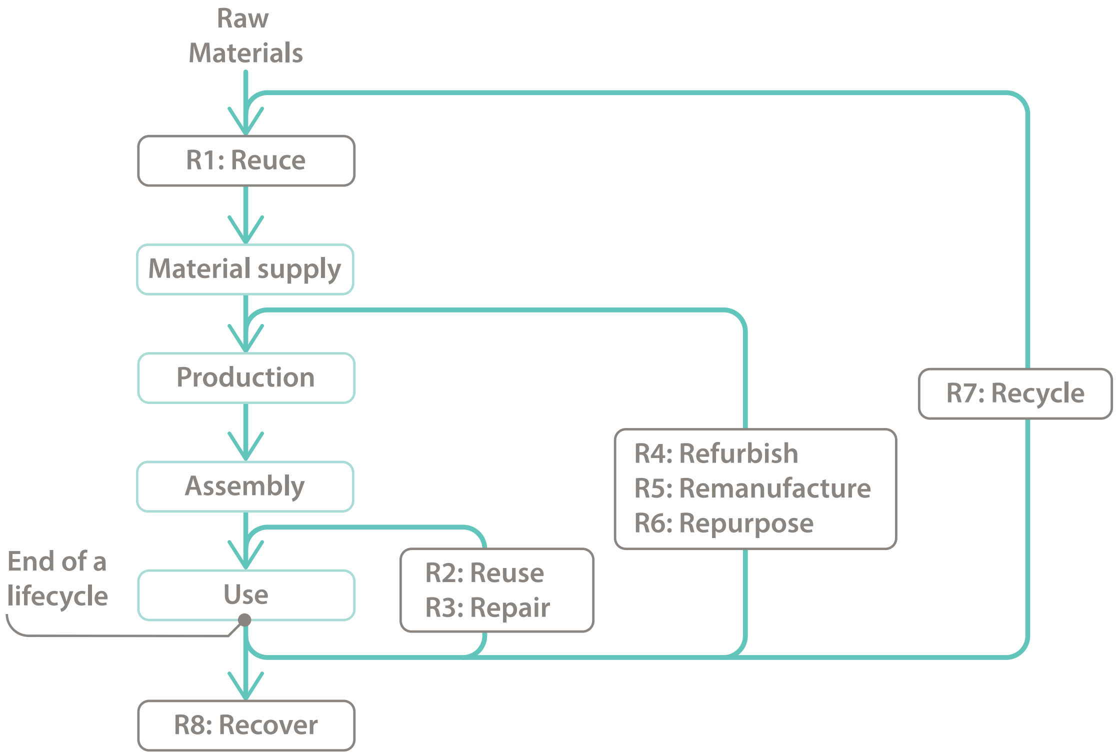

Figure 2: R-Strategies during the lifecycle of a part (Source: Own illustration, translated and adapted form: Rijksdienst voor Ondernemend Nederland (2021) and Durmisevic (2006))

defines Recyling (R8) as: "the processing of materials to obtain the same (high-grade), or lower (low-grade), quality of recycled materials". A higher functional quality means that materials have the same or better qualities compared to the original product. Contrasting, a lower functional quality has a lower applicability of materials after the process. Recovering (R9) can be defined as the combustion of materials or products with energy recovery. Recovery is the least circular strategy of the hierarchy and therefore the least preferred (Rijksdienst voor Ondernemend Nederland, 2021). The strategy is often used if products cannot be used in other strategies and therefore it is important to DFD (Akinade, et al., 2017b; Morseletto, 2020; van den Berg et al., 2020b).

14.3. Circularity in the built environment

To understand the requirements of a DFD building, it is needed to investigate the characteristics of DFD and the building layers of a building. The coming section will provide insight of the lifecycle of a building as well as the building agglomeration layers. Thereby insight is created in the theoretical structure of the building and the application possibilities of the predefined R-strategies.

As mentioned in the problem definition, enabling decommissioning is crucial for the implementation of the circularity in the AEC industry. To improve circularity in the built environment, new principles and guidelines are introduced in the sector (Cihan Kayaçetin et al., 2022) these are called decommissioning strategies (van den Berg et al., 2020a; Akinade, et al., 2017a). A decommissioning strategy is a strategy that aims to recapture building parts to, eventually, redeploy these in new assets (Akinade, et al., 2017a). This means that implementing a decommissioning strategy is applying a R-strategies to the asset. Furthermore, redeployment of larger building parts is preferable compared to smaller, because this is higher positioned strategy in the definition of van Buren et al. (2016, p. 3).

Akinade et al. (2017b) conducted a literature review to get better understanding what data is needed for a comprehensive decommissioning strategy and this could be summarized into three principles. First, use connections which enable reversible construction. Second, design connections which are easily accessible and finally, minimize the number of connections (Durmisevic, 2006; Akinade, et al., 2017b; van den Berg et al., 2020b). The used connections in an asset form the basis of the decommissioning strategy. Therefore, it is key to design connections which could be decommissioned (Durmisevic, 2019; Akinade, et al., 2017b). The released building parts could be disassembled and could thereby be reused (Durmisevic, 2019). Geldermans (2020) underlines this argument by writing: "Technical circularity potential of building products and materials resides at the intersection of intrinsic and relational characteristics." Recycling and reusing building components repiques much less energy, and thereby less emissions, compared to mining new materials (Akinade, et al., 2017a).

Building layers

Frank Duffy recognized that a building consists of various layers with a unique longevity (Durmisevic, 2006). In 1994 architect Stuart Brand further elaborated these layers in his book "How buildings learn: What happens After They're Built". In this book, Brand identified six layers of a building. He states the following: "Our basic argument is that there isn't any such thing as a building. A building properly conceived is several layers of longevity of built components." In this situation Brand acknowledges that a building consists of several operating processes all with their unique timeframe. The construction of a building should allow slippage between the layers to become adaptive (TU delft, 2021) and thereby becoming more suitable for decommissioning (Durmisevic, 2006; 2019). In figure 3 the layers of the model of Brand (1994) are shown. The aim of the model is to disconnect the different layers to facilitate replacement of building components instead of the whole system (TU delft, 2021). This follows the design principles of the DFD concepts, and thereby the principles of the circular R-strategies. Geldermans (2020, p. 268) highlights this by saying: "The differentiation of building layers and parts, in combination with differentiated reutilisation routes, provides leverage for more advanced approaches to circular building strategies, anticipating multiple handling and treatment processes." Understanding the six layers of Brand (1994) will therefore increase the understanding of DFD and circularity.

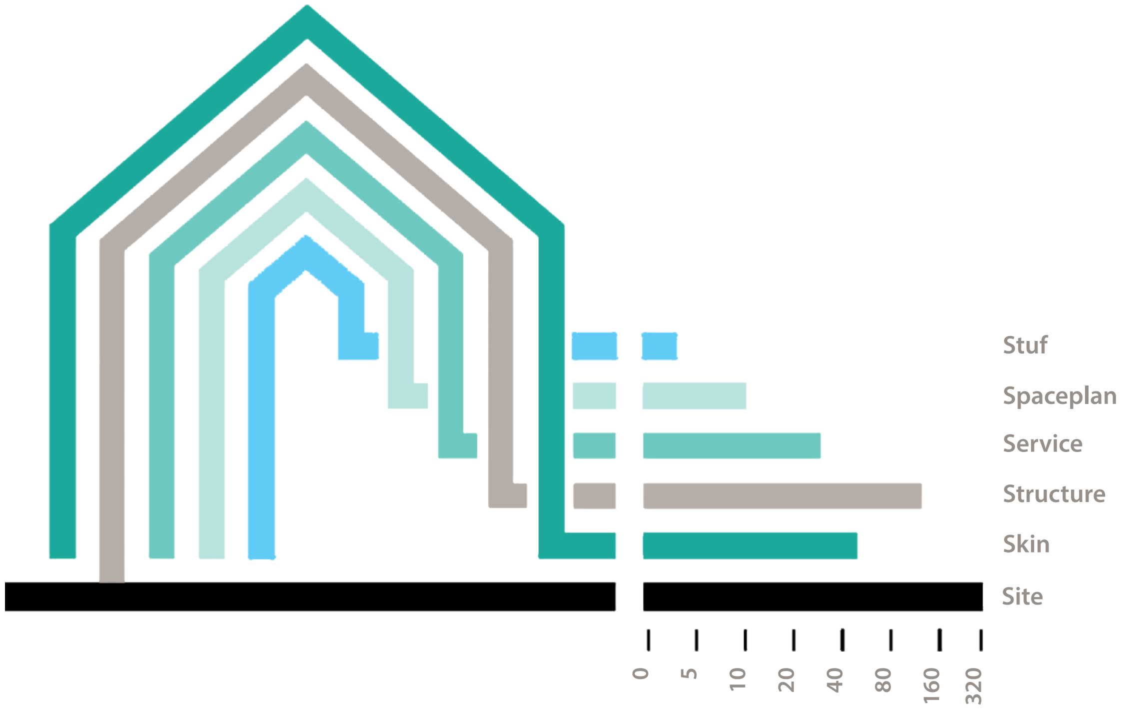

Figure 3: The shearing layers of change diagram (Source: Brand, 1995)

1. Site: the site of the building is the geographical location on the earth. The location of the building has an eternal lifespan and will therefore last forever.

2. Structure: the structure of the building includes all constructive load bearing elements, this includes coulombs and slabs. Brand (1994) states that the structure of a building between the 30 and 300 years. It is not easy to change the structure of the building and therefore minimal modifications in the structure could be expected.

3. Skin: the skin of the building is the external layer around the building that protects the internal components of the building. The lifespan of the skin is around the 20 years. This layer includes, for instance, window frames, cladding, and roofing. Over the years, the requirements of the skin increase and therefore the skin is often replaced earlier.

4. Services: Services of the building include all installations of the building. This layer is becoming obsolete every 7 till 15 years.

5. Space plan: the interior layout of the building is positioned in the space plan. The lifespan could vary a lot, every three years for utility buildings and thirty or more years.

6. Stuff: All stuff in a building includes the thinks which are used by the occupants on daily basis, such as a pen or chairs. Every 5 years the stuff in a building is replaced.

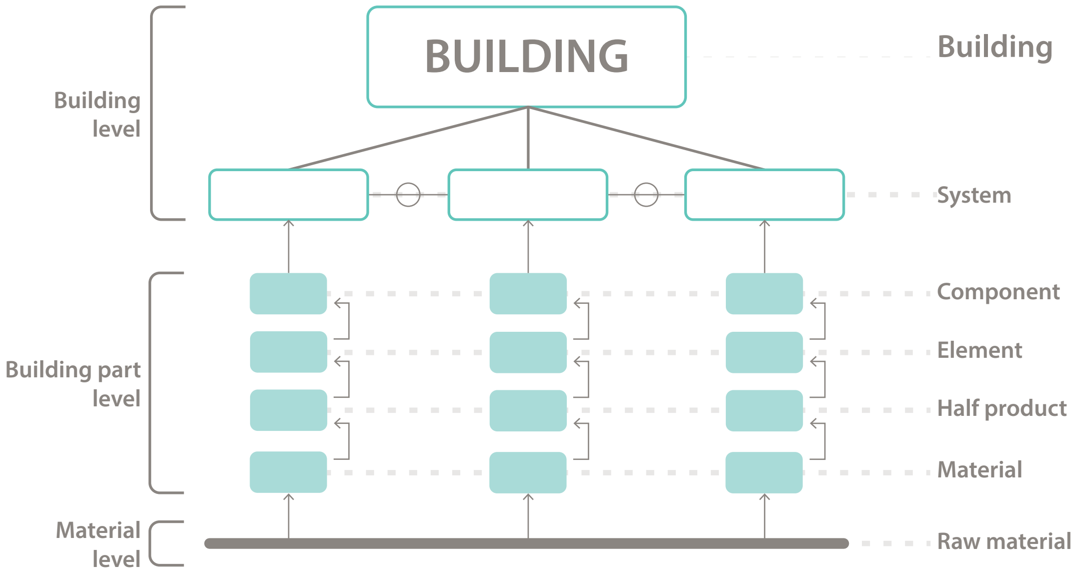

Figure 4: Hierarchy of material levels in building (Source: Durmisevic, 2006)

Levels of technical decomposition

The technical building structure could be presented as an agglomeration of physical building part that fulfil a specific function (Durmisevic, 2006; 2019). In figure 4 the top-down structure of the building system is shown. In this structure the higher presented levels dominate the lower positioned. Durmisevic (2006; 2019) recognizes three main levels in a building which have all a unique technical composition; Building level, Building part level, and Material level. The building level is the first layer and represents whole building and its systems. These systems form a cluster of building parts that fulfil one or more specific functions and are constructed on the building site, such as skin or structure. The second layer is the building part level and consists of four levels of building parts. The four classes of the building parts layer form the basics of a building and are assembled off the building site in a factory. The designers of a building determine the allocation of the building parts in the system level and construction processes related with it. The classes are derived from performance criteria and production flexibility and could be connected to one another, or in other words, classes located in a lower level could be connected to higher located classes and levels. The mentioned designations are relative. A component in one building could be an element in another building. The material layer is the lowest positioned layer wherein the raw materials are positioned (Durmisevic, 2006).

Disassembling, and thereby the implementation of the earlier mentioned R-strategies, is possible in every building level (van Vliet, 2018). As mentioned before, the CE aims to minimize waste and emissions Hence, using higher levels are preferable in the CE. Durmisevic (2006, p. 143) states that that defining lower levels in the hierarchy will increase the transformation capacity of the building, because more specific decommissioning is possible. A designer should aim to configure a building that is dynamic and separates the building levels and corresponding classes, so individual parts could be disassembled.

Design criteria building reusability

A building part is more than just its intrinsic material value. The relational properties play a role here. These properties concern the reusability of the part in future scenarios and consider the design aspects to enable reusability (Geldermans, 2020, p. 108). The design criteria could technically define as, dimensions, connections, and performance time. Durmisevic (2019, p. 39) describes eight design aspects which influence the exchangeability of building parts and systems. The configuration of these aspects influences the redeployment of the parts in the subsequent lifecycle. Durmisevic (2019, p. 39) describes the following aspects: functional decomposition, systematisation, relational dependency and relational pattern, base element of the configuration, assembly and disassembly sequences, geometry and morphology, type of connections, life cycle coordination of elements. In the following sections these aspects are briefly highlighted.

Functional decomposition

Designing a dismountable asset requires making choices of the integration of functions. In other words, the designer determines which part carries which functionality. Every function has unique qualities, requirements, and lifespan. As mentioned in the section building layers, every building layer has its own lifespan consequently every product should be replaced in a different moment of time. By giving one function to one product, the functions become structured and easier to replace (Durmisevic, 2019). Separation increases thereby the flexibility and the applicability of a building part in a subsequent lifecycle.

An example, if a building part has combined function structure and space plan, the building part should be replaced after, according to the theory of Brand (1994), 25 years. Whereas the structural lifespan of the part is longer than 150 years. As a result, the building part with a structural lifespan of 150 years is replaced after 25 because the space plan is not suitable anymore. The building parts become obsolete while they could function an extra 125 years in a structural function.

Systematisation

The systematisation tells something about the number of sequences which are needed to decommission a building (Durmisevic, 2019). The systematisation of a building presents the composition of the building parts to the construction site. This means that building parts could be disassembled in a structured and logical order and replacing building systems is clear and quick. An example, if a doorframe should be replaced, it should be easy to dismantle the doorframe from the wall instead of disassembling the whole wall to replace the doorframe. Thereby less resources are needed to decommission building parts.

Relational dependency and relational pattern

The aspect relational dependency and relational pattern aims to minimize the relations between building parts. The relations of a building element are all connections that a part has with other parts. By minimizing the number of connections, the systemisation of the building becomes less and thereby easier to redeploy building parts. Furthermore, this aspect tells something about the location of an element in the systematisation (Durmisevic, 2019).

Base element of the configuration

A building could be seen as a system of relations between elements. In the system elements could be found which together form a cluster (Durmisevic, 2019). To enable interdependence between cluster a base element should be designed, this element organizes the cluster by integrating all surrounding elements.

Assembly and disassembly sequences

Assembly and disassembly sequence have influence on the complexity of the structure of building elements (Durmisevic, 2019). The sequence determines how the construction and deconstruction phase is formed. The relations and sequence of elements determine the complexity of the construction and deconstruction.

Geometry and morphology

The accessibility of elements can be affected by the geometry and morphology of the element edges (Durmisevic, 2019). The geometry and edges of elements determine the accessibility and simplicity of the disassembly of a connection and is closely related to the assembly sequence. Furthermore, a bad designed geometry is a major cause of damage during construction activities, because elements could be locked in.

Life cycle coordination of elements

Important by assembly and disassembly is the coordination (Durmisevic, 2019). In general, building materials have a wide range of life cycles and often the systematisation, relations and assembly sequence do not consider this. During the process, the elements with a sorter lifecycle should be replaced, and reused, earlier. The coordination should coordinate all aspects to create dismountable buildings.

Type of connections

The core of the all the reusability are the used connections (Durmisevic, 2019). The type of connection between interfaces of elements determines the degree of freedom. The materials used and structure have major impact on the type of connection which is suitable. The connection used between elements is a result of the systemisation, relations, and geometry of the elements.

Durmisevic (2019) recognizes three main typologies of connections: integral connections, accessory connections, and filed connections. In the integral connections the geometry of the elements forms the connection. Durmisevic

(2019) identifies two types of integral connections: overlapped and interlocked. Overlapped connections are connections between horizontal components with a piled imposition. These connections supports or pins are used to prevent displacement. Interlocked connections, on the other hand, are connections in which the edges are shaped differently, just as pieces of a puzzle. They edges keep the elements in place and thereby become connected with each other. Accessory connections are connections between elements which require additional parts to connect elements. A separate tool is used here to link the two elements, such as a screw or nuts and bolts. This requires modifications on the element which could vary a lot by the used accessory. The filled connections are all connections between elements whereby a chemical connection is used to fix the elements. Comprehensive decommissioning of these connections is almost impossible and requires often special deconstruction technologies.

In the three connection typologies different levels of disassembling could be recognized. Durmisevic (2019) states that eight connection types could be used in the AEC industry. Connections with a high number are highly flexible for disassembling and reuse.

I. Direct chemical connection, a chemical connection permanently connects two or more materials to each other;
II. Indirect chemical connection, two materials are connected by an irreversible chemical connection;
III. Direct chemical connection, connection with ire
IV. Direct insert connection, materials are connected by planed insertion of components;
V. Direct connection with mechanical fiction, elements are connected by a mechanical connection, this connection could be removed without damage of the elements;
VI. Indirect connection via depended third component, this connection two materials or elements are separated by a third element;
VII. Interlock connection, the elements are interlocked and connected without fixed devices;
VIII. Indirect connection with additional fixing device, elements are connected by mechanical connections.
IX. Gravity, elements are connected by gravity.

Connection eight could formally not be seen as a connection, because there is no direct relation between the two elements. This could therefore be seen as the most flexible and reusable connection. Furthermore, this connection type could not be defined into one of the three main typologies.

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Nijs et all. (2011) conducted multiple interviews and case studies to review if the connections are used in by construction companies for design for decommissioning. They concluded that the typologies used in the research of Durmisevic (2006) are used in practice and implementation of the typologies will increase the reuse and recycle possibilities of building parts (Nijs et al., 2011). The research of Durmisevic (2006) forms the basis of the connection typology of Durmisevic (2019). Furthermore, van Vliet et al. (2019) published a report to calculate the decommissioning value of built assets. In this report the connection typologies of Durmisevic (2006) were used to calculate the disassembling factor for buildings. Their methodology was validated by conducting five case studies which are designed for decommissioning. They concluded that the used connection typology was suitable in practice.

15. BUILDING INFORMATION MODEL (BIM)

In this chapter an overall description of BIM (Building Information Model) projects, BIM files and other BIM related thermology is presented. This chapter starts with a general description of the qualities of a BIM. Thereafter the work structure of BIM is presented to give understanding how a BIM model is used in practice.

15.1. Building Information Model (BIM)

Since the development of Computer-Aided Design (CAD) files, it drastically changed the process and systems of the AEC industry (Temel & Başağa, 2020). CAD files are digital files in which 2D digital drawings are plotted to exchange data between stakeholders. These models consist of line-types, vectors, and text to visualize assets. Over the years, CAD modelling became more intelligent, and 2D modelling evolved into smart 3D models. In the late 1970's Professor Charles Eastman introduced the first concepts of a Building Information Model, often referred as BIM (Latiffi & Barhim, 2014). The BIM is a smart digital 3D model which contains information and data of a building and its objects. BIM software recognizes the behaviour of objects in relation to each other, which facilitates smoother and quicker modelling processes (Eastman et al., 2011). In this case the designation "Building" refers to any built object and the process of construction of an asset and includes, built assets, civil engineering, and infrastructure works (Barnes, 2019, p. 7). In literature BIM is often used as acronym for Building Information Modelling (Eastman et al., 2011) or Building Information Management (Barnes, 2019; Becker, et al., 2018). Since the introduction of the concept, it has broadened its applications and it could be used for design, production, construction, collaboration, communication, and analysis purposes (Latiffi & Barhim, 2014; Barnes, 2019; Eastman et al., 2011; Becker, et al., 2018). Nowadays, BIM could be used by almost all stakeholders of the AEC industry throughout the project lifecycle (Borrmann & Petzold, 2018; Alizadehsalehi et al., 2020).

Traditionally speaking, the construction of a building is an interdisciplinary cooperation with a multitude of stakeholders (Becker, et al., 2018). Collaboratory working in one BIM environment brings many advantages during all the project phases. Barnes (2019) and Becker et al. (2018) argue that the implementation of BIM could reduce costs, time, and increase the overall project value. Barnes (2019) further states that a reduction in greenhouse emissions could be realized and the trade gap for construction parts is significantly smaller by using BIM. These advantages are mainly caused by improvement of construction process, due to the higher collaboration between all parties and clearer visualisation of dependencies. Furthermore, technical data is shared complete and accurate (Alizadehsalehi et al., 2020; Barnes, 2019). This data could be used by manufacturing organisations for prefabrication and increases the efficiency, whereas the errors and corrections are reduced (Barnes, 2019).

15.2. BIM data

Data is needed from participants of the project to model a BIM. The clients, architect, contractors, and other involved stakeholders should give input for the construction of BIM and the final built asset (Becker, et al., 2018). The data in the BIM depicts, for example, the dimensions, performance, environmental quality of the building or the building parts (Barnes, 2019). The Level of Development (LOD) of the data will increase over time through decision making and elaboration of details (Winch, 2010).

According to Eastman et al. (2011, p. 16) BIM could be defined as; “a modelling technology and associated set of processes to produce, communicate, and analyse building models.” The BIM have four associated characteristics. First, the objects carry quantifiable graphic, and information attributes to represent building parts. The relations between the objects form a set of parametric rules which enable the modelling software to automatically modify geometries and characteristics of related objects (Eastman et al., 2011). Since BIM is a collection objects with a relation between each other, modelling becomes much simpler and more efficient (Latiffi & Barhim, 2014; Barnes, 2019). Secondly, objects contain parametric rules that defines their behaviour among other modelled objects and enables analyses and structuring work processes, such as energy analysis (Eastman et al., 2011). Third, modifications made to modelled objects are represented in all views of which the modification is part of. And finally, the coordinated data is represented in a structured way.

A building modelled in a BIM software tool can show data in a multitude of 2D and 3D views (Eastman et al., 2011). Nowadays, software developers are working on more dimensions to include planning, budgeting, operation, and environmental aspects to make the BIM even more representative (Barnes, 2019; Daniotti, et al., 2020). The views or plans are created by modelers of the BIM software. Furthermore, a BIM object is always a hierarchy of aggregations (Eastman et al., 2011). This means that characteristics of an object changes if modifications are made in higher hierarchical objects. For example, if window sizes are changed, the size and characteristics of the window frame are changed as well. This simplifies working and managing a BIM.

15.3. BIM work structure

Working in a BIM environment requires a working structure. This working structure is based on two realms: the Native Model Environment (NME) and the Common Data Environment (CDE), this is illustrated in figure 5. The

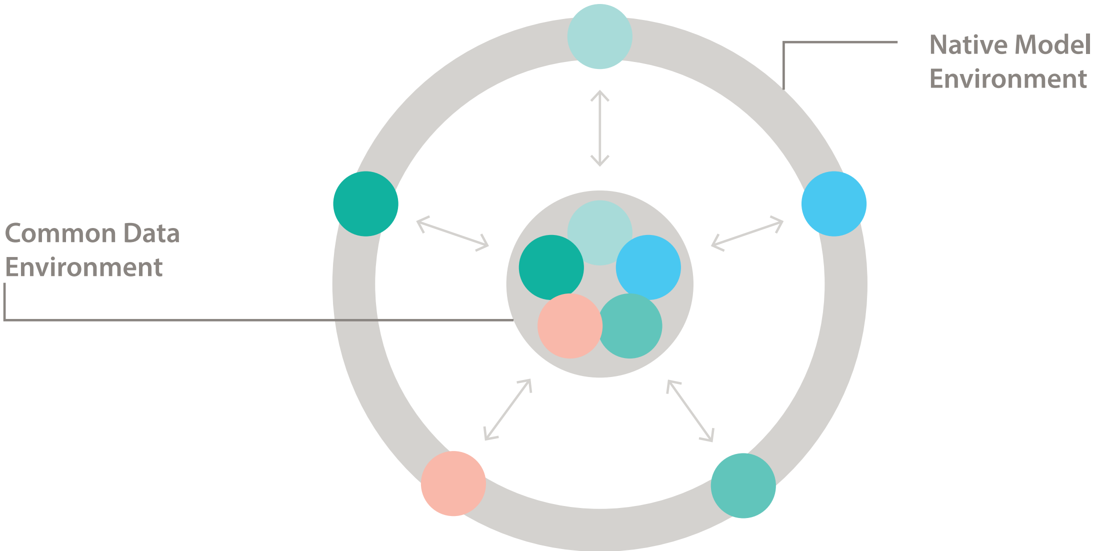

Figure 5: CDE and NME (Source: Baldwin, 2020)

native environment is a BIM modelling space or analytical software used by a stakeholder of the project, such as Revit or Solibri. In this environment stakeholders of the project can analyse or add their own data. After completion of their activities, a copy of their digital model is saved in the CDE (Barnes, 2019). The CDE is used to save all information and data about the project and could be seen as the data hub during the whole project (Alizadehsalehi, Hadavi, & Huang, 2020). This results in a database where all project data is saved, including contracts, schedules, geometrical models, and other sources of data (Barnes, 2019). Daniotti et al. (2020, p. 10) defines the CDE as; “the place where all the subjects involved in a specific job order can store, share, manage and process information in order to carry out their activities.” One of the most important files in this environment is the BIM file (Eastman, Teicholz, Sacks, & Liston, 2011).

The data in the CDE can be accessed, extracted, and shared with other authorised stakeholders of the project. Digital models and technical specifications uploaded on the CDE could have a variety of levels, such as work in progress, and published (Daniotti, et al., 2020), this is further elaborated in paragraph 7.6 Level of Development (LOD). PAS 1192-2:2013 describes the standards, specifications, and codes for practical usage of a CDE (Radl & Kaiser, 2019). This standard is developed by British Standards Institution in cooperation with organisations form the AEC industry (BSI, 2013). Furter specifications of the responsibilities, accessibility, and the LOD could be found in the BIM protocol (Daniotti, et al., 2020), which is elaborated later in this chapter.

15.4. Open Data Format (ODF)

To ensure interoperability of the BIM, an Open Data Format (ODF) is used to exchange BIM. Complete, easy, and reliable data exchange is recognized one of the largest issues for BIM users (Eastman et al., 2011; Barnes, 2019; Alizadehsalehi et al., 2020). Harmonizing the used information Technology (IT) systems is needed to avoid incompatibility of BIM and thereby obstructing the project process (Barnes, 2019). An ODF is a standardized data format which could be opened by a multitude of AEC software without data loss. A second reason for using a ODF is that models, drawings, and other related documents could be unreadable in the future, due to updates in software programmes. ODFs overcome this problem and are therefore crucial for archiving project and building data (Barnes, 2019; EUBIM Task Group, 2016).

A ODF is written in a more general IT language so more BIM software can read and understand the presented data. The most used ODF is the IFC, also known as the Industry Foundation Classes. The IFC is based on the ISO STEP EXPRESS modelling language and the latest version consists of 776 entities which could be used to describe building parts or other relevant aspects. This makes the IFC one of the most elaborate data schemes available in the industry (buildingSMART, 2020). The major drawback of the IFC structure is that it is seriously complex for non-specialists (Daniotti, et al., 2020). The STEP coding is not the only coding what can be used. It is also possible to export an BIM to XML and JSON formats. Another ODF is the Green Building XML, often referred as the gbXML schema (Malhotra et al., 2019). The gbXML is written in the XML coding language (Daniotti, et al., 2020) and consists over 500 hierarchical elements and attributes to describe the BIM (Malhotra et al., 2019). Contrasting to the IFC, the gbXML is structured bottom-up and easy to understand, which facilitates quicker implementation of the schema. One of the major drawbacks of gbXML is that not all building information and relationships could be stored in the format (Gerrish, et al., 2017). The EUBIM Task Group, a pan-European commission formed to stimulate the implementation of BIM across public contracting authorities, advice to use IFC as ODF (EUBIM Task Group, 2016, p. 70)

15.5. BIM WORKFLOW

The project owner starts with a BIM project by structuring information and distributing responsibilities, because this reduces communication faults. In general, one modeler or modelling party is assigned to make changes in the main BIM during the project. During the project the project owner expands and updates the BIM file with extra layers of information and data to make the digital model more complete and elaborate. The main BIM is also referred as the Project Information Model. This model contains all information and data of the whole project during the preliminary stages of the project. When the project is elaborated in higher levels of detail for production purposes, aspect models are constructed. These models are separate small BIMs that contain data over one, or more, building parts (Barnes, 2019, p. 45).

In figure 6, the workflow of a BIM file is shown. Generally, the modeler starts modelling in a software programme and export the modelled file into an

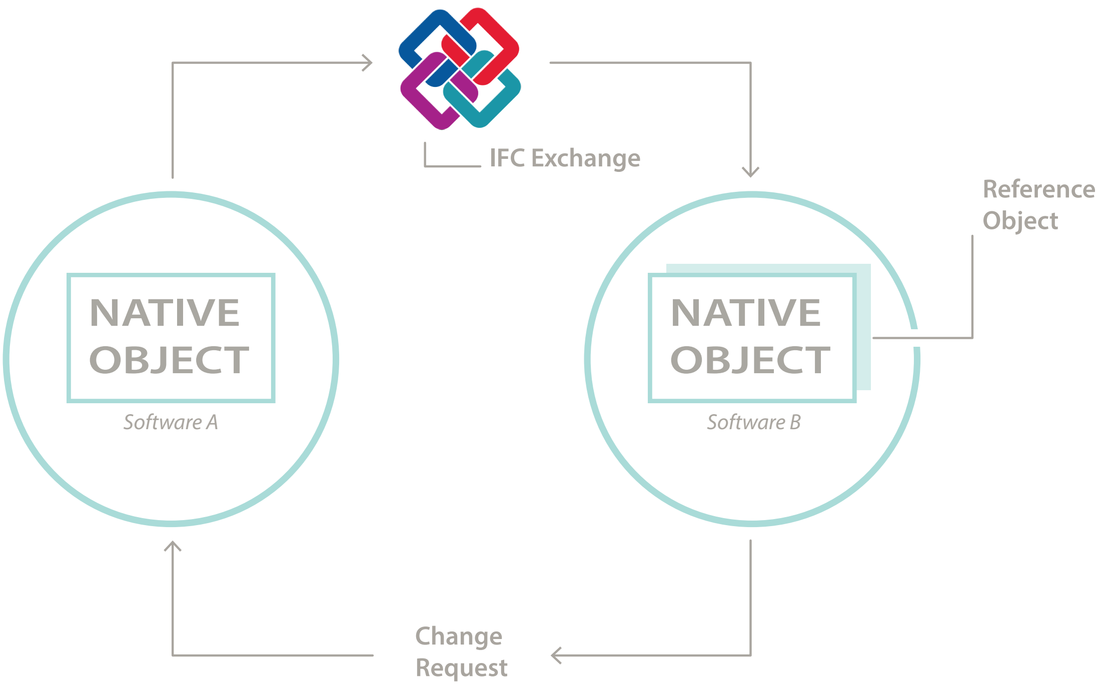

Figure 6: BIM workflow (Source: adapted from Baldwin, 2020)

ODF. The ODF used in figure 6 is an IFC file. The modeler uploads the ODF to the common data environment to enable stakeholders to download and use the ODF. After the stakeholders did their analysis, they could request chances to the ODF by contacting the original owner of the BIM (Barnes, 2019, pp. 36-41). The stakeholders cannot change the main BIM, because this will disorganize the workflow. So, if the stakeholders want to change objects and elements in the building, they must ask the owner to make the changes (Baldwin, 2020).

15.6. Level of Development (LOD)

A BIM contains of a multitude of building parts, to which information and characteristics could be added to define the parts further. In 2013, BIMForum published the Level of Development (LOD) specification which helped clients and organisations in the AEC industry to specify the geometric complexity and data quality of a BIM throughout the project lifecycle (Graham et al., 2018; Becker, et al., 2018). By defining the required data quality, the project stakeholders know at which LOD building parts are, and should, be developed at a certain moment in the project lifecycle (Borrmann & Petzold, 2018). A LOD cannot be assigned to the BIM itself but must be assigned to building parts or a group of building parts, thereby the digital model could contain various levels of LODs (BIMForum, 2021). This is a major advantage for the AEC professionals because it allows them to focus on the most important and more complex areas of a building (Graham et al., 2018).

The BIMForum (2021) describes five LOD with LOD-100 as and LOD-400 the most extensive. BIMForum (2021, p. 17) further describes a LOD-500, but this specification relates to the field of verification and facility management and does not give a more detailed level of geometry and building part information and data. Therefore, the LOD-500 is not further elaborated in this report. Data saved in a LOD could be graphical and non-graphical (Borrmann & Petzold, 2018). Graphical data, also referred as "Level of Detail" (Barnes, 2019), is all data that could be visually seen of a building part, such as the length, width, and volume (BIMForum, 2021). All data of a building part that could not directly be seen is called non-graphical data, such as material, costs, and strength. Non-graphical data is also called the "Level of Information" (Barnes, 2019). The required level of graphical and non-graphical data is defined in the BIM protocol. In the following sections the LODs are further elaborated. The definitions are acquired from the BIMForum LOD specification (BIMForum, 2021).

LOD-100

"The Model Element may be graphically represented in the Model with a symbol or other generic representation but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e., cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements" (BIMForum, 2021, p. 16). The LOD-100 is the most generic detail level and illustrates only masses in the digital model, therefore this LOD is used for mass studies by architects and financial feasibility studies (Rodrigo-Ortega et al., 2021). In this stage it is not possible to recognize floorplans or sections and the final geometry of the asset is not determined by the client.

LOD-200

"The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element" (BIMForum, 2021, p. 16). The LOD-200 is a more detailed representation of a digital model compared to the LOD-100; however, the information and data saved in the digital model should be considered as approximate (BIMForum, 2021). The basic structure and partitioning of the building are further defined in this LOD, so schematic sections and floorplans could be made (Rodrigo-Ortega et al., 2021).

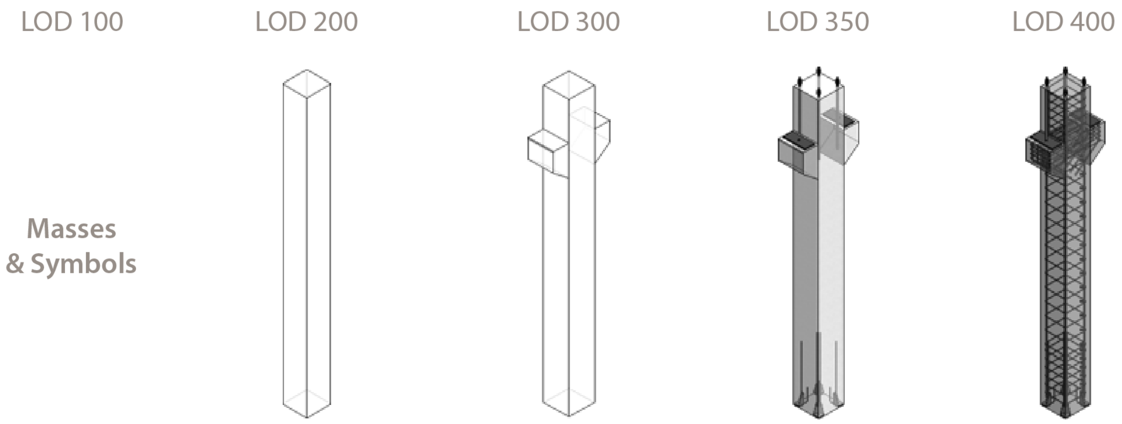

Figure 7: The different LODs (Source: Own illustration, adapted from Aksomitas, 2017)

LOD-300

"The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element" (BIMForum, 2021, p. 16). In this LOD the presented data is accurate and complete and could be used for procurement purposes. Information and measurements are defined in the digital model without external references. A BIM with LOD-300 is sufficient to apply for construction permits (Rodrigo-Ortega et al., 2021).

LOD-350

"The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element" (BIMForum, 2021, p. 16). The LOD-350 is an intermediary level to support coordination in the construction lifecycle and informs the project team about construction processes and the used connection typologies. In this LOD it is clear to a building engineer how building parts should be constructed. However, the connective elements, such as bolts and screws, are not included.

LOD- 400

"The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element" (BIMForum, 2021, p. 17). This LOD is mostly used for production purposes because it provides all information and data about assembly of building parts, such as the welds, bolts, and washers. In practice this LOD is used for automatization purposes.

15.7. BIM protocol

A BIM protocol, often referred as the BIM execution Plan, is a document in which all requirements and responsibilities of a BIM project are defined for coordination, planning, and managing the project lifecycle (Barnes, 2019). The document provides information to the stakeholders of the project and aims to maximize efficiency by registering uniform work processes and deliverables. Every BIM protocol is unique and specified to a single project and could even be used as a legal document.

The agreements in the protocol could be further developed throughout the project lifecycle by the project team. Constructing one predefined protocol is not preferable due to the different requirements of the project phases and dynamics in the project lifecycle (Scheffer, Mattern, & Köning, 2018). Since the agreements in the protocol could change and the prescribed information could influence the overall project, it is crucial that all relevant stakeholders could access an up-to-date protocol (Barnes, 2019).

According to Scheffer et al. (2018) the following aspects could be included in a BIM protocol:

"Management:
1. Roles, responsibilities and authorities;
2. Major project milestones consistent with the project program;
3. Project information model deliverable strategy (for example the Construction Industry Council;
4. Survey strategy including the use of point clouds, light detecting and ranging or global navigation satellite systems.
5. Existing legacy data use;
6. Approval of information; and,
7. BIM authorization process.

Planning and documentation:
1. Revised project plan implementation confirming the capability of the supply chain;
2. Agreed project processes for collaboration and information modelling;
3. Agreed matrix of responsibilities across the supply chain;
4. Task Information Delivery Plan; and,
5. Master Information Delivery Plan.

The standard method and procedure:
1. The volume strategy;
2. Project plan implementation origin and orientation;
3. File naming convention;
4. Layer naming convention, where used;
5. Agreed construction tolerances for all disciplines;
6. Drawing sheet templates;
7. Annotation, dimensions, abbreviations, and symbols; and,
8. Attribute data.

The IT solutions:
1. Software versions;
2. Exchange formats; and
3. Process and data management systems"

A BIM protocol informs all participants of the project about the requirements of the BIM and the structure of the BIM during the various stages of the project. The Bouw Informatie Raad (2017) constructed a standardized BIM protocol for Dutch construction projects. The aspects mentioned by Scheffer et al. (2018) could be recognized in this protocol and could therefore be seen as requirements that are used in the Dutch context as well.

15.8. ILS (INFORMATION DELIVERY STANDARD)

An ILS (Information delivery specification, original Dutch name: Informatie LeveringsSpecificatie) is a document that states what data should be included into a digital model. This is used by clients and contractors to specify their data requirements and structure their data. Thereby the ILS becomes a crucial part of the BIM protocol. Data retrieval by using an ILS ensures that the data could be opened by every stakeholder, is structured, unambiguous, correct, and reusable in every phase of the project. Thereby collaboration and exchanging data is stimulated and simplified, and the transition from CAD to BIM is facilitated (BIM Loket, 2020a).

ILS standards are in various forms and sizes. The most used specification is the BIM basis ILS and is the most basic ILS currently available. Just as the BIM protocol, an ILS could be project specific and always in combination with a BIM protocol in a project (BIM Loket, 2020a). The BIM Basis ILS is added to appendix 1. To inform about the structure and requirements of such a specification.

16. INDUSTRY FOUNDATION CLASSES (IFC)

In this chapter the Industry Foundation Classes (IFC) are further elaborated. The chapter starts with providing the general information about the qualities and applications of the IFC scheme. The chapter continues with elaboration of the modelling software behind the IFC and the used structure within this software.

16.1. Industry Foundation Classes (IFC)

Industry Foundation Classes (IFC) is a ODF that is typically used for interoperational data exchange between BIM software applications in the AEC industry (buildingSMART, 2021a; Temel & Başağa, 2020; Eastman et al., 2011; Noardo et al., 2021). It is an open international standard where data of an asset is stored to share among the participants of an AEC project (Eastman et al., 2011; Temel & Başağa, 2020; Theiler & Smarsly, 2018). The data format is developed by the organisation Industry Alliance Interoperability (IAI) in the late 1980's. In 2005 the IAI changed their name to BuildingSMART and their format developed since then as the standard data format for data exchange in the ACE industry (Temel & Başağa, 2020). BuildingSMART (2021a) uses the following definition to describe the IFC: "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), meant to be vendor-neutral, or agnostic, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases. The IFC schema specification is the primary technical deliverable of buildingSMART International to fulfil its goal to promote openBIM" (buildingSMART, 2021a).

Nowadays, a multitude of governments and private parties use this type of data file to save and exchange their asset data (Temel & Başağa, 2020; Theiler & Smarsly, 2018). The International Standardization Organisation (ISO), the largest worldwide developer of standards, registered the IFC data schema in 2005 as standard structure for the AEC industry (ISO, 2022). The IFC data model, also referred as the IFC scheme, is continuously evolving and updated (Eastman et al., 2011) and is often referred as the PDF of BIM. Like the PDF, an IFC can be viewed, measured, or used as information source for calculations. Once data from a BIM is saved as an IFC, it is not easy reworkable. The mechanisms and parametric rules of BIM are not stored in the IFC during exportation. Therefore, the objects in an IFC cannot be opened in BIM software with the same characteristics (Daniotti, et al., 2020). If an IFC file should be updated, the BIM should be updated and exported to the IFC again as described in the paragraph 7.5 BIM workflow.

16.2. IFC DOMAINS

The IFC semantics are hierarchical organised in four conceptual layers: domain layer, interoperability layer, core layer, and resource layer (Noardo et al., 2021). The layers of the IFC schema are illustrated in figure 8 and are all different means to view the schema. The first layer is the domain layer and consists of entity definitions that are specifically developed for a specific discipline, such as architecture or road. These products, processes and resource entities are normally used for exchange of information within that specific discipline. In figure 8 the tunnel domain is lighter rendered because it is under construction at moment of writing. The second layer is the interoperability layer and includes entities specifically modelled for products, processes and resources which are shared between multiple disciplines in the domain layer (buildingSMART, 2022a). The core layer contains the most general entity definitions and have all a unique identifier (Noardo et al., 2021). The ifcKernel defines the most abstract part of the schema. It has a semantic meaning and understanding of an object, property, or relationship (buildingSMART, 2022a). The control, product and process extensions are a sublayer that further groups the entities. For example, the product extension

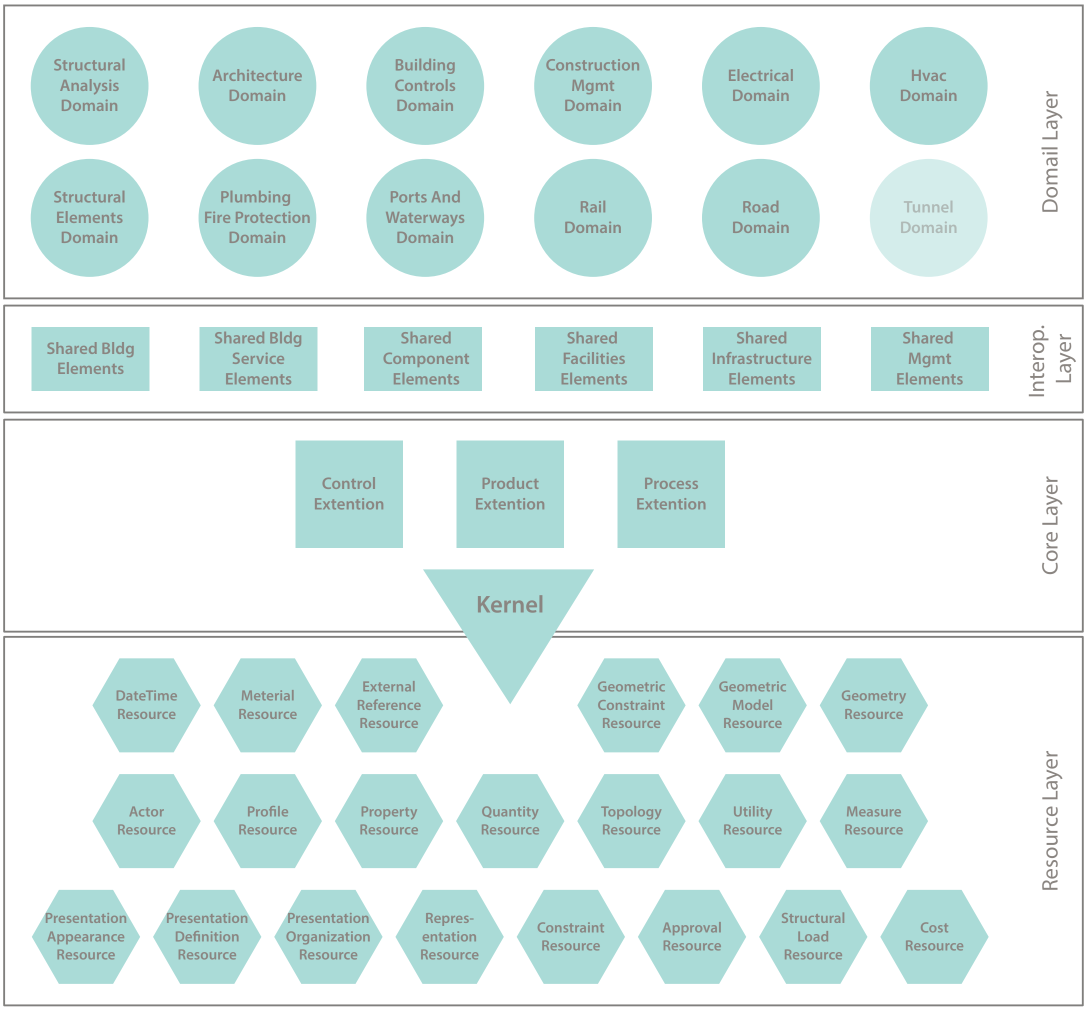

Figure 8: IFC data schema architecture with conceptual layers (Source: Own illustration, adapted from buildingSmart, 2020)

schema groups abstract building parts, such as ifcSpace and ifcSite. The lowest layer is the resource layer and contains all individual schemas of properties and quantities. These properties do not have an identifier and are therefore never used without a declared entity or definition at a higher layer. Information and data in this layer are, for instance, costs, time, and sizes. The separation of layers reduces the IFC file size once the BIM is exported.

16.3. IFC modelling language

When the BIM is stored as an IFC, the BIM software processes the constructed 3D model into the IFC coding structure (Eastman, Teicholz, Sacks, & Liston, 2011; Barnes, 2019). Originally the IFC is coded in EXPRESS modelling language and makes use of UML diagrams (buildingSMART, 2022b). The EXPRESS modelling language is documented in the ISO 10303, also known as Standard for the Exchange of Product model data (STEP). EXPRESS could be visualized in two ways, textually or graphically in diagrams. Both possibilities contain the same information and present, technically speaking, the same data. The IFC uses the objects, processes, and other resources of the BIM as fundamentals to structure the information in diagrams of the earlier mentioned layers (Theiler & Smarsly, 2018). The diagrams are called entities or property and quantity sets. A diagram located in the Core layer is called an entity and a diagram located in the Resource layer is called a property set or quantity set (buildingSMART, 2022a). This standardized format enables the various IFC software programmes to open the IFC model and translate it back to object aggregates, relations, and types (Temel & Başağa, 2020). At the time of writing, there are 352 software applications that could open and run an IFC schema (buildingSMART, 2021b).

Building parts, processes, actors, and other BIM project information are exported to entities in the IFC (Noardo, Ohori, Krijnen, & Stoter, 2021). Each individual building part, process, control, resource actor and group in the BIM modelling software is an entity in the exported IFC model and start with the prefix “ifc” (buildingSMART, 2022a). An entity contains of several attributes which describe pieces of information which identify the characteristics, such as name, owner, or properties and quantities. An entity does not contain data, but refers to other entities, properties, or quantities to derive characteristics. Furthermore, every entity has an identifiable number, this makes the entity recognizable for the software. Figure 9 shows an example of a diagrammatic representation of IFC entity. This entity is called “IfcObject” and consist of nine attributes (GlobalId, Owner, Name and Description, HasAssignments, Nests, ObjectType, Declares, and IsDefinedBy). Every entity inherits the attributes of parent entities in the Core Layer, this is further elaborated in paragraph 8.4. Several entities could be used to store the same kind of building information, this makes the schema complex and could result in inaccuracies underusing complicated qualities (Noardo, Ohori, Krijnen, & Stoter, 2021). Contrary, this flexibility provides a high degree of options to store data.

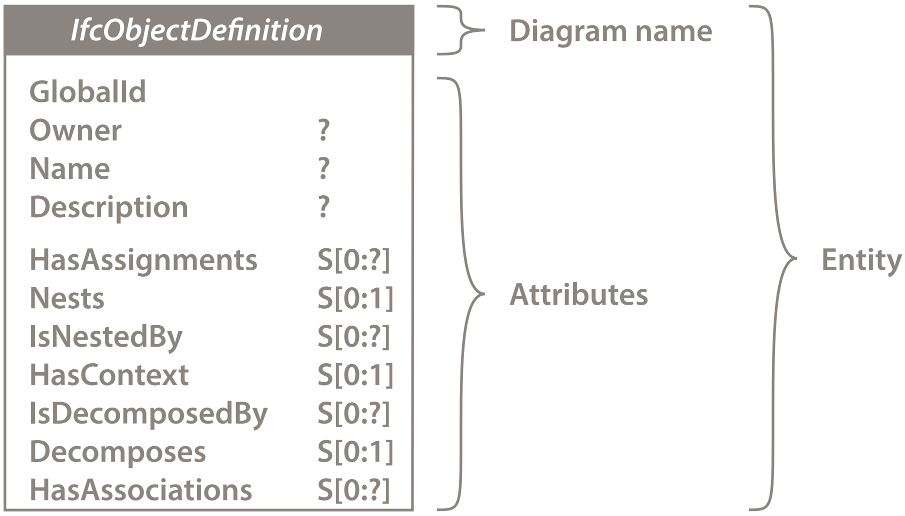

Figure 9 Elements of an IFC entity (source: Own Illustration)

A property set starts with the prefix "Pset" in the name of the diagram and are used to describe the behavioural characteristics of entities, such as the environmental impact, dates, and maintenance quality. A property set is a composition of single properties with a common purpose. One definition within the property set is called a property. A quantity set, on the other hand, starts with the prefix "Qto" and defines quantitative values of one or more entities. Like the property set, the quantity set is composed of single constituents called quantities, and exports numeric values, such as height and volume. Property and quantity are both located in the resource layer and use same relationship entities to link with other object entities (buildingSMART, 2022a). In the new IFC 4.3 there are 2661 property definitions distributed over 462 property sets and 266 quantity definitions distributed over 96 quantity sets (van Berlo, et al., 2021). Furthermore, they do not have a unique identifier which makes it impossible to use independently without an entity, because the values in the sets cannot be interpreted by software (buildingSMART, 2022a). Because the property and quantity miss an identifier, they are also referred non-rooted entities. A multitude of entities could single property or quantity set, which leads to a reduction in file size of the exported IFC. An example, the height of a building level is saved in a quantity rather than an entity. This quantity could be used by all wall entities on that building level to derive their height, so not all entities should individually save height information but only refer to a single quantity.

16.4. IFC core layer hierarchy

The entities in the core layer are classified according to a hierarchical schema. The structure of the schema is based on the existing ISO 10303 standard (Krijnen & Beetz, 2020). The fundamentals of all entities the IfcRoot and contains has an identity number, owner, name, and description. The ifcRoot is thereby the most abstract and basic identifiable definition of in the schema.

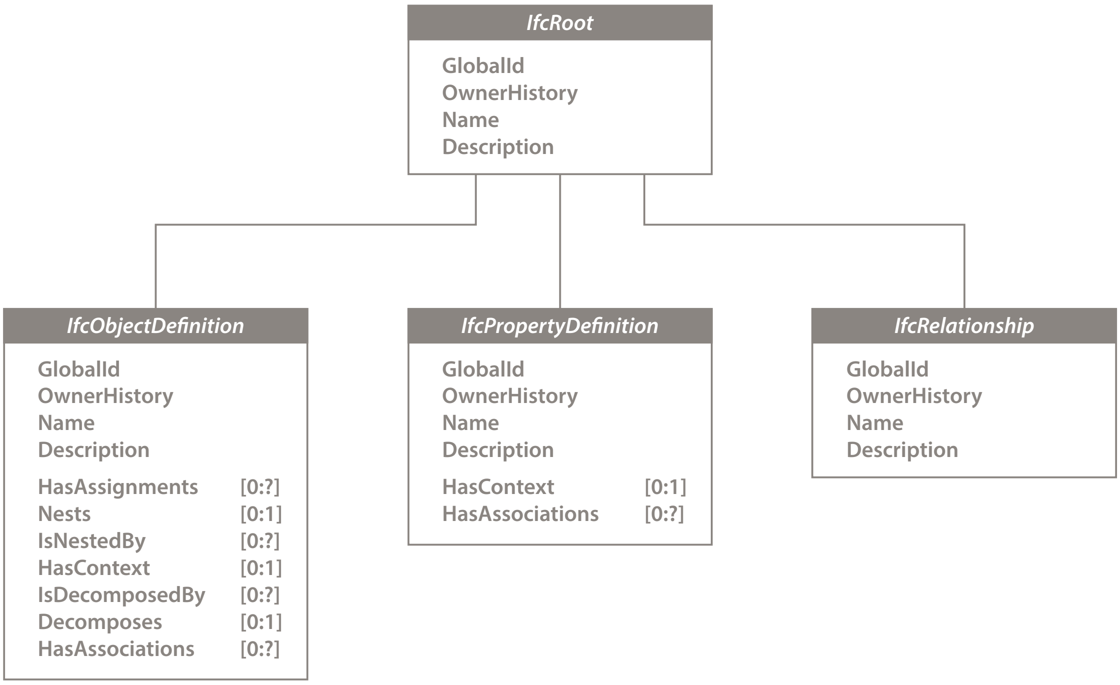

Figure 10: The three fundamental categories of IFC (Source: Own illustration)

All identifiable entities directly or indirectly inherit from the ifcRoot and are therefore called rooted entities (buildingSMART, 2022a). The hierarchy of IFC consists of super-classes and classes, also referred as parent and child entities (buildingSMART, 2020). An entity positioned in one class higher in the hierarchy is called a parent, or super-class, and an entity positioned in a lower class a child, or class. Attributes of the parent are inherited to the child entity and often followed by CamelCase naming (buildingSMART, 2022a; Noardo, Ohori, Krijnen, & Stoter, 2021). BuildingSMART developed three fundamental sub-categories which form the second class in the hierarchy. These categories are objects (IfcObjectDefinition), relations (IfcRelationship) and generalization of characteristics (IfcPropertyDefinition) (Temel & Başağa, 2020; Theiler & Smarsly, 2018; buildingSMART, 2022a). In figure 10 the two highest classes of the IFC hierarchy are shown.

The ifcObjectDefinition is used to semantically describe all physical tangible elements, physical existing items, and conceptual items (buildingSMART, 2020). This makes the object category one of the most versatile entities in the IFC schema. The name of the diagram is a recognizable label for the user of the occurrence in practice of the item. Relations between BIM objects are predominately defined with the relationship category. This category gives meaning to the relations between objects used in the IFC model and the objects and their properties. These relations could connect different objects, such as walls and floors, but also link objects to stakeholders or non-rooted entities of the BIM project. The ifcPropertyDefinition define a group of properties that are assigned to object entities. This generalization of characteristics includes multiple property and quantity sets.

16.5. Relation between entities

Figure 11 shows a part of an IFC derived from a BIM. This diagram shows the relation between an actor and the control capacities related to that actor. The left diagram, the IfcActor, describes the characteristics of the actor. The IfcRelAssignsToActor, is a relation entity, which describes the relation of the actor with a, in this case, responsibility of an actor (buildingSMART, 2020). The used relation entity is determined by the bold typed attributes. The objects, processes, and other resources which this actor controls is not visualized in these diagrams.

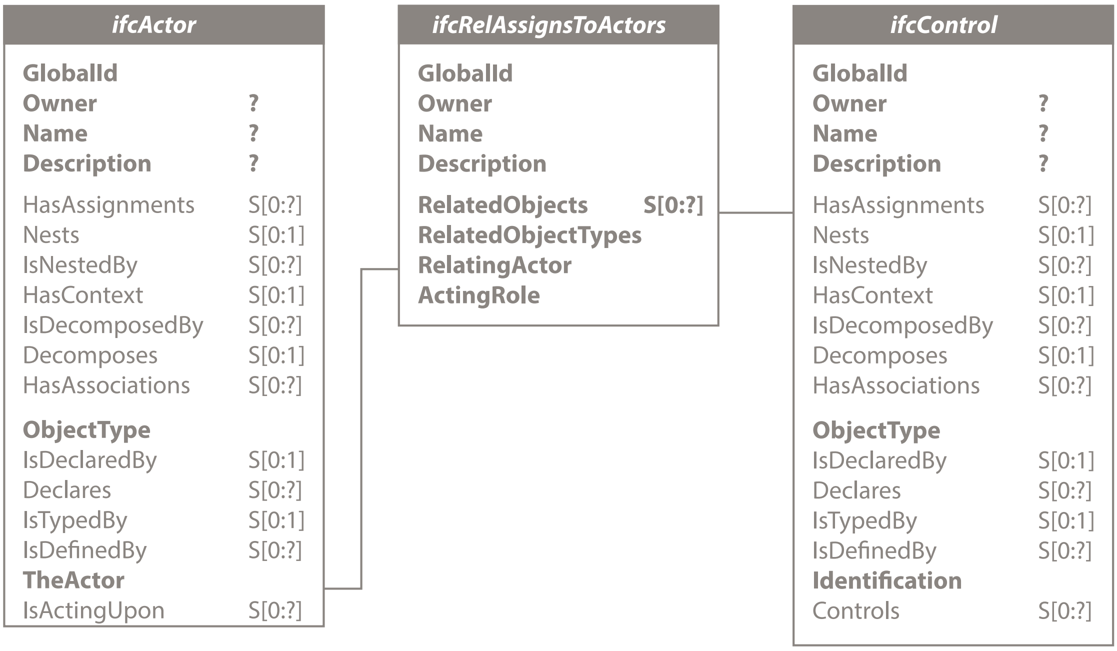

Figure 11: IFC mapping structure (Source: Own illustration adapted from: buildingSMART, 2020)

Part 3

Research Methodology

The following part presents the used research methodology. In this part the steps taken in this research are further elaborated and discussed. Thereby the research process is clarified and the steps towards the end product are illustrated. The first chapter describes the used research method and contains information of the structure of the research and the used data collection methods. Subsequently, the research output is presented with includes a description of the deliverables after completion of the report.

17. RESEARCH METHOD

In this chapter the methodology of this research is explained. It starts with a general description of the goal and ambitions of the report. Thereafter, the used logic and research framework are elaborated together with the data collection methods.

17.1. Goal and logic of inquiry

The conceptual framework of this thesis is shown in figure 12. On the left side of the figure the current state of data structure is shown. According to literature and explorative interviews, held in the beginning of this research, the current data requirements are uncomplete and unknown for reuse component data. The desired situation is shown in the right box of the figure. Thereby data requirements for circular reuse should be identified and

WThe main question of this thesis is a “what” question and aims to learn the concepts, meanings, and motives from modular and linear building companies and to identify the data structure of both construction organisations. This report usages mainly abductive logic to elaborate the current used methods to improve circular data storage and has an explorative nature. One of the main goals involves creating a better understanding of the processes and data requirements in both organisations to be able to construct a Circular Reuse ILS that enables organisations to identify and structure their reuse data.

Abductive reasoning starts with analysing the existing situation by analysing the meanings, interpretations that are used by people to explain the existing situations. Therefore, the first step is to improve the researchers understanding of the behaviour of the studied organisations and processes. This is done by interviewing the linear and modular building organisations. The interviews will give the researcher a more comprehensive view of the means and data requirements of both organisation during a project. Inductive logic is during these early phases because this reasoning enables to draw general conclusions of the process (Blaikie & Priest, 2019).

After elaboration and description of the current structure and motives, improvements could be formulated on the existing process, by comparing and relating the two researched organisation types. By comparing the two organisation typologies it is possible to generate conclusions and new processes. These should be tested and verified in practice to generate a valid

Figure 12: Conceptual framework of this thesis (Source: Own illustration)

conclusion.

17.2. Type of data

There exist a multitude of data generation methods to describe and formulate research. In general, there are two collection methods used in research: quantitative and qualitative. Quantitative research is the most used research typology and concerns with counting and measuring aspects. Data collection methods which can be used in this type of research could be questionnaires, observation, and content analysis of documents (Blaikie & Priest, 2019, p. 201). Qualitative research, on the other hand, focuses on producing descriptions, meanings, and interpretations, which could be realized with, for example, in-depth interviews, semi- and unstructured observation methods, focus groups. The abductive logic focuses on creating better understanding and description of underlaying motives, a qualitative approach is the most suitable for this research, because this enables to describe the motives of both organisations precisely and comprehensively. Thereby more data is generated, and more detailed concussions could be drawn after completion of the processes.

17.3. Data collection

To collect the data for answering the research questions a variation of research methods are used. A research method is a set of procedures which enables the researcher to collect data (Blaikie & Priest, 2019). In this thesis the following methods are used: literature review, mapping, and semi-structured interviews. In figure 18, located on the next page, the structure of this research is shown. This schematical model illustrates the steps which should be taken to complete and to produce all needed deliverables.

Interview and mapping IFC

The research starts with a researching the current IFC structure. To fully understand the possibilities, capabilities and underlaying mechanisms, interviews are conducted together with mapping and the literature study presented in the theoretical background. This is an important objective of quantitative research (Verhoeven, 2014). The inductive logic is chosen to further develop the understanding of IFC and what LOD's and data could be stored in the structure.

Literature review

A literature review is conducted to gain a better overall understanding of the IFC topic, by describing theories, variables, phenomena, and methods used in history (Randolph, 2009). This means that the main aim of the review is to expand the existing knowledge about the topic IFC, and which entities contain which property and quantity sets. Furthermore, it should become clear what characteristics entities could contain and how entities could be linked. This literature review is presented in the theoretical background and forms input for the later constructed interview questions and focus areas on the next stages of this research.

Interviews IFC

Interviews are conducted to increase the understanding of the complex structure of the IFC, because descriptions of the mechanisms behind the IFC structure are developed in the software knowledge field instead of the built environment. This makes it for a non-IFC specialist rather difficult to understand how it is organised. Since the interviews have an explanatory purpose, the interviews are semi-structed, because this enables to ask follow-up questions to deliberate complex and interesting topics further. Conducting interviews will increase the understanding of the concept and the relation

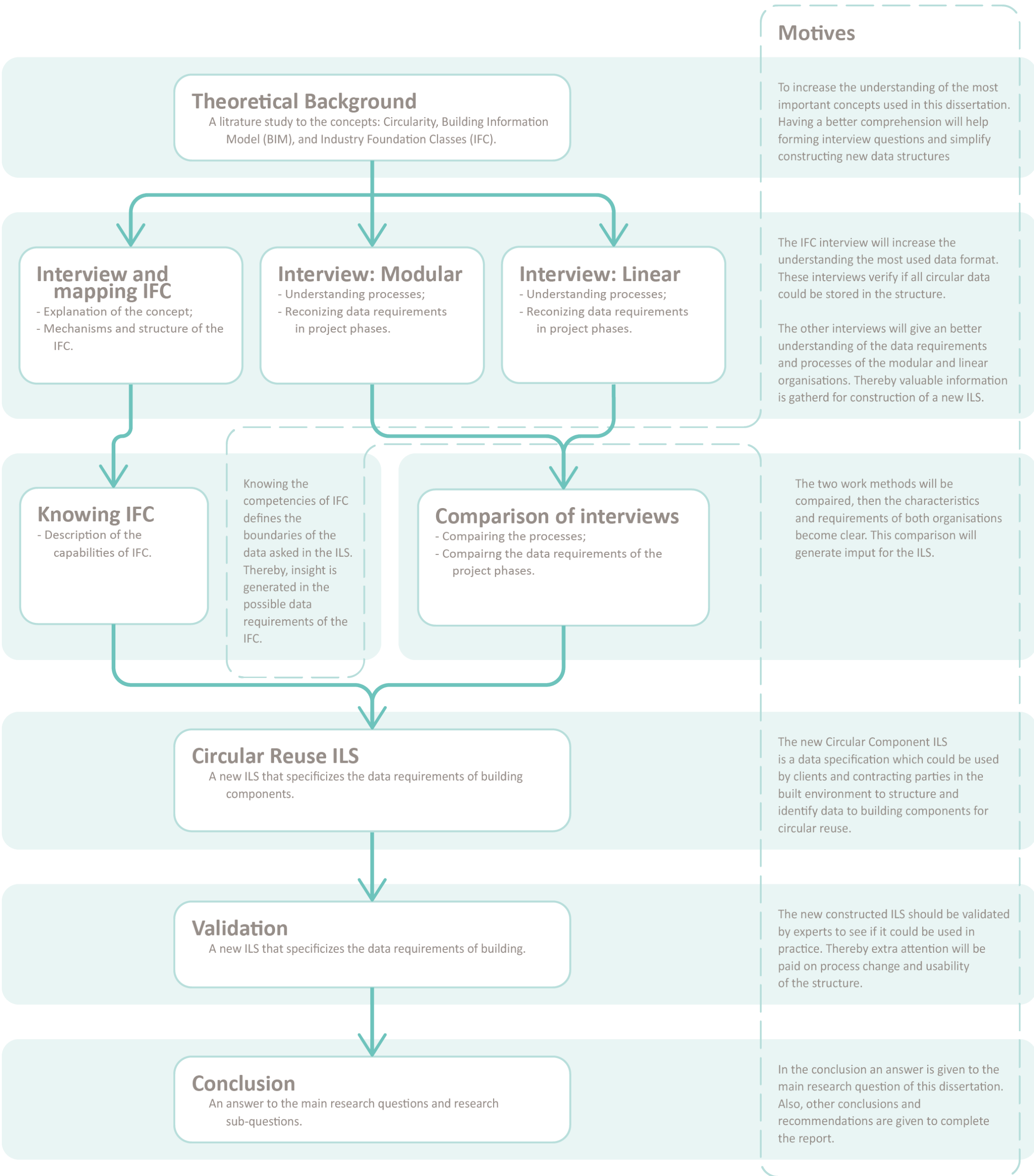

Figure 13: Research structure (Source: Own illustration)

with BIM more raptly. The specialists should be a researcher or software developer which uses the IFC on a regular basis. Furthermore, it should become clear how a BIM is exported to IFC entities and what information, and characteristics could be saved in an IFC file. For the first sub-research question one interview is needed to increase the understanding of IFC. The interview questions asked are in appendix 2.

Mapping IFC structure

A map of the current IFC structure is created to generate a graphic visualization of the schema and explore how it is structured. A mapping method could be used for a variation of research designs to describe and explore a certain topic (Crowe & Sheppard, 2012), which is in this case the IFC schema. When it is finished it can be used as communication element and to analyse the data presented in the structure. The connections between the different entities are visualized in the structure create a complete and comprehensive map. The map will contribute to the understanding of the hierarchical structure of the IFC.

Interviews linear and modular building organisations

Data is needed from linear and modular building organisations to analyse and compare the data management processes. The abductive reasoning and qualitative nature of the research results in semi-structured interviews because the respondent should lay emphasis on topics or information that are important for the used construction methodology. The goal of the interviews is to understand and describe the information management of a linear and modular construction method. During the interviews extra attention is needed on the LOD of the BIM and how this information is archived, because this data is needed during analysis and comparison in later stages. This results in interviewing BIM data management organisations or larger contractors. These interviews should not only unveil what information is saved, but also how it is saved and where during the project lifecycle. The number of used experts depends on the experience and the heuristics of the researched topic (Vermeend, 2010, p. 30). It is recommended to use 2-3 experienced experts or 3-5 less experienced experts. In this report an experienced expert is a person that participated in minimal five construction or modular reuse projects and graduated in a study related to the built environment. This results in minimal 2-3 interviews with linear BIM experts and 2-3 modular BIM experts for this report. In table 2 the interviewed for this research are shown.

The interviews will start with general questions about the interview concepts. These questions are asked to verify the knowledge of the respondent and compare the answers with the theories and definitions described in literature. Furthermore, the respondent will be asked to explain their work and build processes. This explains the different steps the organisation takes during a project.

Interviews linear building organisations

The interviewed linear building organisations are organisations that

Respondent number	*Function*	*Organisation*	*Goal*
Respondent 1	IFC-specialist	IFC developer	See text underneath
Respondent 2	BIM-modeler 1	BIM-specialist and coordinator	See text underneath
Respondent 3	BIM-modeler 2	BIM-specialist and coordinator	See text underneath
Respondent 4	Project manager Circularity	Modular/circular contractor	See text underneath
Respondent 5	Head technique and development	Modular/circular contractor	See text underneath
Respondent 6	BIM-modeller	Modular/circular contractor	See text underneath

Table 2: Research structure (Source: Own illustration)

specialize in BIM construction and management. The work method used by the organisations is based on BIM data and work structure, as described in chapter 7: Building Information Modelling (BIM) or has a lot in common with this structure. The organisation is involved during the construction and, ideally, maintenance, because this will generate a more complete view of the data management after completion of the building. The organisations construct or model assets with a linear aim, this means that decommissioning is included in the project plans. Thereby a decommission date is not set and building parts are not returned to the organisation for circularity after a lifecycle.

After the general questions about the concepts are asked, the following subjects will be addressed: information during construction and archiving of building information. The interview questions for all linear builders are the same and listed in appendix 3. Questions will be asked about BIM object properties, and the LOD of the BIM during the design and engineering of the asset. The main aim of these questions is to identify which properties are filled in and to what extend they develop objects and connections. Further, in this section is asked if all information is included in the BIM or if they use other data storage formats. In the second part of the questions are based on archiving building information. In this part of the interview more will become clear of the archived LOD of the BIM or IFC model and why this LOD is chosen in this next phase. Furthermore, it should become clear how information is saved in the IFC, and if IFC is used. Because this will increase the understanding of the exportation to the IFC entities and will give insights to the understanding of the organisations of IFC.

Interviews modular building organisations

The interviewed modular building organisations should have multiple projects and modules with a temporary aim. Temporary, in this case, means that the constructed built assets will not have a permanent location and are returned to the organisation after a lifecycle. Thereafter, the assets could be disassembled, so building part reuse is possible and implemented in the workflow of the organisation. In this case the organisation is involved during construction, use, and decommissioning stages of the asset and takes an active role during the phases. The modular assets comply with the Dutch building code for dwellings and have thereby not a temporary feel and quality. This means that the construction method used by the modular organisations could be deployed for longer term housing and has a habitable finishing.

After the general questions about the concepts are asked, the following subjects will be addressed in the modular building organisation interviews: Elements and Materials, Connections, and Data storage. Like the linear building organisations interviews, the questions modular interviews will be identical for every respondent and could be found in appendix 4 In the Element and Material subject, more information is gathered about the information saved of the objects in BIM. During this part of the interview questions are asked to identify which properties are completed of an object. If this does not become clear, the researcher asks follow-up questions to identify the properties. The next subject addresses the used connections. During the interviews of the modular builders more questions will be asked more about the used connections compared to the linear, because Durmisevic (2019) states that the connections form the basis of DFD and this information is needed to identify with connection typologies could be used for building component reuse. Thereby modular building organisations need to think more elaborate about their connection typologies and save more data of the connections. The final subject is the data storage. Here the modular builders are asked about the data structure of their work activities, and this will be the longest part of the interviews. The respondents are asked to explain their data structure during and after construction. The aim of the questions is to uncover how they store data and why the data is structured as they do.

Interview techniques

During the interviews it could be helpful to use different interviews techniques to gather as much data. Successful interviewing starts with listening, summarizing, and asking follow-up questions (Verhoeven, 2014). An interested interviewer will, generally spoken, gather extra and more detailed information. This means that the researcher should have a serious and positive attitude, speaks a correct tone and volume, and looks presentable. These three aspects show the interviewee that the interview is taken seriously by the interviewer and stimulates the interviewee to give more elaborate answers. Every interview should be taken seriously and should be prepared comprehensively.

During the interview it is possible that there is a moment of silence. The respondent could be waiting on a follow-up question of the researcher, or he or she is thinking about a following note. In second case, it is sensible to wait as a researcher and let the respondent think before a subsequent question is taken because this could lead to interesting new insights (Verhoeven, 2014). Therefore, the researcher should always give the respondent a moment to think before asking a following question.

If the respondents give long and complex answers, it is good to paraphrase and summarize the answer to check if it is understood correctly by the researcher. This ensures that no mistakes are made in the interpretation of the answers (Verhoeven, 2014). The researcher can ask follow-up questions to collect in-depth information from the respondent. Important is that the answers of the experts are aligned with each other.

Comparison of interviews

After the interviews with both organisations should be compared to identify the LOD of the models and the required data in the BIM during each phase of the project. By defining the development in each phase, the requirements of the BIM become clearer and thereby the process of constructing a BIM become understandable. The required LOD and data requirements of each project phase could be used during the construction of the Circular Component ILS, because this ILS will also influence the construction process of a BIM.

Validation

External experts will validate the new circular data work structure and correlated process to prove the outcome of this report. These experts will assess the feasibility and guarantee that the provided Circular Reuse ILS is applicable in practice. In this case a series of validation interviews will be executed for verification. These independent experts should have sufficient knowledge of one or more of the presented concepts in the Theoretical Background and could be from practice or science. At least one expert per concept is needed to complete the verification. Experts with multiple knowledge areas are preferred because they can verify the overlap between the concepts as well. The respondents are persons with experience in more than five circularity or BIM projects and and graduated in a study related to the built environment. Decommissioning organisation, organisations that manage the material passport, circular advisory bureaus, BIM modelers, modular and linear building organisations, are examples of experts which

Validation number	*Function*	*Organisation*	*Goal*
Validation 1	Circular Decommissioner	Project coordinator Data & Circular Innovations	See above and next page
Validation 2	BIM- modeler	BIM-specialist and coordinator	See above and next page

Table 3: Respondents and their function (Source: Own table)

could be contacted to verify the outcome. The used experts to validate the Circular Reuse ILS are presented in table 3.

A guiding document together with the ILS will be presented to the experts. These two information sources will explain the preliminary results of the research and are distributed among the validating experts at least three days before the validation interviews. A more detailed description of the deliverables during the verification could be found in paragraph 10.1 ILS guidelines. The handed-out documents will give the experts a uniform information level.

After guidelines and Circular Reuse ILS are reviewed, a discussion could take place and involves the following aspects: is the provided structure usable in practice, is there a demand for the constructed documents, and finally, what influences has the structure on their workflows. The discussion starts with verifying the required circular data, because this could have influence on the exportation structure discussion. Questions and ambiguities will be explained to improve the movie and export guidelines. Furthermore, the experts could express their views on the presented work and name additions or change requests.

17.4. Research process

The research process elaborates the steps that should be made to gather the research data and product. The pervious sections provide a description of the used structure and methods in this report. The process starts with a literature review to describe the concepts of BIM and circular reuse more elaborate. These two concepts form an important pilar in this research and gives guides during the elaboration of the IFC schema. Thereafter, the interviews, mapping and literature review are executed to understand the mechanism and the export possibilities of the IFC. This will result in a complete understanding of the used concepts throughout this report. Next, interviews with BIM and modular building experts could be executed. These are compared and analysed to develop a new work structure for circular reuse with BIM. Finally, the new work structure is verified with decommissioning and circular experts in the AEC industry to generate the final conclusions

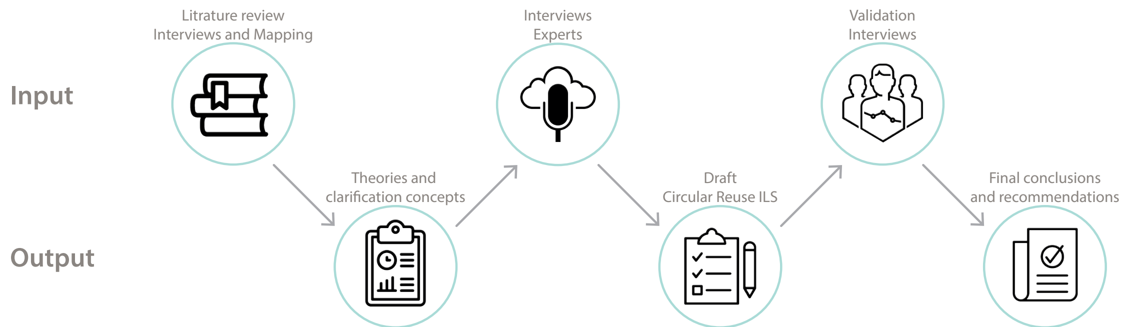

Figure 14: Research process (Source: Own illustration)

and recommendations.

17.5. Data analysis

After executing a data collected it needs to be analysed to draw complete and comprehensive conclusions (Verhoeven, 2014). In this section the used techniques and instruments used to analyse the gathered data are described. Quantitative research rarely has a single outcome and are largely depended on the interpretation of the researcher. Therefore, it is essential to describe the motives and the interpretation behind the collected data in detail.

Quantitative research has no prescribed structure. The processes of analysis and data collection alternate. During analysis this could result in incomplete or incomprehensive answers to research questions. This could mean that an extra round of new data collection is executed to collect missing data and checks and complements the data from earlier rounds. In this extra round it is possible to include the results of the data of earlier rounds.

Mapping structure

In the data analysis of the map entails a descriptive analysis and network extraction (Aria & Cuccurullo, 2017). The hierarchy between the entities become clear by the mapping and the characteristics of the layers could be recognised. This results in a schematical view of the entities and corresponding attributes in the IFC.

Semi-structured interviews

The conducted interviews form spoken audio recorded files that need to be transcribed to analyse the collected data. The transcription of the interviews will be a verbatim translation of the interview. The steps which should be taken to analyse the data structured in a framework (Verhoeven, 2014).

1. Exploration of the data, by reading the transcribing again and splitting the text into the addressed subjects and questions;
2. Evaluate the used thermology, are the interviewees referring positive or negative and what other values could be recognized;
3. Code the discovered fragments and subjects;
4. Group the comparable fragments;
5. Identify a hierarchy, which information is important, and which is less important according the participant;
6. Search for connections between the fragments, in the hierarchy headings and sub-headings could be identified;
7. Structure the document, questions are asked why relations are existing and how is the hierarchy created;
8. Draw conclusions;

Before the interviews an interview protocol is constructed. This protocol ensures that the questions are aligned with each other, and a red line could be found throughout all interviews. Furthermore, this protocol ensures a complete outcome of the interview. The interview protocol describes the goal of the research and the main objectives of the interview and helps thereby the respondent with formulating the correct concepts and theories before the interview is conducted. Important is that the interviewer stays open-minded during the research, because in this approach all situations, and motives should be explored to find a suitable outcome (Verhoeven, 2014). The interviews are conducted with Dutch speaking respondents to avoid misinterpretation and are recorded and transcribed. Therefore, the citations presented in the following chapters are literal translations of the quotes from the transcription.

17.6. Verifiability

Verifiability is one of the key elements of research. In verifiable research the research outcomes could be checked by other researchers and is therefore a key element in the reliability of the research. To increase the validity of this research a study database is constructed. In the study database the generated data is saved.

The logbook

To improve the validation of this thesis a logbook is used (Braster, 2000; Verhoeven, 2014). During the process of the research process choices are made that could influence the conclusions of the report (Verhoeven, 2014). In this logbook the daily activities and made choices are described, as a result, at the end of the research a complete overview is generated where all choices and milestones are exhibited. The logbook could be used to measure process and spotting mistakes during the research process. It is further used to keep the accompanying mentors acquainted with the process and is uploaded in the study database.

It is important to describe the chosen approach and why certain paths came to a dead end to ensure that mistakes could be analysed, and bigger steps could be made in future research.

Meeting reports

During the research process the researcher and the mentors are frequently meeting to discuss the process of the report. Every meeting will be documented in writing and uploaded to the study database. In the meeting reports the progress, choices and questions of the student are discussed. Just as the logbook, the meeting reports are used to monitor the progress and reflect on the activities and are uploaded in the study database.

17.7. Data plan

The data produced by this report and related products will be publicised in accordance with the FAIR guiding principles, as described by Wilkinson, et al. (2016). The abbreviation FAIR is a representation of: Findable, Accessible, Interoperable and Reusable and lay emphasis on the reusability of newly produced data for individuals. Furthermore, this should enhance machines and individuals to find and generated data more easily. An overview of these principles could be found in table 4.

After completion of the P5 report, the full document including appendixes

Findable	F1	(Meta)data are assigned a globally unique and persistent identifier
	F2	Data are described with rich metadata
	F3	Metadata clearly and explicitly include the identifier of the data it describes
	F4	Metadata clearly and explicitly include the identifier of the data it describes
Accessible	A1	(Meta)data are retrievable by their identifier using a standardized communications protocol
	A1.1	The protocol is open, free, and universally implementable
	A1.2	The protocol is open, free, and universally implementable
	A2	The protocol is open, free, and universally implementable
Interoperable	I1	(Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation
	I2	(Meta)data use vocabularies that follow FAIR principles
	I3	(Meta)data include qualified references to other (meta)data
Reusable	R1	Meta(data) are richly described with a plurality of accurate and relevant attributes
	R1.1	(Meta)data are released with a clear and accessible data usage license
	R1.2	(Meta)data are associated with detailed provenance
	R1.3	(Meta)data meet domain-relevant community standards

Table 4: The FAIR guiding principles (Source: Own table, adapted from Wilkinson, et al. 2016)

and other documents will be published in on the repository of the Technical University Delft. The P5 thesis will be identifiable by a Digital Object Identifier (DOI). Other versions of the report and presentations could be retrieved by contacting the author of the report.

The participants of the research, in form of the interviewees, will be anonymized to ensure their confidentiality. Before interviews or verification moment the participants are asked to fill in the "informed consent form". In this form is constructed by the Technical University Delft Human Research Ethics Committee to ensure that the safety and comfort of the volunteering parties is protected. The consent form will be mailed at least 2 days in advance of the interview.

APA referencing style is used to refer to all external literature or other sources in the thesis. A complete list of the references could be found after part 7 of the report, located before the appendixes.

17.8. Ethical considerations

Conducting research requires asking difficult questions to formulate new answers. This could create tension between the researcher and the participants of the research (Alderson & Morrow, 2020). Ethical research is based on agreed standards which are designed to protect the stakeholders of the research to creating harm to individuals, communities, and environments. The goal of ethical research is to increase the sum of good and to protect others (Israel & Hay, 2006, p. 2).

In this research qualitative interviews are conducted and the suitable ethical standards should be taken in consideration. Saunders et al. describe five (2009, p. 185) describes six factors that must be adhered to conduct ethical research.

1. Privacy of possible and actual participants;
2. Voluntary nature of participation and the right to withdraw partially or completely from the process;
3. Consent and possible deception of participants;
4. Maintenance of the confidentiality of data provided by individuals or identifiable participants and their anonymity;
5. Reactions of participants to the way in which you seek to collect data, including embarrassment, stress, discomfort, pain, and harm.

After the collection of data, the researcher should share the findings with the participants. The participants should have the possibility to be critical about the transcription and the conclusions (Mero-Jaffe, 2011).

18. RESEARCH OUTPUT

After completion of this report, there are various products produced. The products are the results of competing the steps described in the research method. Furthermore, this chapter describes the capabilities of the Circular Reuse ILS in more detail.

18.1. ILS GUIDELINES

The goal of this report is to create an ILS wherein circular data could be queried on component level. This data is needed building components to reuse them in subsequent lifecycles. The guidelines inform building engineers which data from a building component and how this data should be stored accordingly. Thereby this ILS could contribute by decommissioning and checks all decommission tool requirements stated by Akinade, et al. (2017a), namely, improved collaboration among stakeholders, visualisation of the deconstruction process, quantification of recoverable materials, deconstruction plan development, performance analysis and simulation of end-of-life alternatives, and improved building lifecycle management.

These guidelines and ILS are suitable for assets with a permanent aim. This means that the constructed asset does not have a decommission date planned before construction is completed, thus the asset has an undefinable lifespan. Thereby the used files should be accessible and operational over an unknown period. Furthermore, the guidelines should be easy to implement for the stakeholders of the project.

Target group

The Circular Reuse ILS should focus on the contracting side of the building process, this means that the ILS should primarily be used by BIM modelers that have clients with a circular aim. Thereby the users of the ILS are truly diverse and could come from various aspects in the built environment, such as developers, contactors, and engineering firms. By having this ILS, the modelers know the requirements of a digital model that could be used for circular reuse on component level.

Other users could be the clients, these clients could use this ILS to enquiry data from contracting parties. Thereby the Circular Reuse ILS provides principles to check the required data in a BIM and to make an assessment to the pricing, coming processes and requirements in their constructed asset.

Figure 15 Transformation after using the Circular Reuse ILS (Source: Own illustration)

18.2. Dissemination and audiences

The conclusions of the thesis will be interesting for different audiences. The gained knowledge is intended to for every organisation that aims to further develop their insights in BIM, IFC and circular decommissioning. The generated knowledge could serve as fundamentals for an updated version of the IFC, IFC specialist, and digital material platforms, such as Madaster, will have an extra interest in the research because the outcome will influence the operational actives of the organisation or person. Furthermore, the partitioners of the study will have interest in their contribution to the document and the conclusion. These partitioners will therefore get a notification of the finished product when this is uploaded to the Technical University Delft repository.

Part 4

Research findings

In this chapter the results of this report are described. A description of capabilities of the IFC forms the starting point of this chapter, wherein the possible modelling languages are described and are linked with the LOD. Subsequently, the interviews are described with with the needed LOD of building parts and some required properties. These inputs form a proposal for a circular reuse work structure.

19. GENERATED DATA

The collected data of this research is presented in this chapter and contains further elaboration of the capabilities of the IFC and the workflows and structure of linear and modular building companies. The data presented originates from the interview transcriptions and, in case of the IFC, the mapping and additional literature study. This chapter ends with a comparison between the linear and modular building structures and advice gained from the interviews.

19.1. IFC

In the following paragraph the capabilities of the IFC are further clarified. The characteristics of the scheme are truly diverse and could be used in multiple situations. However, the interviews and mapping of the IFC expressed that the scheme is extremely complex for unexperienced users and thereby difficult to understand by users of the scheme in practice. The mapping of the IFC is added in appendix 5. This paragraph ends with a description of the limited flexibility and changeability of the scheme.

LOD

First of all, the IFC schema is an enormously elaborated open data structure with more than 700 unique entities and this is reflected in the LOD that can be attained after exportation of a BIM. The IFC specialist mentioned that it is possible to model extremely detailed and the LOD presented in the IFC depends on the use case, the asked information, and geometric quality from the client. The LOD that could be generated is the highest level described in this thesis, namely the LOD-400. This is highlighted by the following augment by the IFC-specialist: "but you also have the ifcRelConnectsWithElements, and these could be screws [relation between screws and an object], and that is extremely detailed. You must model every screw and process that. It happens, I have seen such models". BIM advisor 1 recognizes this by saying: "increasingly suppliers [..] model all studs, isolation, and sometimes fasteners, bolts, and plates." The respondents mention that the IFC could be as detailed as the digital model needs to be. After mapping the existing IFC schema the same conclusions could be drawn. As identified in the map there are various entities with a lot of property and quantity sets related to it. LOD-400 is recognized here as well because there are entities for finishing, such as wallpaper, paint (ifcCovering), non-mechanical fasteners (IfcFastenerTypeEnum) and mechanical fasteners (IfcMechanicalFastener), such as bolts and washers. Furthermore, property sets could be added to describe the tools and quality of those connective elements. This clarifies that connective building parts could be modelled in a high LOD.

Information and data of building components could be saved on a variation of levels, from the generic level of the component itself or more specified to the characteristics of materials used in components. BIM Loket (2020b) describes this on their site in the documents: Leeswijzer kozijnen and Hand-

Out ILS Gevel. These documents state that property sets and quantity sets, and thereby information and data, could be saved on a variation of levels and that the modeler chooses required data level of the building parts to export in an IFC. Technically, this means that the modeler decides which and how much IFC entities are used to define building parts. For example, a whole window frame could be exported into an ifcWindow. This means that all sub-building parts, such as the window, glass, and glazing beads, have the same characteristics as the whole window frame, because they are all saved in the same entity. On the other hand, it is possible to export all sub-building parts into separate entities and the property and quantity sets associated with it. This means that the IFC file contains information about smaller building parts compared to exporting it to an ifcWindow. This makes the IFC file bigger and more complex to read for IFC viewers and users of the IFC file. If smaller building parts are used, it becomes impossible for BIM and IFC software to recognize the original building component, because it is currently impossible to group building parts and define them as one building component or element. The structure of the IFC could also be recognized in the levels of technical decomposition of in Durmisevic (2019), where the various levels of technical decomposition are described. Thereby the IFC can provide information and data of all building systems levels presented in the hierarchy of Durmisevic (2019).

The object needed in the IFC should be modelled individually in the BIM as well, otherwise the exportation tools will not recognize the object and cannot export them into an IFC entity. If, for instance, a client wants to count the number of letterboxes in the IFC, all the letterboxes should be modelled separately. When a letterbox is in a door and the door is modelled as one single object, the software will not recognize the letterbox in the door and thereby does not count it. This also means that the LOD of the BIM determines the maximal LOD of the exported IFC. Contrary, if the BIM is modelled in high LOD, the BIM can be exported to lower developed levels in the IFC. This could be done by choosing more general entities or excluding building entities. Furthermore, IFC exportation tools enable the modeler to choose the IFC entities that building parts are exported to. The entities in the IFC schema have, like described in chapter 8, an assigned place with corresponding attributes, property, and quantity sets. To ensure that all data is exported correctly, the proper entities and names should be chosen to ensure complete data storage, otherwise it is impossible for the exportation tool to transfer and recognize all characteristics of the object. BIM-advisor 1 describes this in the following quote: “It all starts with naming the objects correctly, because if you want to verify if, for example, the width or direction of rotation of the main door is correct, you must know that it is a door and related to an entrée space. So, the space behind the main door is always the entrée space. This makes the main door distinctive form all other doors. […] the main door should have the correct properties to verify if the door is wide enough” Furthermore, BIM-advisor 2 emphasis this further: “One of the most important aspects is that the objects know their function. I already mentioned it a couple of times this interview, but I’m saying it again: objects should know their identity. […] that is the first test: Do all objects have the correct name and does the name correspond with the formulated standard?" According to the respondent objects in a BIM or IFC should have the correct identity and thereby the correct entity should be used, or else data could be lost.

IFC can describe geometry in high detail. However, since there are multiple export options to generate geometry, it becomes complex for the modeller make the right decision. Every organisation developed its own workflow and exportation structures which exports building parts differently. This results in a multitude of exportation structures with a variety of entities to describe the geometry of building parts and, sometimes, results in difficulties during the generation of geometry by an IFC-viewer. The reason for this is that viewers repair errors and have different starting points to formulate the IFC model.

Mapping the IFC entities and the used properties identified that properties and property sets could contain four data types: Numeric, Text, Enumerations, and Boolean. In the numeric properties numbers could be filled in. These numbers could be values of a product, such as the U-value or length, or the result of a sum, such as the area or Rc-value of a cavity wall. New calculations could theoretically be added. However, this requires constructing new properties. Calculations should be added manually to fill in the new undefined formulas. Text properties could be filled in with words. These could, for example, define the name of the street or name of product type. Text properties are hard to process for software since it cannot read what the text expresses. Enumerates are a predefined list of text or numeric values that could be filled into a property. This is useful if only certain values could be filled in, such as fire resistance classes. The final data types are Booleans. This property could identify if a value is true or false, for example if a building part is structural or used as external part.

The interviews, mapping and literature study confirms that all levels of technical decomposition and design criteria for building reusability, as described in Durmisevic (2019), could be exported to the IFC. Thereby the IFC is suitable to save technical information and data for DFD and could be used to save documentation of the R-strategies. The data types in the properties should be in the form of the four presented typologies for the scheme, otherwise it becomes impossible for the IFC, but also for BIM, to store the data.

Knowledge

According to the BIM-advisors, there is limited usage and knowledge by private organisations of all capabilities of IFC. BIM-advisor 1 acknowledges this statement by saying: "I have never really looked into all documentation [of IFC]. It is super complex. […] There are the Shared Building Elements, and that is basically what we use on a day-to-day basis, because it is more understandable. These are the only things I what is usable for us and the end-user." The advisor does not have all the knowledge about all the available entities which could be used to export a BIM to. This is noteworthy because the BIM-advisors organisation has a variation of clients with different aims and corresponding information requirements. According to the documentation of buildingSMART (2022a), the Shared Building Elements are generic descriptions of building components and elements, so the archived IFC do not contain data from specific smaller building parts. They are not the only organisation that do not use all the functions of the IFC, this is highlighted by saying: “There are limited people that fully understand the IFC” and “The average modeler in the Netherlands could find the export function, but doesn’t really know what happens during that process, no that’s for sure.” The IFC-specialist recognizes the limited knowledge too by saying: “What a lot of people do is just modelling in Revit or Archicad and then directly exporting to IFC.” This results in IFC exportations with standard defined entity specifications. This could lead to information and data loss in the archived IFC file.

The lack of understanding is caused by the size and complexity of the schema and often a standard ILS is used to structure the IFC. Still, not every BIM modeller and tool exports the same properties to the same entities and property set. The IFC-specialist underlines this by stating: “ifcPropertySets are are different from entities in the schema. Attributes are defined by the entities and only visible when they are opened in a text editor. IfcPropertySets and the IfcProperty (often SingleValue) define the name and the value of in the model [IFC model]. This makes it flexible, but also means that one tool or modeler exports more data compared to others.” Further, BIM-advisor 2 underlines the lack of data structure in the following statement: “Contractors that developed an ILS, or choose a predefined ILS, does not know how the ILS works and what they are asking. So, they just copy it form the site and send it. And if you ask annoying questions, they do not know the answer.” Organisations use ILS to structure their data but do not know why they need information and how this should be structured accordingly. These statements highlight the lack of knowledge about the needed data after completion of construction.

These two sections underline the lack of data requirements and knowledge presented in the problem statement. The limited use value of the IFC in decommissioning phases could be derived from this. It could be that more data is stored in the BIM models than is exported to the IFC. However, later in this chapter will become clear that the BIM modelers do not know what should be included in a circular BIM. A part of the solution could be educating modelling parties to export all their data.

Changes

After the IFC is archived, it is almost impossible to make major changes. It is possible to change the values of data because these could be found in the code of the IFC and changed, but modifications to the geometry of building parts is almost impossible.

If major changes should be implemented, the source should be modified and exported again. The source is in this case the BIM. During the exportation to IFC, the parametric rules of the BIM software are not copied into the IFC. It is possible to open an IFC into a BIM modelling software, but then the objects are not recognized by the BIM modelling software. This makes modelling and editing the model awfully hard. BIM modeler 1 explains this by comparing the IFC to Word: "In Word, for example, you can edit and assign headers. That is the title, that's heading 1, heading 2, this has style 'paragraph', this has style 'quote'. And that is all logic that Word understands, that is behind it in the .docx file, but as soon as I make a PDF, that logic is gone. If I then take the text and put it back into Word, it is not suddenly heading 1 again. He does not know that. it is just text with an edited text size, so that is exactly what happens with IFC" Further BIM modeler 2 expresses that loading a IFC into BIM software is not supported sufficient: "it is really a drama to load an IFC [in BIM software], let alone edit it and then export it again. So I would never advise you to do that in any case"

Still, there are some applications which could help with deleting and modifying entities from the IFC file, but more changes are hard to process, such as cut-outs and extensions of components. This means that single values could be changed simply

It is impossible to retrieve data of an IFC file and load it in a BIM software. BIM software can open the IFC file, but then the build objects are not recognized. This results in a digital model with volumes and without identification of the modelled items, or in other words, the software does not know what is presented in the modelling space. Thereby the BIM software does not recognize the parametric rules of the building parts which makes modelling very inefficient. Hence, modelers are remodelling the complete asset when buildings are renovated. Another option to overcome this problem is to save the BIM as well, but then the BIM needs to be updated regularly to the latest software version.

19.2. Linear building organisations

In the following sections the work method and data requirement of the linear construction companies is elaborated. The linear construction companies all used the same principles to structure and export their BIM, so the described method used by all the interviewed linear organisations. The differences spotted in the organisation structure and archiving are caused by using different ILSs and client specific orders. Furthermore, in the coming sections a description is given about suppliers of a construction project. Not all stakeholders are currently using BIM for construction and production, therefore the description should be seen best case scenario.

Linear building organisation process

During the design and construction processes the BIM is saved in a CDE. Both respondents use the work structure as described in paragraph 7.5 BIM work structure. This results in a CDE with all digital models, building specific calculations and technical specifications of the constructed asset. Suppliers of building parts construct aspect models, or CAD file, for their production process and upload these models in the CDE. This results in a CDE with different files and aspect models with different LODs. The models are not merged into one main BIM because this could lead to unclarity and extensive complexity. Furthermore, a complete digital model with all production specifications brings no advantages for the client and contractor. IFC is used to communicate between the parties due to the completeness and the interoperability of the schema.

After the construction phase is completed, the main BIM could be exported to an IFC to store all data for the longer term. Often the basis ILS is used to structure the exported values and properties of the BIM into an IFC. This results in an IFC which contains all data modelled in the main BIM. However, this does not mean that all data is included in the IFC, since new versions of the BIM are constructed during design phases and data could become obsolete after grading the permit. BIM modeler 2 was asked if all data is included in every phase the following answer was given: “We do not include this data as standard because we do not use that data ourselves. Of course, this data is added to the model when requested by a client” This means the data which is not used by them is not copied or checked in the model because this makes the model simpler and easier to work with, this is further elaborated under the heading “Development of the BIM”. This IFC file could be stored in a material passport exchange to enable data accessibility for the longer term. Sometimes the organisations save the BIM for the longer term too, because of the difficulties of changing the geometry in the IFC. Thereby it becomes easier for the client to make major changes in the asset and the digital models aligned.

Development of BIM

The development of the BIM of a linear organisation follows the basic steps of a project lifecycle, this means that they start with a digital model that is based on volumes and spaces, so a LOD-100 BIM. Subsequently the BIM is further developed in higher LODs, and more detail and data are added to the objects. In the initial stages, the BIM is modified by architects and developers with low LODs, because LOD-100 and 200 BIMs are easier and quicker to change and modify. BIM-advisor briefly highlights this 1 in the following argument: “An architect would probably find it too much trouble to draw all the building parts because he is constantly shifting walls to know how thick these should be, and how much space it takes, and if an opening can be modelled. But how it is constructed is not so interesting for him, nor for the design. That’s only interesting once you start constructing it. So, he [the architect] prefers to keep it simple, while the building engineer just wants to know: how much does the element weigh? And what is the composition of the wall?” This highlights that the BIM evolves from a simple model to a much more detailed and elaborate model during the design phases. During this process data is connected to the objects of the BIM to enable building specific calculations. Eventually, the BIM is developed to LOD-300, and specific information is added to the 2D modelling space to develop LOD-350 drawings that are sufficient for construction. When BIM-advisor 2 is asked to the end LOD of their BIM, the following answer was given: "quite detailed […] We get our details directly from the model. We try to add as little as possible in there. Sure, we're not going to draw in the lead flashing and lintel and stuff. But the most important things need to be in there" This highlights that LOD-300 or -350 is reached after they are completed with their construction model.

After the permit application, the BIM could be further developed for construction purposes. This means that the BIM of the architect is, sometimes, replaced by more manageable smaller BIMs or redundant data is removed because this is easier in the process. It should be noted that after awarding the building permit, data could become obsolete. Therefore, could be chosen to delete the data for follow up versions to keep the digital models smaller and clearer. BIM-advisor 2 mentions the following about this: "We do not include this data standard, because we [as engineers] don't use that data ourselves" and "this data [data for LCA and structural calculations] because this is ensured in the building permit, only if the client requires us to" Thereby calculations, or data for the calculations, are not always stored during the engineering of the construction model.

The linear organisations aim to minimize the data in the model. BIM modeler 2 expresses: "When the geometry is rather simple, a lot of data space is saved [..] Yes, of course you want to limit that as much as possible to keep it workable" More data in a BIM also means more modelling and an increased chance of faults, because the tasks become more complex and elaborate. Furthermore, the organisation aims to minimize the information and data otherwise the needed digital storage becomes too big. The modeler highlights this by giving an example of a project: "If the geometry is simple, that saves a lot of data. Because if you look at project X, which requires digitising six thousand homes, that really involves hundreds of terabytes of data. Yes, of course you want to limit that as much as possible to keep it workable" This highlights that data should be minimized as much as possible to reduce the overall data requirements. A final argument for smaller models is that more software programmes can read the digital model. "The tooling often determines the limit a lot of the data lines in it" thereby BIM modeller 2 illustrates that not all IFC readers are capable to read complex models and data rules, same goes for online portals.

According to the respondents, keeping the digital model as small as possible is key for a workable and manageable BIM. Hence, the models should be cleaned of obsolete data. BIM modeler 2 mentioned that they clean the IFC before a customer receives it: "Before we send an IFC to a customer, we have a Python script that cleans up the IFC of all the data lines that the customer does not request, so that it is also just a pure model which they can continue with" The model in received by their client contains, sometimes, less data than the original model. This could mean that data is added to the model that could be useful for the modeler but is not useful or requested by the client. Hence, that not all data is available during decommissioning of an asset.

Maintenance

After the construction of the asset is completed, the use phase starts, in which maintenance activities take place. According to linear organisation 2, BIM is increasingly used during maintenance activities, by making a BIM with maintenance data. The data and LOD in a maintenance BIM or IFC are different compared to the construction BIM, because maintenance activities a lower LOD and different data is needed. Currently, the construction BIM is not used anymore and becomes obsolete, because modelling a maintenance BIM is financially more attractive than restructuring the construction BIM to a maintenance BIM or IFC. BIM advisor 2 argues the following about this: "We want performance requirements, recorded in data, but also a geometry to be able to construct a building. And then we need a model that could be used in our real estate database. However, that means that certain geometry must be removed from a construction model and a lot of data has to be added. [..] it's, it's become so cheap to digitise property for a use phase that they're saying, just do it again so we have a model that can be used real estate database one-to-one. This means that the construction BIM is not used the use phase.

A maintenance BIM or IFC has a lot of placeholders to describe building parts. These placeholders are forming a link with rational technical specification and planning tools of the asset managers. Placeholders are objects which are further defined in technical specifications. This means that the placeholder defines only the location of an object and does not not inform the modeller about the information and data behind it directly. A placeholder could be anything, such as a black box, line, arrow, or number, provided that the modeller knows where the corresponding technical specification is located. This further means that the geometry of the placeholder is less important because the appearance, typology, and other information and data is further defined in the technical specification. The use of placeholders is maximized because it reduces the overall file size of the digital model. In the use-phase the IFC is the preferred data file because this is interoperational and is thereby suitable for communication and performance analysis in different software.

Data requirements and ILS

BIM-advisor 1 states the following: "The BIM basis ILS, is used in almost every project and concerns inter alia a correct filename, correct entities should be linked with the correct objects, naming building stories" The basis ILS informs the modeler about the structure of the BIM and the used entities in an IFC. Furthermore, the basis ILS ensures that the structure and content is almost identical in every project and thereby facilitates clear communication, higher interchangeability of files, and higher efficiency during construction and deconstruction. However, these guidelines are not sufficient according to BIM advisor 2 by stating: "Clients state that they need data […] A lot of clients say: the basis ILS must comply. Ok, that is fine, but the basis ILS only says: think about it [data requirements] and doesn't clarify how it should be structured or what name we should give objects" This means that objects are not necessary assigned to the correct entity. The basis ILS only states that the correct entities should be used but does not elaborate in detail which objects are related to specific entities. This is in contrast with the mentioned requirements of an IFC, in which the correct entities should be used to identify objects. As described before, modelers often use the standard exportation tool of their BIM software. However, Revit, for example, usage different export classes are than IFC and thereby attributes and properties are not assigned correctly.

During the interview the following argument is made by BIM-advisor 2: “Every organisation has its own requirements and specifies the ILS thereby further. So, it suits their asset management system better” This does not have to be a problem, but underlines that the LOD of the data and geometry in digital models differs. BIM advisor 1 adds to this: “That [basis ILS] is the basis, so in fact everyone should comply with it. Furthermore, every contractor or architect has his own information delivery specification [..] And they are diverse, so everyone makes his own standard” This could mean that digital models do not have to be as structured and complete as the ILS prescribes and that the advantages of the method are not optimized in practice. BIM Loket (2020a), the developer of the basis ILS, describes the following: “Incorporate the relevant building physics properties into the objects” However, BIM Loket (2020a) does not further define what relevant data is, so there are no data requirements of objects stated in the basis ILS. The basis ILS is thereby primarily a structure and not a data requirement specification and does not prescribe a specific LOD. Fire Ratings, on the other hand, should be stored in the digital model according to the basis ILS.

When BIM advisor 1 is asked if geometry is included in ILS the following answer was given: “No, that is not included. But I believe that in the ILS ontwerpen en engineering something is described about the geometry” and “It is super complex to check if the geometry is detailed enough. How are you going to do that? Count the number of polygons? If the geometry of an element is simple, then there are just a few [polygons]” The geometry described in the ILS O&E (Design and Engineering. Original Dutch name: ontwerp en engineering) describes objects based on their length, width, height, cut-outs, lugs and rebates, and dilatations, but does not require to include information and data about the detailed geometry of the connections between objects. Consequently, it is impossible to identify the building sequence from the digital model by using the ILS O&E. Other ILS configurations do not contain geometrical requirements at all and make therefore not explicit what building sequence is used (BIM Loket, 2020a).

Occasionally, a waste treatment method is registered to manage the building parts after deconstruction. The waste treatment methods described by the Rijkswaterstaat (2022) aim to manage and enforce waste streams of all types. However, the described methods are not intended to replace the end-of-life concept and are therefore not circular oriented.

Connections

During engineering in the design phases, the organisations think about the connections between elements. The performance of the connections is registered in the BIM to ensure that the connection has the correct properties. This means that the fasteners are not prescribed but the characteristics are, for example, the strength and visual appearance. When the final faster is known, this is not modelled, because of limited time. This means that the used final connection typology is not defined in the BIM. When clients ask to model the fasteners, the organisations are willing to model these. Currently there is no major advantage for modelling the fasteners because it is irrelevant for clients to know where fasteners are located. Some suppliers model the fasteners in their digital models because these could be used for production purposes. Still, these are often not included in the BIM because it does not add extra data for the client and makes the model unnecessarily complex.

Recap BIM linear organisation

The interviews expressed that de BIM develops according to the process visualised in figure 21. Linear construction starts with LOD-100 and develops till LOD-300 or LOD-350. These models are further developed in more detailed aspect models for construction and production purposes. Notable in this schema is the transition from the construction phase to the maintenance phase, there the LOD of the model drops significantly from LOD-350 down to LOD-200. The highly detailed models are not needed anymore due to lower and simplified requirements during the maintenance phase. The construction models with LOD-350 are often stored in a material passport platform to ensure that this is still available. However, during decommissioning no model is specifically designed for disassembly or checked if it is suitable for decommissioning.

For data requirements in a BIM, ILSs are used. These data standards ensure that information is asked in a structured, complete, and uniform manner. However, every client usage a different ILS and adds their own requirements on top of it. Furthermore, the BIM basis ILS, the most used ILS, does not require specific property sets and is therefore more a structure than a data requirement specification. In practice this results in ununiform data in BIMs. Furthermore, the required data could differ a lot from phase to phase. This means that valuable data in one phase could be obsolete and thereby useless in other phases. This results in various numbers of models with other data specified in the models, so a LOD-350 model in the design phase could contain different data compared to an LOD-350 in the construction phase.

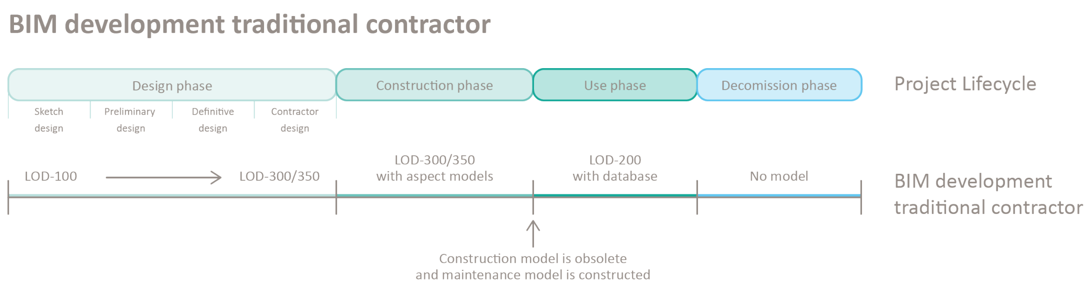

Figure 16: BIM development traditional contractor (Source: Own illustration)

	Overall building LOD	2D details available	Data for permit application	Data for construction	Data for maintenanc
Desgin phase	LOD 100 - LOD 350	Yes	Yes	Yes	Yes
Construction phase	LOD 350	Yes	No	Yes	No
Maintenance phase	LOD 200	No	No	No	Yes
Decommission phase	N/A	N/A	N/A	N/A	N/A

Table 5: Data availability linear construction without material passport (Source: Own table)

In table 4 this is illustrated in more detail for a building project without material passport. The overall building LOD shows what the general LOD is of the building. This means that aspect models or one main digital model contains this LOD. There is a lot of difference between the data supply in each phase. The difference between the construction phase and the use phase is illustrated in figure 21 is shown in more detail in table 4. Another interesting row is the decommission phase. There is not developed a digital model and data for decommissioning. This underlines the quote of the decommissioner stated in the introduction of this report: "I simply need more information, I currently don't know how to disassemble buildings" There is no model constructed for: constructing a decommissioning plan and analysis of building materials. Still the maintenance BIM could be used during the decommission phase, but that model does not have much detail.

If the linear organisation stores data in a material passport, more data is available during maintenance and decommissioning. However, the used ILSs illustrate that data could vary, so the development of decommissioning plans and analysis of building materials could impossible when not all required data is stored.

Summarizing, the LOD of the BIM differs every phase and the data in BIM differs every project.

Modular building organisations

The work method described in the following sections is a genetic view of the work method used by modular building organisations. Not all modular builders are working with this exact method, but then the methods are derivatives of what is described in this paragraph. The differences in workflows are a result of using different sub-contractors and their modelling software or differences in building performance calculations, such as MPG and LCA. Despite that, they all use the same principles to construct their BIM and store the same information and data for a subsequent lifecycle.

Modular building organisation process

All modular builders constructed a standard work method which is used in every project they participate in. This method is based on standard building components that could be reused in following lifecycles and form thereby the core of their system. The databases used are operated by the organisations themselves, because then they could reuse the data generated in previous projects in new projects.

A modular project is structured in the work visualized in figure 22. All projects start with retrieving object types and geometry from the database or product configurators. These families form the basis of every design the modular builders are creating, this is highlighted by modular builder 2: "These are ready-made elements [...] in the basis we have a few implementation forms. They are standard, we have standardised them. A customer can buy them". This structure is also processed in their digital models according to

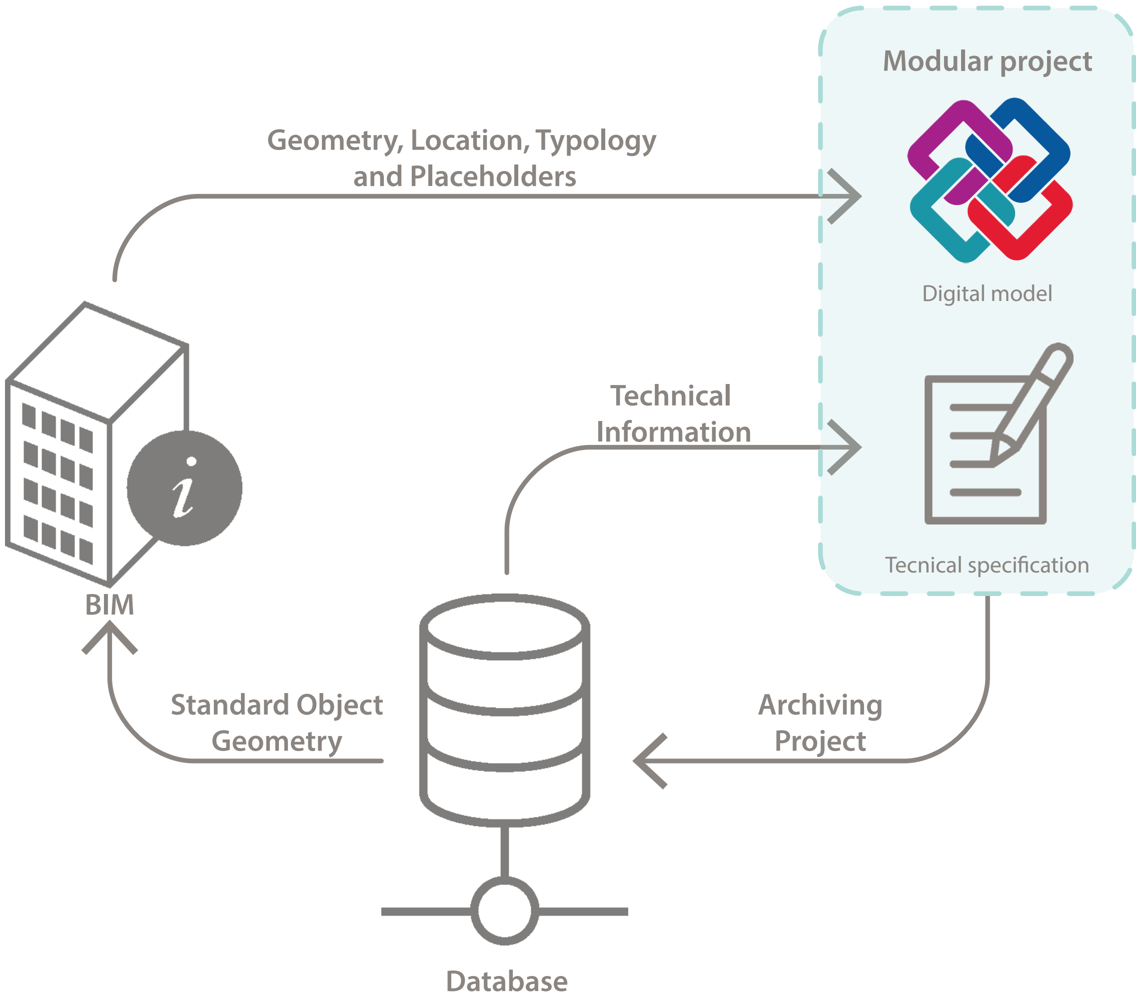

Figure 17: Work structure modular builders (Source: Own illustration)

modular builder 2: ""I'll just call it standard units, which are just put in a place so to speak, so then you just have your standard Revit list on which you base a building" These building parts are modelled in BIM software, such as Revit or Archicad, and possible client specific orders are added to complete the final asset configuration. By structuring the families and types in the database, the BIM becomes more structured as well. All reusable components are labelled for recognition purposes in the forthcoming lifecycles. The digital models in a modular project contain data about the geometry, location, and typology. After the whole asset is modelled in BIM, it could be exported to an IFC or saved as a BIM for longer term, for clarification reasons the IFC logo is used in figure 22. Storing data in a BIM for subsequent lifecycles is possible because some projects have a short lifecycle and therefore have low risk of obsoletion of the BIM file. Basic information is saved in the BIM because it simplifies the BIM and makes it easier to manage. This means that the objects contain minimal data for building calculations, such as LCAs or structural analysis. The digital model defines the location of the object, and the technical specification defines all other data of the project. The digital model and the technical specifications have a fixed structure, so the data is complete and uniform.

The geometry of the components is standardized and chosen by the modular organisation. Important is that the building components are manageable in size and weight. Too big components could not be transported properly, and smaller parts are financial not feasible. Further bigger parts mean less waste if changes should be made in a subsequent lifecycle. This highlights that the level of technical decomposition is an important factor for modular construction.

Construction analyses are done externally by remodelling the BIM in construction software, because creating a link between BIM and the structural software is not possible. This originates from the lack of support of construction tools by the IFC. The technical characteristics of the building part have at least LOD-350 because this level is required to construct the building.

Development of the BIM

A consequence of the work structure of the modular builders is that elements of the BIM are already LOD-350 during the early design phases of the project. This means that a large part of the digital model is already very detailed and the constructed families. Later in the process the model is added with client requirements.

Modular builders do not want to store all data in the BIM file, because this creates problems during modelling. This is highlighted by modular builder 1: "There is, of course, a moment that a model contains too much information […] Especially when you want to make minor changes, then you must change too much" and "We aren't going to model every screw. That is nonsense, because the file [the BIM file] becomes too heavy. On average, a BIM-file is far too big for this kind of operations" Modular builder 2 underlines this by stating: "The more elaborate your model is, the more problems you get" and "I mean, you can model everything, but it must be useful. Everyone [building engineers] knows that Fermacell is covered by a wallpaper" Both respondents highlight that an extremely detailed BIM is not preferable. Too much work for modelers and too heavy for the hardware to process everything are the main reasons to reduce the BIM file size and LOD. Therefore, the modular organisations choose a combination of BIM and an external database to structure their data. The BIM of the modular organisations contains only basic data about the location and identification of the building components. This results in a BIM with properties that contained detailed data about the geometry, labels, typology of objects, and placeholders. This information is primarily used for production, planning and automatization purposes.

Modular builder 2 states further that having a lower LOD in the BIM does not mean that data is missing by stating: "When you model everything precisely in 3D, then it is possible to recognize how something could be decommissioned, so in that detail. By, for example, recognizing the profile that is used to slide parts in. You can derive that [the decommissioning process] easily from the details in the model. Then, of course, you as a structural engineer [..] have are able to find out how you can do that" According to the respondent, a structural engineer has sufficient knowledge to recognise construction and decommission sequences, so not all building parts are required in the digital model to understand how the final asset is constructed and disassembled. This means that not all objects need to be modelled and stored in the BIM, and thereby IFC. Durmisevic (2019), describes that it is important to know what the construction sequence is. However, according to the respondent, this data is not obliged to be presented separately the digital model, if the LOD of the geometry in BIM is high enough. LOD-350 is minimal needed for the geometry to recognize the building sequence of an asset and is therefore needed in a BIM project for decommissioning. Furthermore, the builder argued: "Everyone [building engineers] knows that Fermacell is covered by a wallpaper" This implies that it is not necessary to model everything because there is a certain knowledge and logic available by building engineers. Modular builder 3 adds: "We do indicate when parts are glued [...] We screw everything, basically. Therefore, we don't mention it [screws in the digital model]". In case of the third builder, only the irregularities are specified. This means that the use of screws is seen as common knowledge and logic of engineers.

Archiving the digital model

After the construction is completed, all information and data are stored in their database. All data generated during the construction phases are saved during the whole project lifecycle, from completion till disassembly. This means that the LOD modelled in the BIM and in the technical specification is identical during construction and the archived documents and files. Thereby the archived documents and digital models have 350 as LOD. Furthermore, the data is structured in the same configuration. Hence, the technical characteristics are saved in the technical specifications and the geometry is secured in the digital model. Thereby the data of the component is sufficient to apply for a building permit in a subsequent lifecycle. The data that should be added to building parts depends on the location and thereby building layer of the asset. However, sometimes it is unknown what function the building part is used in a subsequent lifecycle, for example, partitions could be between two rooms and two houses, this could interestedly be the same kind of wall. However, between two dwellings data is needed of the wall about noise and fire regulations and between rooms is not necessarily needed. To increase flexibility all data should be saved.

Data requirements

Modular building organisations need different information and data during the lifecycle of a project compared to the linear constructors. First, data is needed to comply with the building code and application of building permits. This is stored during the whole lifecycle of the project because this is needed in a subsequent lifecycle too. Thereby characteristics of the building components should be known and saved to enable reuse for projects in subsequent lifecycles. Modular builder-2 mentions the following: “In most countries where we operate, 60 minutes [fire resistance] is a very normal situation. In the Netherlands, 60 minutes is more of a normal situation, and abroad 30. We have to choose standards to meet the requirements [of the building degree]” and “Well, the Dutch fire resistance is taken. The Rc-value is not Rc-value of here [the Rc-value of the Netherlands], but the u value from Belgium, because it’s higher. The one in Belgium has a value of 5 instead of 4.5. And because we have products internationally, we can also reuse it internationally” The standards they choose are based on the reusability internationally and based on the building regulations of the countries they are working in.

Modular builders have a database that contains data about typology, identifier, noise resistance, weights, geometry, various emissions, fire ratings, structural characteristics, retour dates of building parts used in projects. When modular builder 2 is asked what data and geometry they store in a project, the answer was brief and clear: “Everything is stored” Every detail is needed for reuse of the component or material because they influence the building performance, decommissioning processes, or transportability of the building part. Modular builder 1 mentions the following data should be available: “if an external party is given that wall one day and wants to reuse it, then you actually want to know, of course, what your technical specifications are for all the materials in it. And that is particularly about your Rc, and your sound, things like that. So that you know what the qualities of the wall are to be able to reuse it” Modular builder 2 adds to this: “All the digital information is attached to the system, about what is in that module of 3 by 6, or 3 by 7. What material is in there for the roof? That roof has a fire resistance of 30 or 60 minutes? Do the columns have a fire resistance of 90 or 120 minutes? All that sort of data. Rc-value, construction of the roof, is it an intermediate floor or a top roof, a roof with a cut-out for a light”

Connections

The used connections of a modular builder are screws and bolts and nuts between the dismantled building parts. The primary reason for using these types is the speed of decommissioning. Modular builder explains this clearly by saying: "The disassembling value of products depends on the labour and the value of the material after disassembly" Thereby the respondent acknowledges that easy to dismantle connections are key in the decommissioning value of an asset and not all connections could be designated as circular. Furthermore, when other modular builders were asked why they primary use screws, and boults and nuts, they answered both: "because it is quick" The first and second connection typology of Durmisevic (2019) become thereby unsuitable for decommissioning, since a lot of labour and time is needed for disassembly of the building parts. Modular builder 3 argues that chemical connections are not circular at all, because building parts damage when they are disassembled. The fourth connection typology is the most circular according to the modular builders, because this requires the least labour time. In addition, the used connection typology should be certified by the government to be able to use it. Thereby, the interlock connection and gravity of Durmisevic (2019) are no longer applicable.

Furthermore, modular builder 2 stated the following: "When you model everything precisely in 3D, then it is possible to recognize how something could be decommissioned, so in that detail. By, for example, recognizing the profile that is used to slide parts in. You can derive that [the decommissioning process] easily from the details in the model" Modular builder adds to this quote: "you could look at the details and then you recognize the building sequence" Both citations tell something about the building sequence as well as the connection typology because it should be recognisable how to decommission a connection. The respondent adds to this quote the following: "One thing what could be done is to model the connections precisely, so someone could recognize afterwards what connections are used. And then I must dismantle it like that. But it is also possible to link that information later" Thereby the respondent states that the connection typology used, should be recognisable or described in documentation. This does not mean that LOD-400 is needed, this is highlighted by modular builder 1: "A model of a screw is just a line in our model [BIM]" To distinguish the connections used they use placeholders in BIM. In this case the line is interpreted as a screw without modelling the screw as an object and the related processes are thereby evident too. In this case the used LOD is not clearly assignable, because modelling every screw in detail is LOD-400 and modelling no screws is LOD-350. This makes the required LOD between the 350 and 400, because it is not needed to know the exact location of a screw but knowing that screws are used is needed.

Recap BIM modular organisation

In the beginning of a modular project, the BIM is constructed from predefined building parts that are derived from a standardized family. Thereby, the LOD of the modular BIM becomes LOD-350 since the constructed families are already LOD-350. Figure 23 shows that the BIM stays at this LOD during

	Overall building LOD	2D details available	Data for permit application	Data for construction	Data for maintenanc
Desgin phase	LOD 350	Yes	Yes	Yes	Yes
Construction phase	LOD 350	Yes	Yes	Yes	Yes
Maintenance phase	LOD 350	Yes	Yes	Yes	Yes
Decommission phase	LOD 350	Yes	Yes	Yes	Yes

Table 6: Data availability modular construction (Source: Own table)

the whole lifecycle of the project. This means that no data and geometry differences are processed in the BIM during the project lifecycle.

The building parts are linked to a database that contains all data for the whole project lifecycle. This means that the design phases of a modular contractor have a high LOD as well as the rest of the phases. Furthermore, all data is stored for maintenance and construction, this enables the modular builders to find a suitable ensuing life for the released building parts, this is illustrated in table 5 and figure 23. The available data, drawings and models is consequent in every phase of the project lifecycle.

Summarizing, the LOD of the BIM is consistent every phase and the data in BIM is consistent in every project.

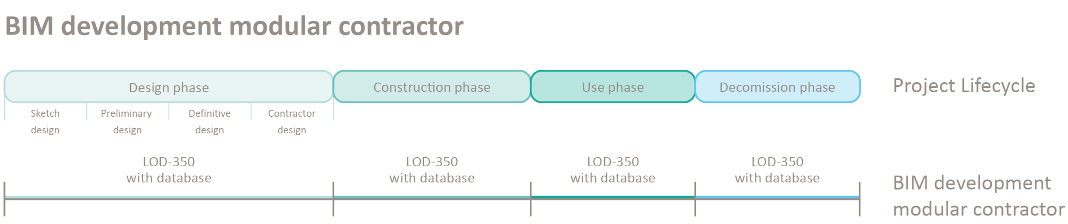

Figure 18: BIM development traditional contractor (Source: Own illustration)

20. COMPARISONORGANISATION TYPES

In this chapter the linear and modular organisations are compared to recognize the differences and the data requirements and BIM development of both organisations throughout the project process. The goal of this chapter is to find the required LOD and data requirements for the circular component specification.

20.1. Linear and modular organisations process

Both organisation typologies use different approaches to structure their data. The linear organisation uses BIM as base point and modular organisations use their database as base point for new projects. This means that the modular organisations first investigate how their current assets, and thereby the stored objects in the database, could fit in their new projects. This difference could clearly be seen in figure 19. Both organisations have very different starting points and thereby LODs of their models. Linear organisations develop new assets whereby new, more generic; models are first constructed, whereas modular organisations use more detailed predefined building components to construct their BIM. The database is crucial in the storage of their rented assets because this contains all data of previous projects and thereby data for new projects. This is possible due to standardization of their building parts, and thereby object library. The standardized building parts are already saved in their database and could therefore be directly used in new projects rather easy. Linear organisations, in contrast, do not have a link between existing objects and their new constructed asset.

Before the permit application, linear organisations use their digital model as design and calculation tool. The needed data of objects are included to calculate building specific calculations and apply for the permit. Thereafter, this data is not as intensively used anymore and sometimes deleted or not transferred to other versions of the digital model. Thereby the model becomes smaller and clearer for later phases. This means that not all data is transferred

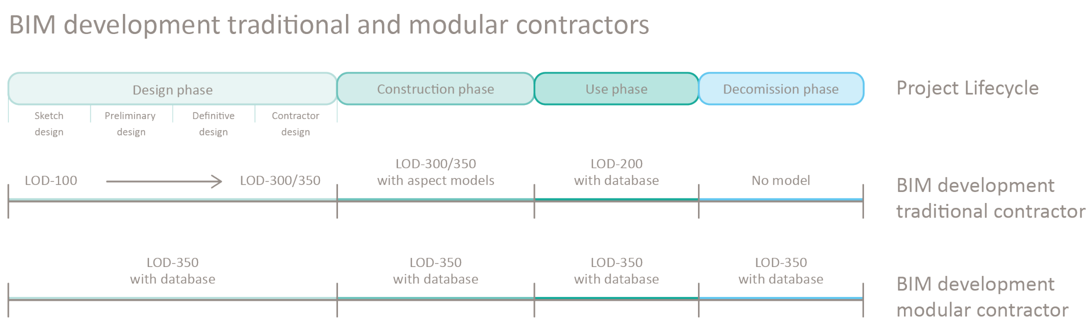

Figure 19: Linear and modular processes comparison (Source: Own illustration)

between the phases of a project, even within phases data demand could differ and change in the model. Contrastingly, the modular builders store all data in their own database during all lifecycles of the project because they need that data for permit application in later ensuing lifecycles, as a result the LOD and data of their digital model does not change during the design phase.

Two other interesting differences occur in the maintenance phase and the decommissioning phase. Modular building organisations store much more data during the use and the decommission phase. According to the linear organisations, the modular organisations store too much data in the use phase for maintenance activities. The modular organisations keep the same LOD compared to the other phases because this informs about the capabilities of the building components and the deconstruction processes of an asset. This technical data is needed for application of permits in subsequent lifecycles. Linear organisations, on the other hand, need much less technical data after construction because maintenance requires different data compared to construction activities. Thereby the digital model of the linear organisations

	Overall building LOD	*2D details available*	*Data for permit application*	*Data for construction*	*Data for maintenanc*
Desgin phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	LOD 100 - LOD 350	Yes	Yes	Yes	Yes
Construction phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	LOD 350	Yes	No	Yes	No
Maintenance phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	LOD 200	No	No	No	Yes
Decommission phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	N/A	N/A	N/A	N/A	N/A

Table 6: Data availability modular construction (Source: Own table)

becomes simplified and some values that were needed during construction become obsolete. This makes the linear digital models not suitable for circular decommissioning, because data is missing about qualities of building components and decommissioning methods. Furthermore, the connections are visualized differently. Modular builders model or draw the used fasteners in their digital model or drawings, by using placeholders, text, or standard building engineer knowledge. This enables building engineers to disassemble the joints carefully. Linear constructors do not make explicit the used fasteners, thereby it is unknow how the building parts are connected and could be disassembled.

20.2. Data requirements ILS

This chapter describes what data is needed in the information delivery standard to comply with the requirements stated by the linear and modular builders. This data is retrieved from the interviews and researching the building degree. The result of this data collection could be used in the data specification for circular component reuse.

This paragraph informs about the required data of a circular building component. The following requirements are needed of the building components walls and floors. This means the described regulations have a direct or indirect relation with a building component and not with the design and structure of the asset itself, for example the length of escape routes, the energy production, and minimal dimensions of spaces. The described requirements are based on the 2022 version of the building degree 2012. Still, the coming years these requirements could be expanded, and rules could become stricter. Moreover, the requirements are based on buildings without a monumental status and fall under the house use function.

20.3. Building degree

The technical data of a building component should be sufficient to reuse this in a subsequent lifecycle. According to Hobma & de Jong (2016, pp. 36-37) the environmental permit of the Netherlands has four major tests criteria by which the applications is examined: urban planning regulations, technical sounds and safety, aesthetics, and health and environment. These are reviewed by a governmental body during the application of the permit. One ground for granting the permit is that the asset should comply with the Dutch Building degree. The building degree describes the minimal technical requirements of an asset, and thereby the characteristics of a building part. These characteristics are the following: structural capacity, fire resistance, ventilation, acoustic insulation, energy performance, environmental performance, daylight. This means that building components should contain data to ensure that these requirements could be met.

Energy calculations and BENG

In the start of 2021, the building regulations are further enhanced by introducing the BENG regulations. BENG abbreviation of Bijna Energie Neutraal (translated: Nearly Energy Neutral). This requires making energy performance calculations of an asset and sets thereby requirements to the used building parts used. The goal of these regulations is to minimize the energy usage of a building and increase the amount of renewable energy (Ministerie van Binnenlandse Zaken en Koninkrijsrelaties, 2022). To do an BENG calculation, the following data is needed of a building component: area (m2) connected outdoor, to Rc-value (m2K/W), U-value (W/m2K), and area of glass (m2) with corresponding solar heath factor (van Bueren et al., 2012).

MPG

New buildings larger than 100 square meters require an MPG calculation (Ministerie van Binnenlandse Zaken en Koninkrijsrelaties, 2022). An MPG expresses the environmental impact of the construction materials used in a new built asset. MPG stands for MileuPrestatie Gebouwen (translation: Environmental Building Performance). The goal of this calculation is to minimize the environmental impact of the materials used in a building and to stimulate the use of circular and biologic material. An MPG is the sum of all LCAs of an asset (Rijksdienst voor Ondernemend Nederland, 2020). An LCA is an analysis of all environmental impacts of a building component expressed in euros and the goal of the LCA could differ per project. Therefore, the inputs for an LCA should be included in the data rather than the outcome. To calculate an LCA the following data is needed of a component: Abiotic resource depletion (kg Sb-eq.), Abiotic fossil resource depletion (MJ), Freshwater ecotoxicity (kg 1,4-dichlorobenzene eq.), Climate change (kg CO2-eq.), Marine aquatic ecotoxicity (kg 1,4-dichlorobenzene eq.), Ozone layer depletion (kg CFC-11-eq.), Terrestrial ecotoxicity (kg 1,4-dichlorobenzene eq.), Photochemical oxidation (smog) (kg ethylene-eq.), Acidification (kg SO2-eq.), Human toxicity (kg 1,4-dichlorobenzene eq.), and Eutrophication (kg PO43--eq.) (Ecochain Technologies B.V., 2021). Furthermore, the function of the building component is needed, this is done by the NL-SfB (Stichting Nationale Milieudatabase, 2021).

For execution of LCA programmes the BIM is exported to a platform or connected with a plugin (Nationale Mileudatabase, 2022). Thereby the outcome and inputs of the calculations is processed in external documents instead of in the properties of BIM. Linking the the values of these external databases and plugins to the BIM is currently impossible because the BIM cannot retrieve data from external databases and consequently calculating those values to construct a complete LCA. Therefore, the LCA calculations should be added separately.

Structural requirements

According to the building degree, a built asset must be able to withstand all forces that may occur to the building. Therefore, structural data of building components should be included. The permit assessor should be able to examine the loads, forces, and used safety factors related to the building and components to grand the permit. Since the function, loads and safety factors in a subsequent lifecycle are not known, the whole construction calculation should be included. This ensures that the calculation could be checked and, if necessary, modified in a following lifecycle. The structural calculations make explicit the following criteria: used loads and forces, safety factors, weight of the components, function, strength classes, used material, geometry, and if applicable: reinforcement and steel profiles (Ministerie van Binnenlandse Zaken en Koninkrijsrelaties, 2022). Furthermore, a KOMO certification should be included to ensure that the structural calculations are correctly executed in the component (Nederlandse BouwDocumentatie, 2018).

Like the LCA calculations, it is impossible to add all structural calculations, because the used formulas must be verifiable. Thereby all the formulas should be added as text to the digital model which result in a lot of manual work just to add all calculations into one file, whereas the calculations are already presented structured and clear in a separated file. Furthermore, a link between the properties of the BIM is in that case not constructed. Thereby changes in the size and qualities require executing calculations again and manually coping it again into the BIM. A dynamic link is thereby missing between the calculations and model, which makes it pointless to add the structural data into the BIM itself.

Safety

During a fire, a built asset should give individuals sufficient time to escape and search, without risk of collapse of the asset (Ministerie van Binnenlandse Zaken en Koninkrijsrelaties, 2022). Building components should have a fire resisting rating to ensure that the asset could withstand a sufficient period. In the Netherlands, this is expressed in number of minutes. The fire rating of a component informs a building engineer in which part of an asset the component could be deployed.

A constructed asset should give an accommodation area sufficient protection from noise outside (Ministerie van Binnenlandse Zaken en Koninkrijsrelaties, 2022). This means that the building component should have a sound insulation value, expressed in decibel (dB). Further, contact sounds, noise caused by touching surface areas, are regulated as well. Both values should be known to calculate the overall noise nuisance in an accommodation area, this means that the DnT,A,K (characteristic insulation value airborne noise), the LnT,A (insulation value impact sound) should be known. These are all expressed in dB.

A constructed asset should have minimal impact on the air quality. This denotes that the materials and construction methods used do not contain characteristics that harm the internal air quality of the building.

External appearance

External building components, building components that have direct contact with outdoor spaces, should comply with the reasonable requirements of external appearance (Hobma & de Jong, 2016). The data and architectural aspects of the building components should be sufficient to assess if the external appearance of the building meets the prescribed aesthetics requirements of the external appearance committee. These requirements prescribe criteria of the maximum geometry, used materials, architectural quality, colours, façade, and roof structure of the constructed asset. Therefore, these characteristics should be included in the documentation. The appearance of the building component should be explicit, by indicating the component on a façade drawing or described in the IFC. This results in accurate visual presentation of the asset with description of the used materials, colour code, texture, and structure of the materials. The RAL code, IFC model and the NAA.K.T. method are used to describe the external appearance.

NAA.K.T. method

A uniform description of materials and surface finishing is still not fully implemented in the AEC industry. Thereby BIM software programmes do not understand what is meant by a description (BIM Loket, 2020). In this case this is needed for the requirements of the external appearance committee in the Netherlands. Therefore, the BIM Loket developed the NAA.K.T. method. This structure aims to provide an unambiguous description of building materials and their appearance. NAA.K.T. is an abbreviation of NAAm_Kenmerk_Toepassing (translation: name_characterisic_application). This ensures that all materials and appearances of materials are described in a uniform method, which helps software to understand the provided description. Therefore, this method is used to depict materials and their finishing in the reuse ILS.

Building elements

External building components have elements that should comply with the building degree as well. These are primary window and doorframes which are part of the building component wall. Often these elements have significant impact on the appearance of the whole building. Therefore, the frames should comply with the same requirements as the rest of the wall, this results in data of the geometry, architectural quality, colour, used materials. The opening direction windows and doors should be included as well. Furthermore, the glass surface of the frame should be included because this is needed for daylight calculations. Sometimes, frames are part of the natural ventilation capacity of the building. In that case the capacity, location, colour, and ventilation duct type should be included as well. Often these building elements require execution certifications to ensure that the building part meets the predefined requirements. These certifications are primarily for burglary resistance and energy performance. Certifications should also be added to ensure that the building parts do not have to be tested before using in a subsequent lifecycle.

Further, it could be that the building component is part of the installation or smoke exhausts. Then the capacity, location, colour, and type should be stored as well.

20.4. Other required data

The interviewees mention that the environmental permit requirements still are not sufficient because the component could have other characteristics which are missing. Transportation specifications should be included as well. This implies that geometry, weight, and provisions for lifting defaces should be explicit.

Part 5

Solution implementation

In this part the requirements and the research findings of part 4 are processed into a new data delivery specification called the “Circular Reuse ILS+”. In this part the newly constructed tool is further elaborated and highlighted to provide an understanding of the capabilities and related workflow of the designed tool. Thereafter the ILS+ is validated by interviews by two organisations that experience changes in their workflow after the tool is used. Thereby process changes, the demand of the market and responsibilities connected to the ILS+ are elaborated.

21. CIRCULAR REUSE ILS+

In this chapter the research findings are translated into a new data structure and requirements. This resulted in the excel "Circular Reuse ILS+" and corresponding guidelines. The following sections provide an explanation of the developed ILS+ with the functioning, structure, and target group of the ILS+. The full "Circular Reuse ILS+" with guidelines could be found in appendix 6.

21.1. Required documents and files

In the current BIM environment, it is unfortunately impossible to store all data into one single decommissioning file. This is caused by the structure of the IFC since this is not capable of including certifications and complete calculations of building components. This results in multiple files which are described in this chapter. To store all data there is chosen to construct two document types: an IFC file and additional PDF documents in form of 2D construction drawings and details, certification, and calculations of the decommissioned components.

General structure

In figure 20 illustrates the required structure of this ILS+. At the top of the illustration the main IFC file is shown. This IFC is a 3D presentation of the whole building and illustrates basic data, geometry, and location of the demountable building components. This model requires LOD-200 or higher, and the dismountable components are modelled separately to be recognizable and identifiable. Basic data is connected to the main IFC to minimize the complexity and size of the file. The required data in this model is presented in the excel "Circular Reuse ILS+" in the tab "DataRequirements". Every demountable component has a unique ComponentID to identify the component in other models and documents. Important is that the correct ComponentID is used consistently and in all files so data is always linked to the correct digital and physical component.

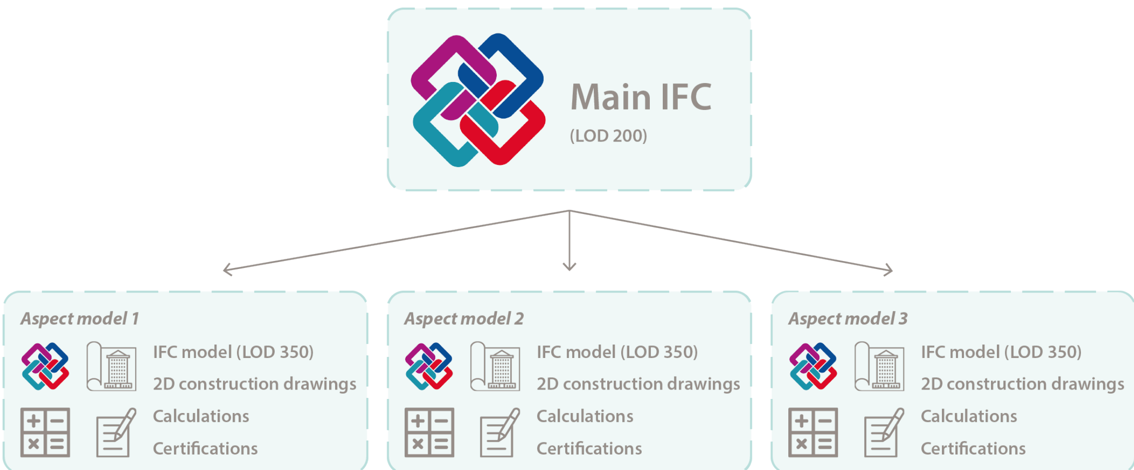

Figure 20: Main IFC and aspect models

Figure 20 also illustrates three aspect models related to that main IFC. Every demountable component should have a separate aspect model with all required data from the "Circular Reuse ILS+" Excel file and is modelled in LOD-350. The aspect models require a higher LOD and more data because these are used for performance analysis during reuse in ensuing lifecycles. As mentioned before, having complete IFC models does not guarantee that the building component could be reused. The aspect model should therefore be complemented with: 2D construction drawings, structural calculations (if the component could be used structurally), LCA calculations, and performance certifications to enable circular reuse. Furthermore, the ComponentID should be noted in all the documents to recognize the correct building component.

Required IFC models

The aspect models are used in ensuing lifecycles for performance analysis and design purposes. They give designers and builders input of the performance of the demountable component and reuse possibilities. Therefore, it important that all demountable components have their own separate aspect IFC, this results in separate models of each individual demountable building component. Every reusable, for example, wall or floor has thereby a IFC model with all related data and geometry that could be used for performance analysis after a finished lifecycle. In figure 20, three aspect models are presented. However, in practice this number could be a multiple of this, depending on the size of the asset. All the aspect models are represented in the main IFC to localize the components in the whole building. This main IFC is a presentation of the whole building with all demountable components modelled separately. This ensures that the aspect models could be recognisable, and the geometry of the whole building is presented. The following IFC models should be constructed:

- Main IFC
- Aspect model of every demountable component

Other documents

Every aspect model should be linked to drawings, calculations, and certifications to enable reuse of the building component. Organisations that use the building components in subsequent lifecycles need safeguarding that the components work according to specifications and should know how they could be disassembled. Further, some documents are needed during permit applications. Adding these documents to the project information is important because these are used as evidence for virtuous building and execution.

The 2D construction drawings and details

These drawings are all constructive drawings and details that are needed to construct the asset in the first place, these are also needed during decommissioning. These drawings are used to provide future building engineers with enough information to recognize building sequences and know which techniques are needed to disassemble the components from each other. 2D drawings are needed because it creates more insight in the building sequences and connection methods compared to just the IFC files.

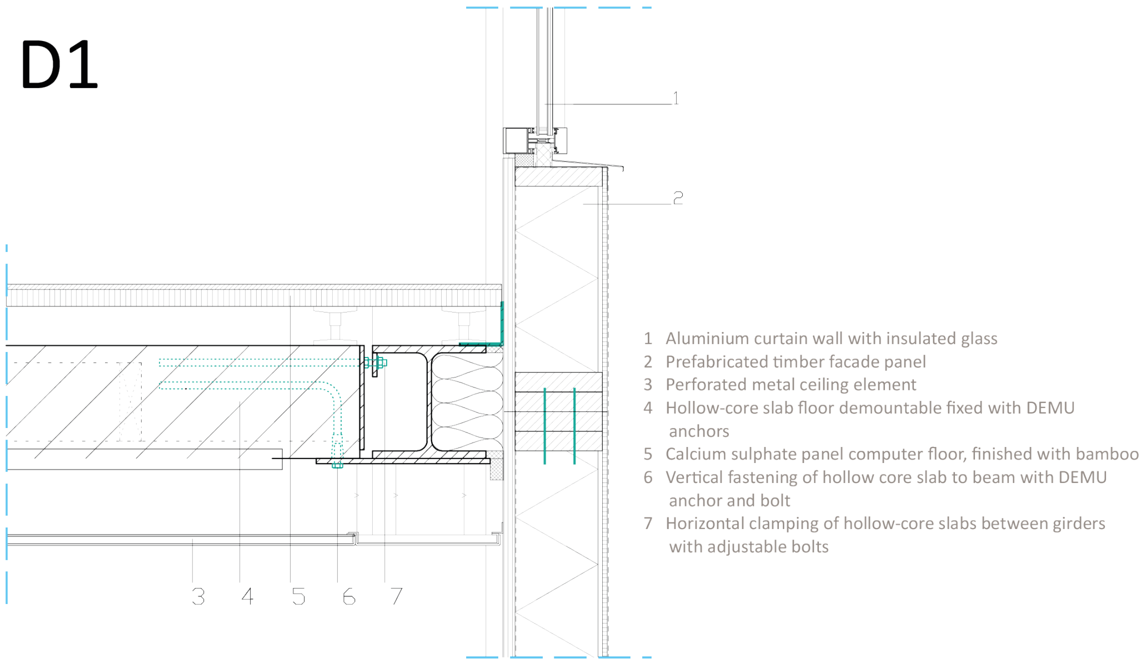

Figure 21: Main IFC and aspect models

In the details it is important that fasteners are visualized, this means that the screws, bolds and other connectors are presented. An example of such detail is illustrated in figure 21. The fasteners of the detail are visualized in green. These are not needed in the IFC models because this will increase the overall file size and the IFC becomes too complex. By visualizing the fasteners building engineers of the future could recognize the used connection techniques and disassemble the components to reuse the building. Together with the IFC aspect models and the main IFC, the construction drawings provide enough data to construct a decommissioning plan.

LCA calculation

New buildings larger than 100 square meters require an MPG calculation for application for a building permit. An MPG expresses the environmental impact of the construction materials used in a new built asset and is the sum of all LCAs of an asset. Therefore, the LCA calculation of the component should be added to the documentation of the building component. These numbers ensure that an MPG calculation could be made, and that the component could be used for permit applications in subsequent lifecycles. The inputs of the calculations are the most important aspect since the calculation itself could differ per LCA. An LCA calculation does not have a set structure and the inputs should therefore be explicit to use in subsequent lifecycles. Adding these inputs to an IFC is not preferable since it is impossible to create a dynamic link between the LCA calculations and the IFC. Thereby, manually adding the inputs to the IFC could lead to mistakes and data contamination. Furthermore, adding the whole calculation is simpler and quicker. To calculate an LCA the following data of a component should be explicit from the calculation:

- Abiotic resource depletion (kg Sb-eq.);
- Abiotic fossil resource depletion (MJ);
- Freshwater ecotoxicity (kg 1,4-dichlorobenzene eq.);
- Climate change (kg CO2-eq.);
- Marine aquatic ecotoxicity (kg 1,4-dichlorobenzene eq.);
- Ozone layer depletion (kg CFC-11-eq.) ;
- Terrestrial ecotoxicity (kg 1,4-dichlorobenzene eq.);
- Photochemical oxidation (smog) (kg ethylene-eq.);
- Acidification (kg SO2-eq.);
- Human toxicity (kg 1,4-dichlorobenzene eq.);
- Eutrophication (kg PO43--eq.).

Furthermore, the NL-SfB code is needed to complete the calculation, but this is already needed for identification. Therefore, this code is added to the excel "Circular Reuse ILS+". A link to the LCA calculations could be added to the property "LCACalculations" to create a direct link from the IFC to the LCA calculation document. Furthermore, in the description of the LCA, the ComponentID should be added to link the calculation to the correct component.

Structural calculations

To enable redeployment of building component, it should be possible to check the structural calculations. These calculations are required during the application of a permit. In subsequent lifecycles the safety factors and used loads must be able to be controlled per component, otherwise a building permit cannot be awarded. Testing building components after disassembling is often undesirable since it is a time consuming and financially unattractive process. These certifications could not directly be included in the IFC. However, the "Circular Reuse ILS+" defines a new property called "StructuralCalculations" herein a link to the certification could be added. Thereby a link to the calculations is realized to find the calculations directly from the IFC. Each structural calculation should have a correct ComponentID that links the component to the calculation. The following data should be explicit in the structural calculations:

- Used forces on the component;
- Used load(s) on the component;
- Safety factors;
- Strength of the component in X, Y, and Z direction;
- Used profile;
- Used material, inclusive correlated strength class;
- Weight of the component;
- Function of the component;
- And if applicable: reinforcement ratios.

Performance certification

Certifications of the assembling of the component should be added to ensure that the component performs according to the calculations. The certifications are used by organisations in subsequent lifecycles to ensure that the quality of the building component is aligned with the performance requirements and calculations. This certification could be, for example, an CE certificate, KOMO certification or Bouwgarant certification. Like the LCA and the structural calculations a property set is added to the IFC that requires a link to the certification and is called “PerformanceCertificate”.

21.2. Guidelines Circular Reuse ILS+

NR.	Name	Note
1.	Create a new folder	Create a new folder or place to create a project folder. This folder is used to store all project data.
2.	File name	Always ensure uniform and consistent naming of models and documents within a project. Every model should be aligned with the following structure: <projectname>_<discipline>_<aspect>.ifc For example, ResidentialJansen_structure_roof
3.	Construction level arrangement and naming	Each (aspect) model usage the following structure for naming building stories. <number><(optionally)floor letter>space<description>. For example, 00 GroundLevel and 01a FirstFloor. Assign each object is to the correct building story
4.	Modelled correctly	Check the following aspects: - Is the local position of models coordinated close to the point of origin? - Are all fasteners visualized in the details? - Are the components recognisable in the main BIM/IFC? - Does the BIM include all data from the “Circular Reuse ILS+”? - Are there are no duplicated components? - Is the model free from intersections between building components? - Are all predefined property sets from the excel “Circular Reuse ILS+” added? If one of these questions is answered with “No” add extra data or model further or adjust the model.

5.	Name all components	Give all building components a unique ComponentID. This identifier links the location of the component with the technical component data.
6.	Correct use of entities	Use the Entity as described in the "Circular Reuse ILS+" (ObjectType tab) for the object
7.	Export the BIM to an IFC	Check if all the previous steps are completed and all data of the "Circular Reuse ILS+" excel is added to the models. Then the BIM could be exported the BIM to an IFC. After exportation, place the IFC into the project folder.
8.	Add all certifications and calculations	Add a copy of the required certifications and calculations to the project folder. Make sure that the building components are identified with the ComponentID.
9.	Add all construction drawings	All drawings needed during construction should be stored in the project folder for decommissioning. Ensure that all connections around the building components are added and place these to the project folder
10.	Upload the project folder	Upload the whole project folder to a material platform to ensure that all data is accessible for a decommission stakeholder in the future.

Table 7: Steps for completion of Circular Reuse ILS+ (Source: Own table)

21.3. Circular Reuse ILS+ Excel

All the required data for reusing building components is structured in the excel "Circular Reuse ILS+" and could be used for projects which aim to reuse building components in following lifecycles. In the excel, required data requirements and exportation structured are defined for each object and thereby ensure that data is complete, structured, and uniform. A building engineer is thereby informed about the data requirements for exportation of a BIM in new circular AEC projects. The document becomes useful for the clients as well as the contractors and is based used for exportation to IFC.

The Reusable Component ILS consists of 4 tabs which all have a specific function. These tabs inform the modeler about the required data, correct naming, location, used entities, data typology, and correlated enumerates. The functioning and aim of the tabs are briefly highlighted in the following sections.

ObjectTypes

The tab ObjectTypes identify to which object typology should be exported to which entity. This is important to ensure that all data is stored in the correct place and complete. These characteristics are enough to inform the modeler to export the correct entities and use the correct name in all the files. Further, the modelling software recognises uniform names and can conduct analysis. The ObjectType tab shows a table with the correct names of the objects, the correlated IFC entity, predefined type, and a description of the object and the source of the description.

Since the aspect model and the main model both require different LOD, a lot of object types are included. A higher LOD means, overall, a high variety of building parts that are used. Therefore, this list is extensive. The list is based on the predefined standards of the NLRS. However, the allocation of entities is correct and could therefore be used in other software programmes too.

1. ObjectType: The name of the object in the BIM;
2. ifcEntityClass: The name of the entity that the object should be exported to;
3. PredefinedType: The predefined type is a further specification of the object occurrence;
4. Description: A description of the object occurrence;
5. Source of the description: The source of the object description.

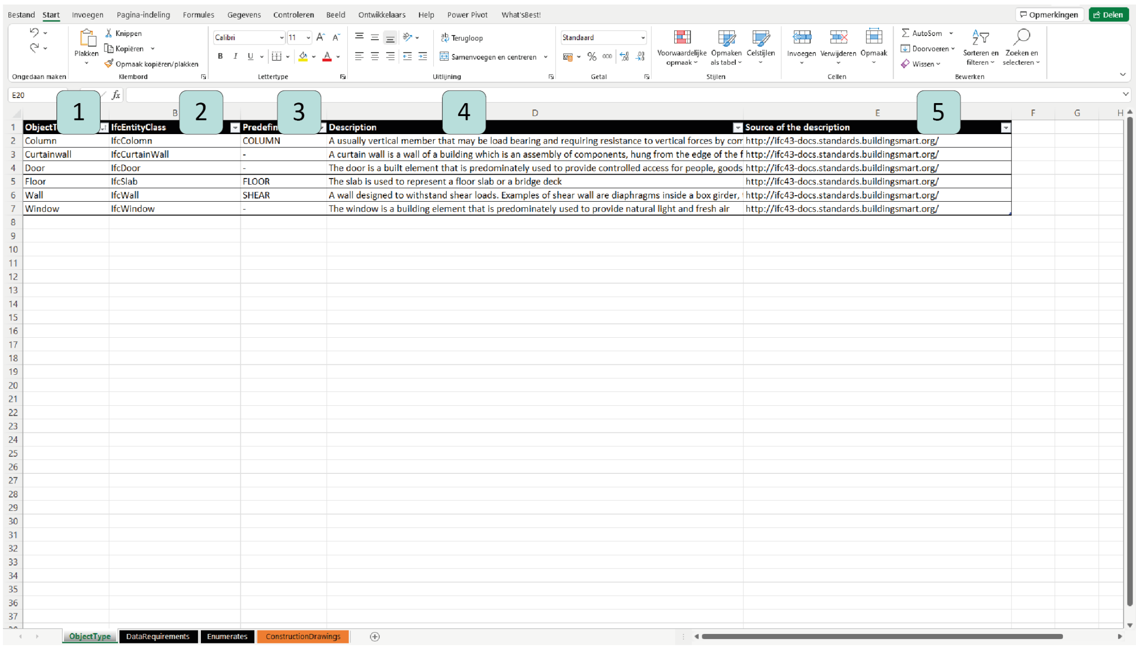

Figure 22: ObjectType tab in Circular Reuse ILS+ Excel (Source: Own Illustration)

DataRequirements

There is a lot of data that should be included to the components to enable decommission. All identified data requirements are presented in this tab and therefore this tab is the most important and detailed tab of the excel. This tab informs which properties should be included in the IFC to enable circular reuse. The used property sets are derived from the buildingSMART preformulated property sets and from other ILSs. These are used to minimize the number of new property sets and thereby increase the recognisability and uniformity of the data. However, these current property sets are not sufficient to describe all data, therefore a custom property set is created called "Pset_Circular_Reuse_ILS+".

1. ObjectTypes: The researched object types are presented here. When an X is in a cell the property should be added to the object properties;
2. PropertyType: This column informs to what property set the data should be exported.
3. Parameter: The parameter shows the name of the property. The name "parameter" is derived from other ILS standards;
4. Unit: the unit of the data;
5. DataType: The form of the data;
6. MainModel and AspectModel: These columns show in what model the data should be stored. An X in a cell means that the property should be included in the model;
7. Example: An example of the data in the IFC;
8. Description: A description of the property;
9. Source of the description: The source of the property description;
10. Explanatory note: A brief explanatory note why the property is needed for circular reuse;

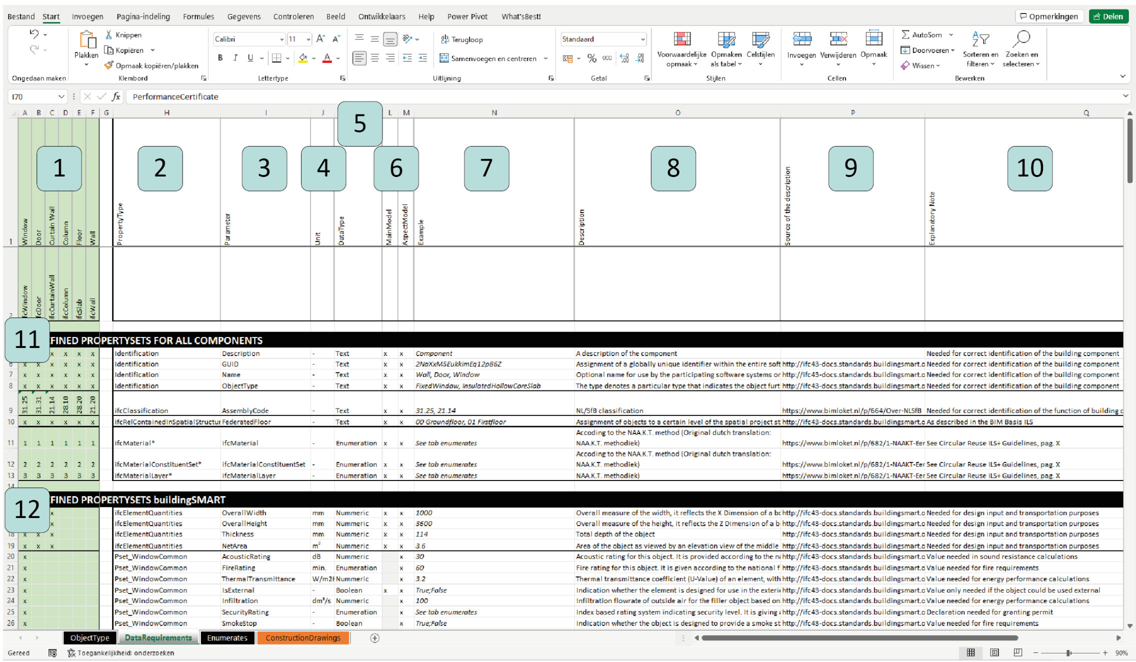

Figure 23: DataRequirements tab in Circular Reuse ILS+ Excel (Source: Own Illustration)

11. Predefined property sets for all components: Required standard property sets for all components;
12. Predefined property sets buildingSMART: Required buildingSMART property sets.

Materials of the objects should be added to the IFC too, this could be done with use of three different property sets. The use of the property set depends on the composition of the component. The ifcMaterial is used for homogeneous objects, this means that only a single material is used in the object. If a multitude of materials is used in the object, the ifcMaterialConstituentSet should be used. This could be used for a multitude of material and could be assigned to parts of a building component. The last option is the ifcMaterialLayerSet. In this entity different layers of one object could have a specified name and thickness. Important is that the NAA.K.T. method is used for naming the materials. This standardized naming structure ensures uniform and clear naming of materials. This simplifies recognisability and findability of the materials. A guide to implement the NAA.K.T. method could be found in chapter 8.

Enumerates

Some of the Parameters have an enumeration as datatype. This means that a value of a predefined list should be filled in for a specific property and ensures that organisations use the same data name in models. In this tab these parameters are presented, and the building modeler should use one of these enumerations during the naming of materials, fire rating and security rating. The names presented here are derived from the NAAK.T. method.

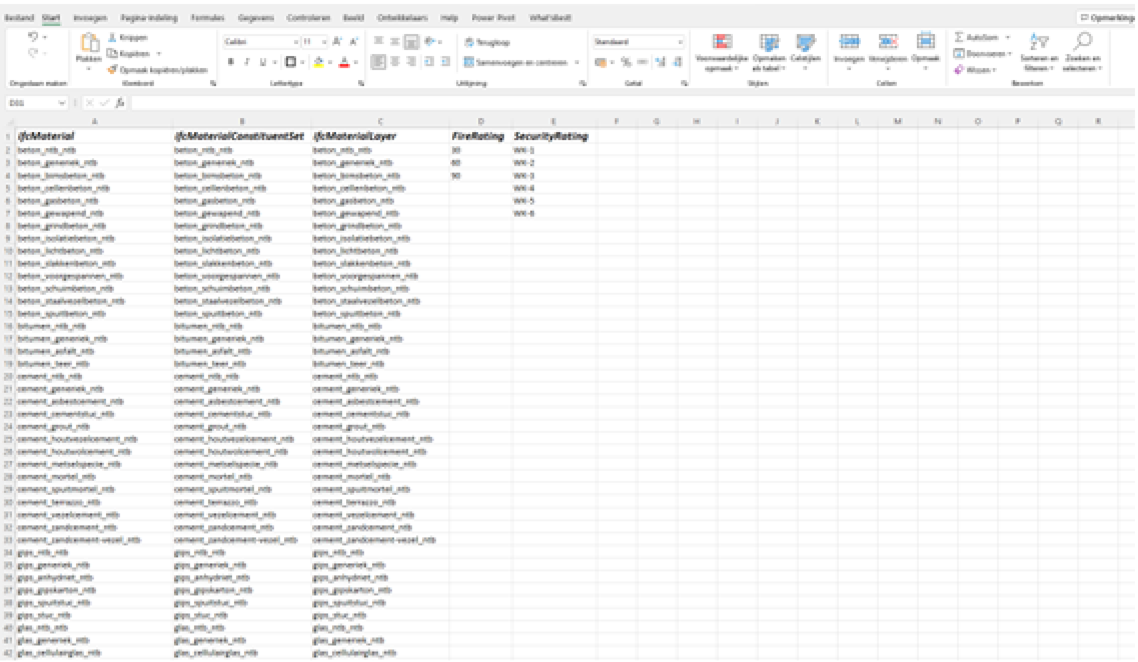

Figure 24: Enumerates tab in Circular Reuse ILS+ Excel (Source: Own Illustration)

ConstructionDrawings

This tab illustrates which drawings should be added to the project to deconstruct the asset. It is important that all drawings required for construction are also presented during the deconstruction phase. Therefore, they should be added to the project folder too. In the detail drawings it should be explicit how the joint could be decommissioned. This means that the mechanical fastener should be modelled. In case of a chemical fastener, a description or note should be explicit how the joint can be disassembled without damaging building parts.

21.4. Target Group

The target group of this ILS+ is very diverse. Many stakeholders could use this ILS+ during a project lifecycle. The following sections elaborate the target groups further.

Contracting party

The main users of this ILS+ are the contracting parties with clients with a circular aim. Every contracting party could use this ILS+ if they use BIM in any form during construction of their new assets. This means that the function of these organisations could very diverse, from BIM-modelers till modular contractors. The contracting parties are the main target group of this ILS+ because will spend the most time applying and checking their model with the provided documents and will thereby add the most value in their processes and structures.

The required data in this ILS+ could be completed in the later stages of the project process since most of the required data is generated during the definitive design and construction design phases. In the initial stages, the ILS+ could be used as guideline during the construction to a definitive product. This makes it easy and clear what data should be delivered and at which place it should be stored. Thereby the contracting party can check any time if the deliverables meet the requirements and thereby the specification of the client. The researched objects are formulated clearly, however, a building consist of more that these components and is therefore not directly complete for an overall circular reuse of an asset. Furthermore, the client could add their own requirements on top of this ILS+ and thereby the data could not be complete after applying this ILS+.

This ILS could further be used by contracting parties that are willing to change their linear business model into a circular business model. Thereby the contracting party could use this ILS+ and required documents to structure their data and check if their data supply is complete for redeployment. Thereby the ILS+ could provide a useful starting point of their analysis.

Clients

These guidelines provide circular oriented clients to define their data requirements of their digital model in new constructed assets. By using this ILS+ the client is ensured that the data is complete, structured, uniform, and succinct. Every circular oriented client could ask contracting parties with BIM processes and modelling to implement the data requirements of this ILS+ in their models.

The provided structure enables clients to check if all data is complete, uniform, and structured and could be added to the BIM protocol in the beginning of a project lifecycle. During its lifecycle the client could check if all data is generated and definitive. How the checking process is implemented in the project is not included in the ILS+ and should be added to BIM execution plan. Furthermore, the client could add their own additional data requirements to this plan if they need more properties of an asset. Furthermore, the circular value of their asset increases, which could lead to a financially higher asset value in the future.

Future decommissioners

The data added to the digital models will help the decommissioning party significantly. The data will reduce the overall insecurities of the building composition and thereby reduce risk, increase the redeployment value, reduce lead times, and enable better pricing. Thereby, reusing the components is much easier and attractive since processes and data is available, clearer, and structured. By implementing this ILS+, decommissioning becomes more structured and the released building parts could be analysed for new reuse possibilities.

22. APPLICATION OF THE ILS+

In this chapter a brief explanation is given how the data is structured after applying the ILS+ to a model. This shows that required data from the Circular Reuse ILS+ could be stored in the BIM and could be exported to an IFC file. A small model is constructed to illustrate how this ILS+ structures the main IFC model and the aspect model correlated. The BIM is constructed in the software programme Revit. The modulations in Revit could also be executed by other BIM software.

22.1. Main model

As described in the "Circular Reuse ILS+" and the correlated "Circular Reuse ILS+ Guidelines" the main model is a more graphical presentation of the constructed asset. In this case a custom asset is constructed which consists of two construction walls, a floor, and a column.

After the BIM is modelled correctly, the data required of the ILS+ could be added. In figure 25 a screenshot of the "Circular Reuse ILS+" presented with the required data in a main model. The figure shows property types related to, mainly, identification and geometrical characteristics of objects. The Furthermore, the model requires a minimal LOD of 200. Thereby higher LODs are also sufficient but not required.

The properties defined in the "Circular Reuse ILS+" are completed in the Revit model and then exported to the IFC file. In figure 26 the used main model is visualized. The two screenshots show the the model in the NME, the Revit, and an IFC viewer. Thereby the geometry of both models is the the

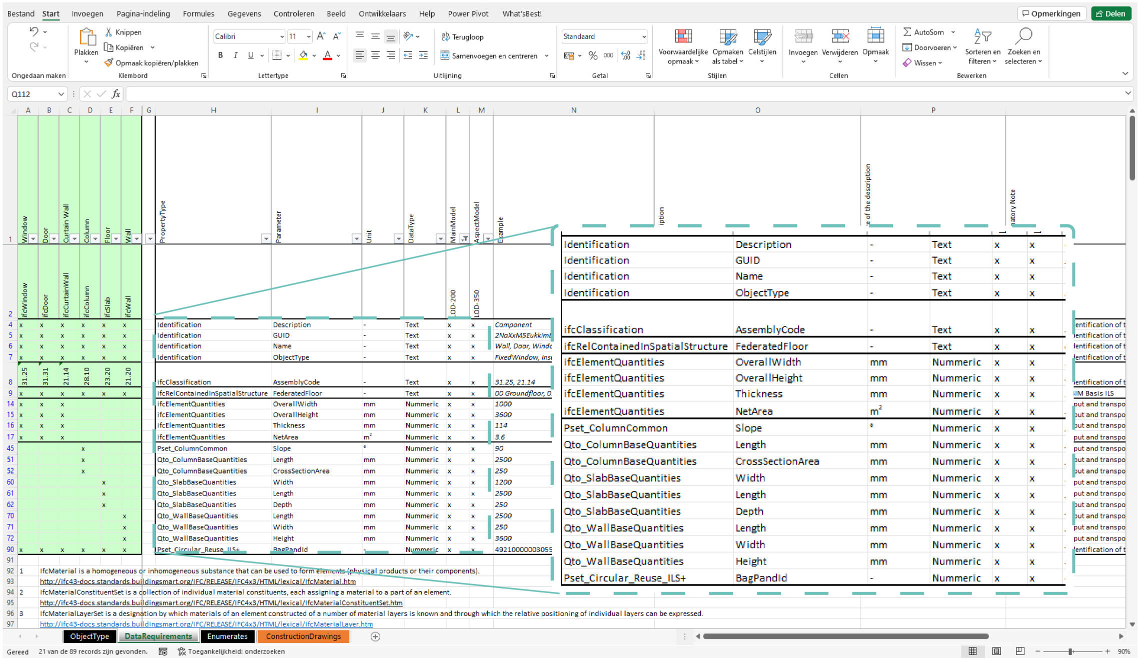

Figure 25: Requirements of the main IFC model (Source: Own illustration)

same. Also, the floor names are correctly transferred in the IFC file.

In the IFC file the grid is exported too. This is done to find the building components easier. In this relatively small model, it is not a problem to find the aspect models. However, in bigger models this could be helpful. It is not needed but could be useful for engineers unfamiliar with the building.

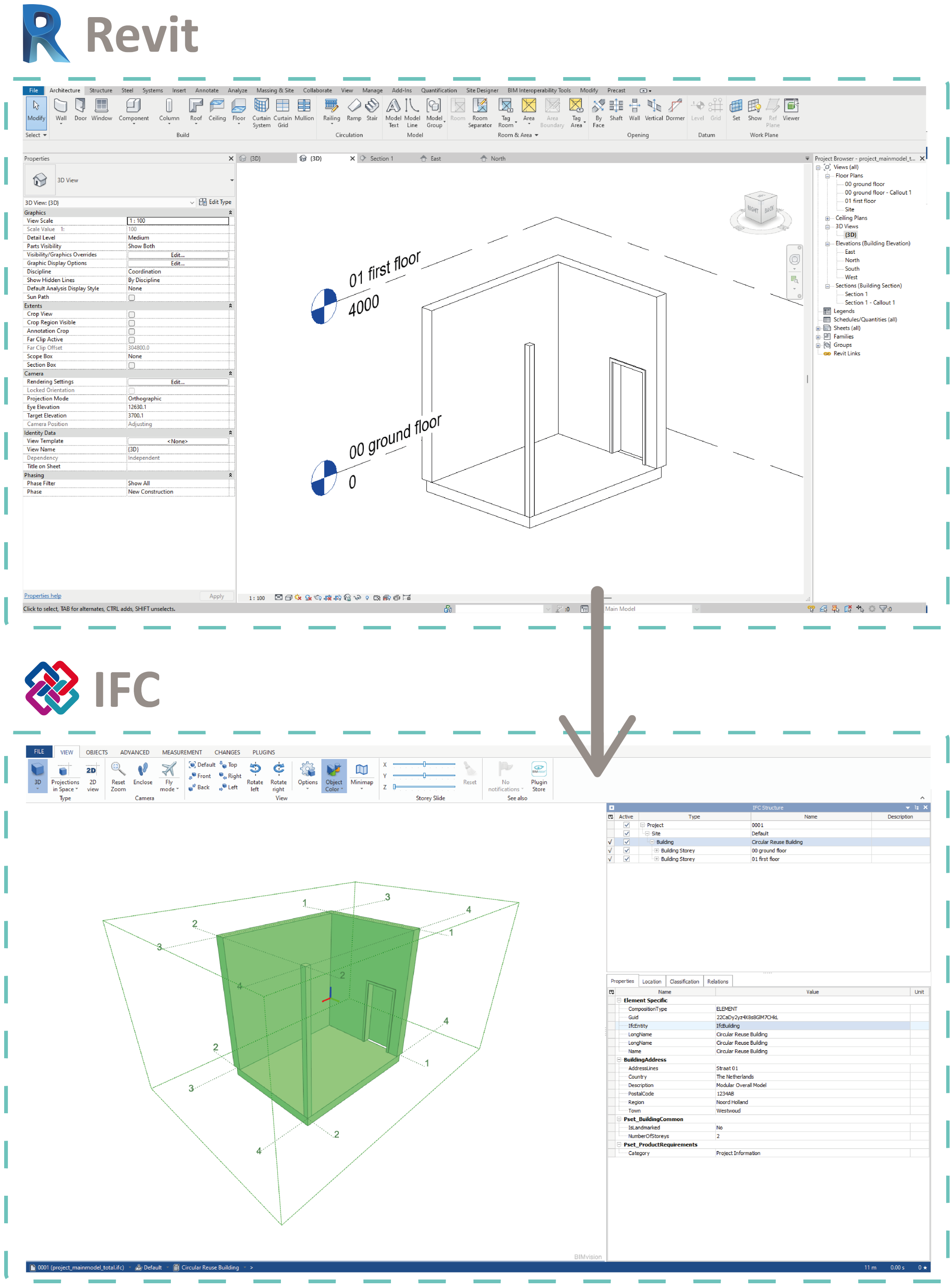

Figure 26: Comparison main model Revit and IFC (Source: Own illustration)

Other important properties that should be filled in were the identification of the objects. These could be filled in the project information in Revit. In the IFC these properties could be found in two layers: project properties and building properties. The location of these properties is nicely structured and correspond with the structure of an ILS. Thereby the location of the properties is correct and complete. All requirements stated in the "Circular Reuse ILS+" are now stored in the IFC.

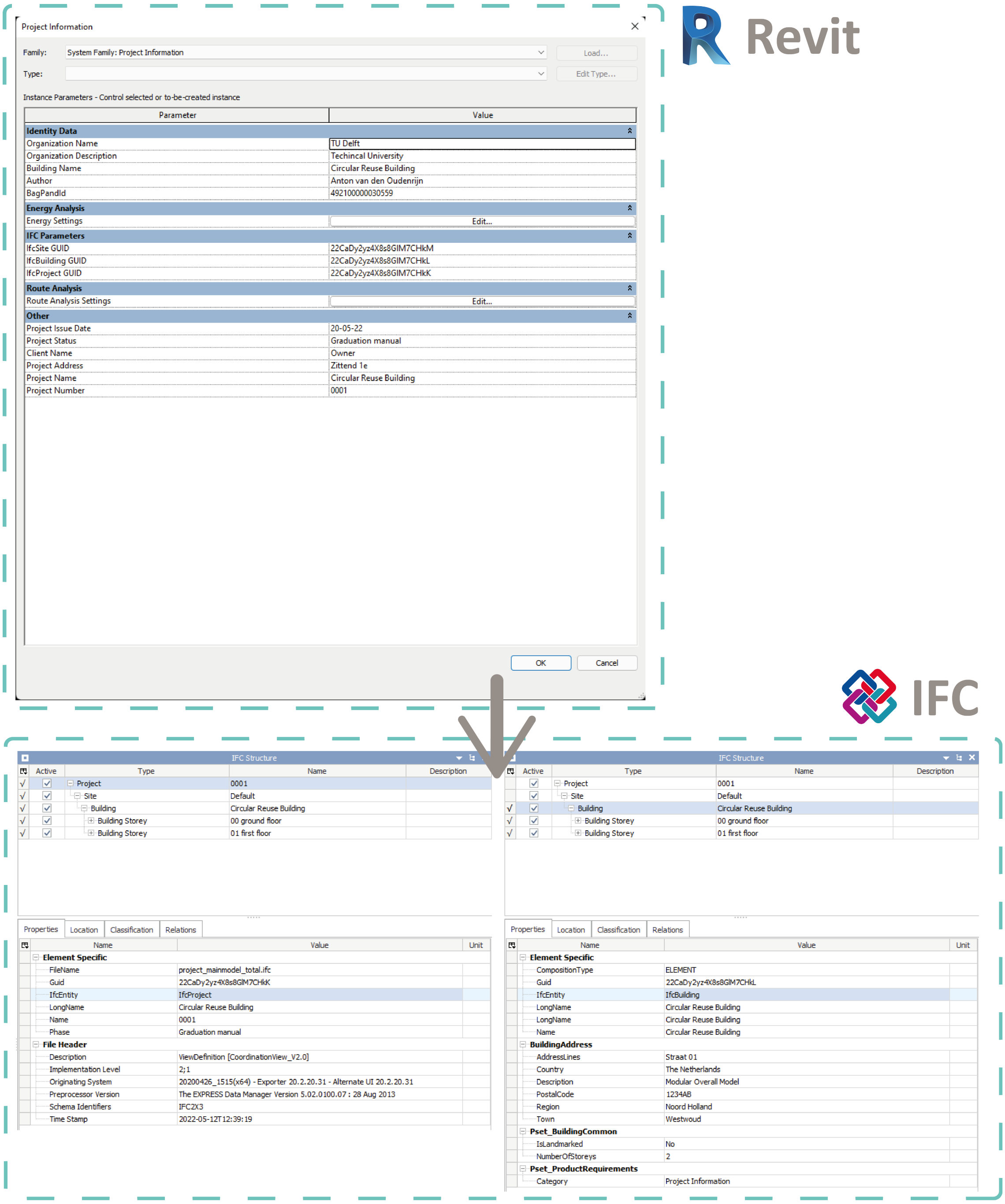

Figure 27: Comparison main model Revit and IFC (Source: Own illustration)

22.2. Aspect model

Other data is required from the aspect model. First, the LOD of such model is much higher compared to the main model because this model could be used for analysis during decommissioning and analysis in future redeployment. In this example a commissionable wall is chosen to show that all data could be added.

The construction of the aspect model consists of the same steps as the main IFC. Thereby the model should be structured and named correctly, as described on page 12 of the “Circular Reuse ILS+ Guidelines”. In the aspect model other properties should be added to complete the model. In figure 28 the properties are added to complete the wall component. Most of these properties are derived from the the buildingSMART documentation and should therefore be carefully copied to store them in the correct location.

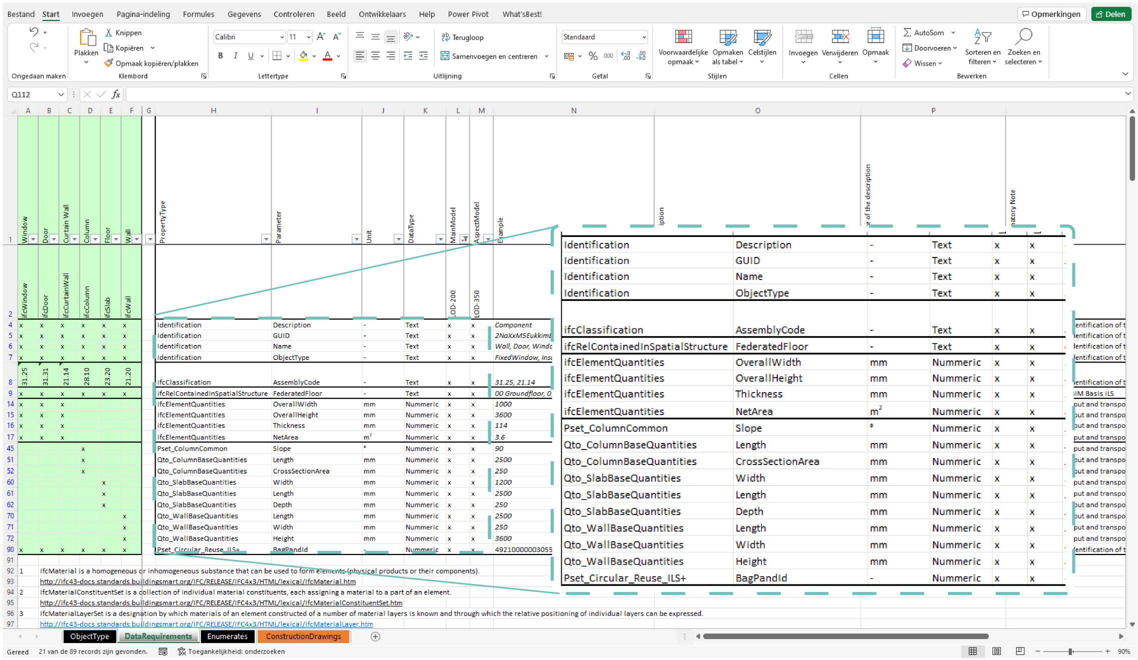

Figure 28: Requirements of the main IFC model (Source: Own illustration)

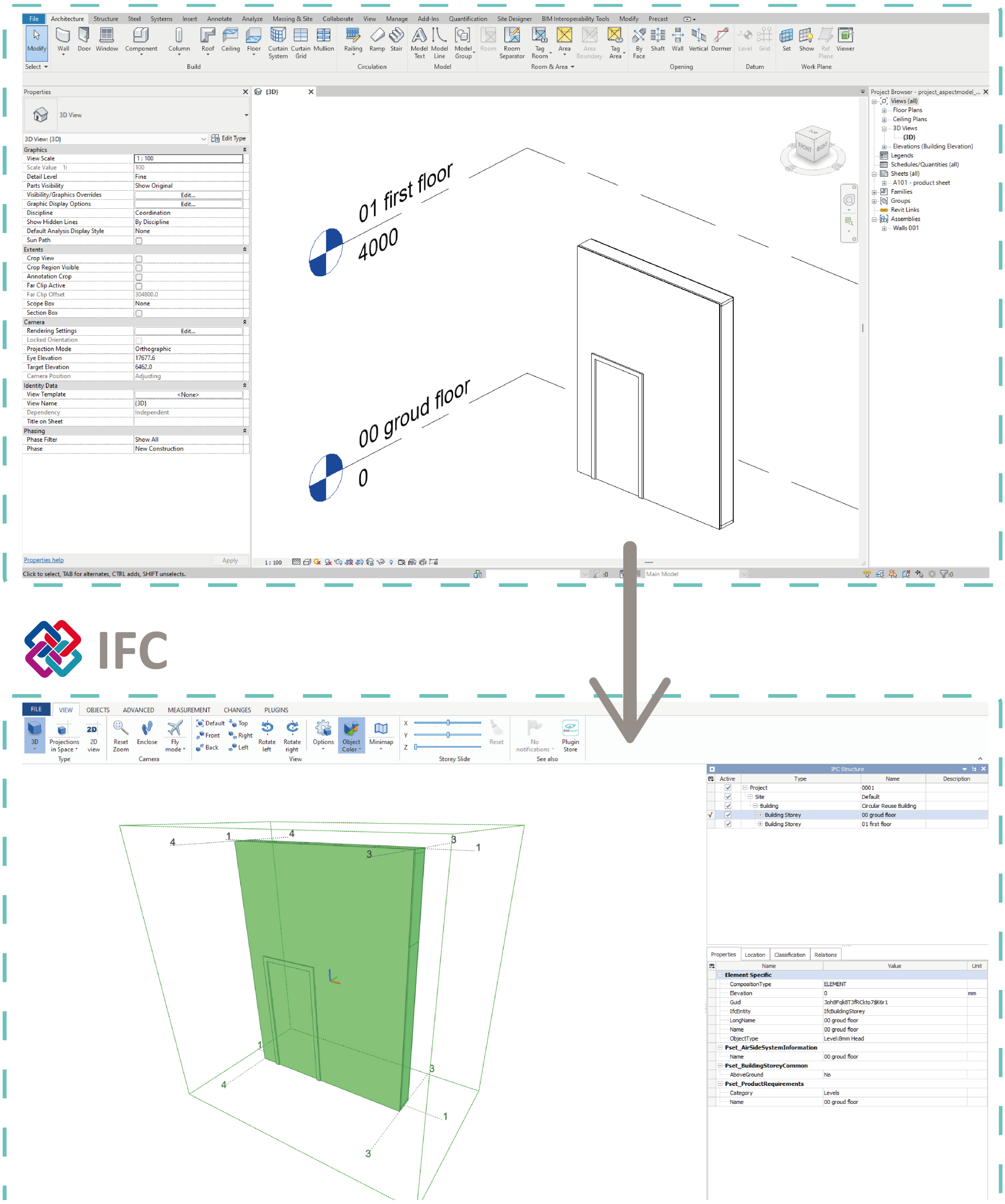

Figure 29: Comparison Aspect model Revit and IFC (Source: Own illustration)

Figure 29 demonstrates the aspect model in the NME and in a IFC viewer. In this model the same geometry is exported. Furthermore, the IFC is structured with the correct layers and names.

Figure 30 illustrates that the BIM component properties are copied into the IFC. To allocate the properties to the whole wall instead of the lower agglomeration levels, an assembly should be made. This groups the elements and thereby the properties could be added to all the elements.

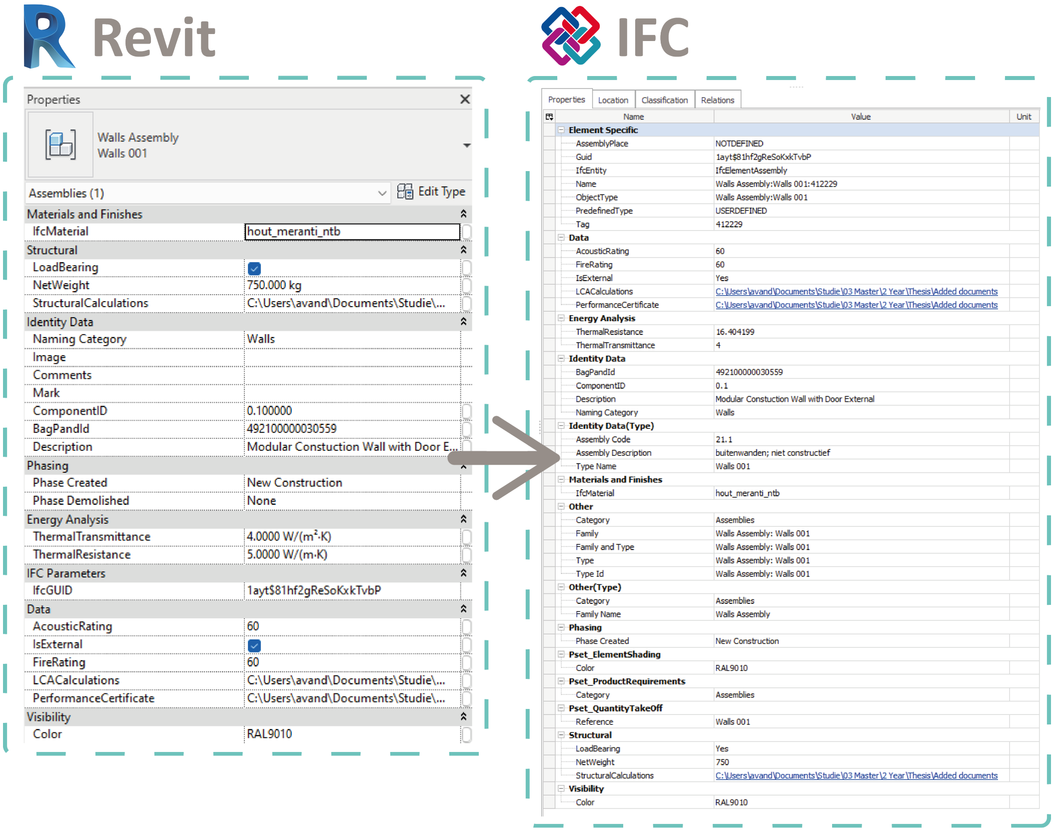

Figure 30: Wall properties in Revit and IFC (Source Own Illustration)

In figure 31 the properties of the door positioned in the wall is shown. Also, here the properties required by the "Circular Reuse ILS+" are completed.

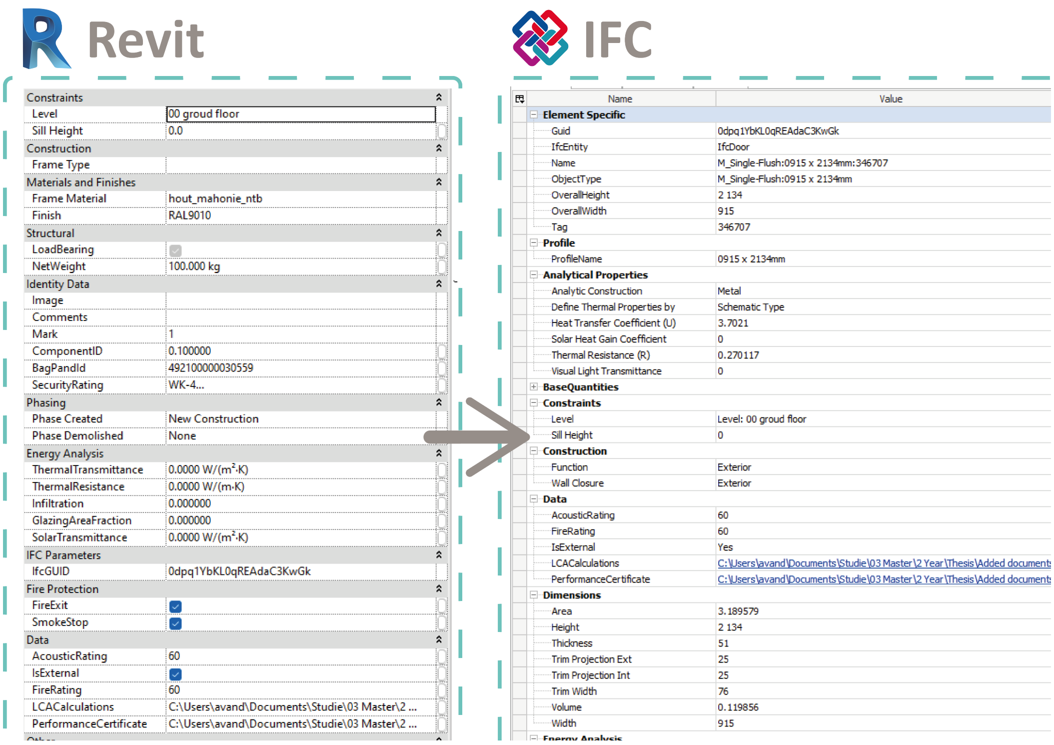

Figure 31: Door properties in Revit and IFC (Source Own Illustration)

22.3. Additional documents

As mentioned in the “Circular Reuse ILS+ Guidelines” complete IFC models does not directly mean that the building components could be reused. In the Revit and the IFC the location of these documents is added. In this case a local location is found to store the data. The location should be accessible for external stakeholders too, otherwise the documents could not be used by decommissioners and redeployees of the future.

Wall Closure	Exterior	
Data		
AcousticRating	60	
FireRating	60	
IsExternal	Yes	
LCACalculations	C:\Users\avand\Documents\Studie\03 Master\2 Year\Thesis\Added documents	
PerformanceCertificate	C:\Users\avand\Documents\Studie\03 Master\2 Year\Thesis\Added documents	
Dimensions		
Area	3.189579	m2
Height	2 134	mm
Thickness	51	mm
Trim Projection Ext	25	mm

Figure 32: Location of additional documents (Source: Own Illustration)

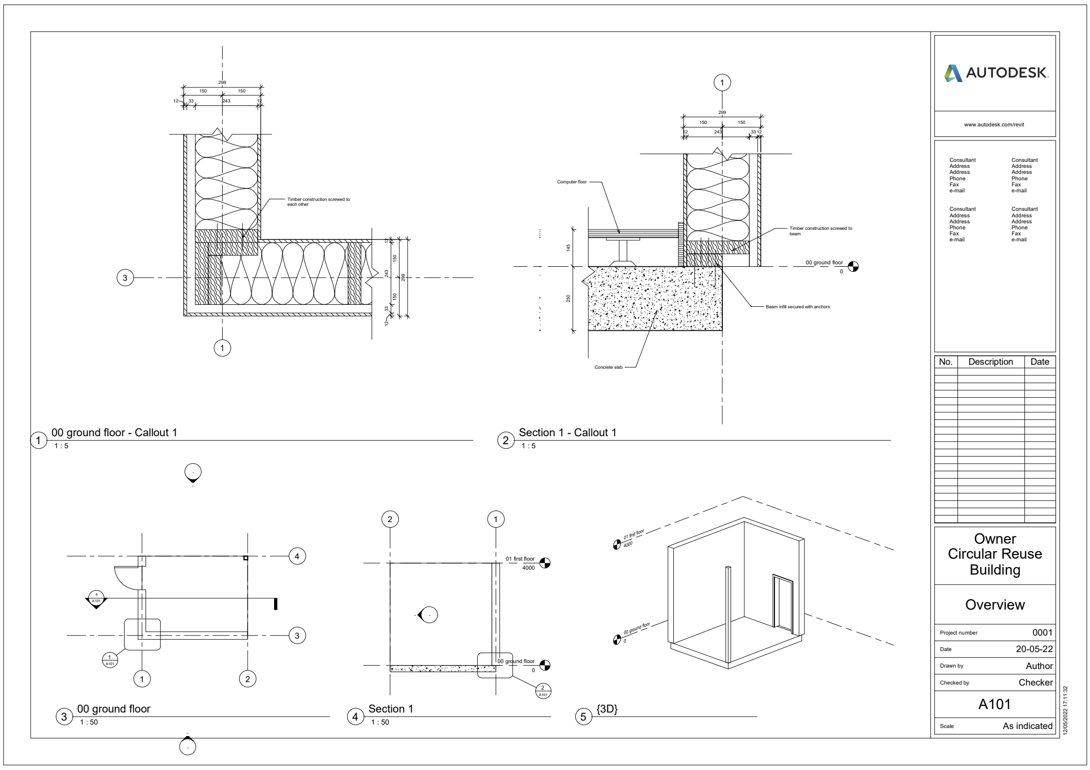

Figure 33: Location of additional documents (Source: Own Illustration)

Furthermore, the documents should be complemented with detailing and construction drawings. This ensures that the decommission sequence is clear and the techniques could be recognized. In figure 33 the details are illustrated together with sections and a 3D view.

23. VALIDATION OF THE ILS+

In the coming sections the implementation of the ILS+ is discussed. This data was derived from two interviews: one with a circular decommissioner and with a BIM-modeler. The goal of these interviews was to identify: how the ILS+ would influence their processes and organisation? if the ILS+ is complete? and if they can use these documents and structure in their organisation? The interview with BIM-modeler focusses mainly on the construction of the circular reuse BIM, whereas the circular decommissioner focussed mainly on the utility of the data retrieved from the ILS+.

23.1. User group

The user group of this ILS+ is very diverse. The circular decommissioner mentions the following: "I would say that every building organisation can use this ILS, whether it is a construction company, or a developer, or a housing association, or an investor, it really shouldn't make much difference" The list of potential users is from the client as well as the contracting side of the market. The BIM modeler mentions that is ILS+ is mainly focused on the contracting parties by stating: "You do this [using the ILS+] for the contractors' side and perhaps even on the developers' side, because ultimately these are the parties who are going to manage real estate and sell the products back on the market." Thereby the BIM modeler states that the developer of the building components, and thereby seller, profits the most by implementing this ILS+. The developer could profit in the future by selling the building parts, because that organisation is the owner of the components. Contrastingly, the circular decommissioner recognizes the owner of the asset as someone who profits by saying: "And for clients as well, but they will start using it if they have a circular business model, because then they also benefit from storing the data" By implementing the circular business model the client sells the building parts to other parties and thereby could make a financial profit.

Both interviewees recognize that the selling party would profit significantly of storing this data, because the building components could be sold in the future. However, who the owner of the data and building parts is, remains unknown after the interviews.

23.2. Demand of the market

Both respondents recognize that the current demand of the market is rather low, but it will grow in the future. Circular decommissioner mentions that: "The current demand will, I think, still be relatively low" The BIM-modeller further highlights this by saying: "Well, I don't think there is a huge demand for it [the ILS+] currently" Later the modeller added to this: "I definitely think there is a need, especially since circularity is obviously going to become more of a topic in coming years" The BIM modelers does not recognize a demand but a need. This implies that the modeler is not willing to implement this itself and that a demand should be created. The circular decommissioner's view aligns with the increasing future demand: "Well, I think that this demand is only going to increase or will increase" And sees why the current demand is rather low: "due to the fact that not all companies are working on this theme [circularity] yet, or that their current business model is still linear" The circular decommissioner states that more should be changed than only the data availability and that the market is currently not ready for such standards. However, both respondents acknowledge that this ILS+ will provide value in the future.

23.3. Influence in modelling process

Key in the implementation of this ILS+ is that the guidelines are complete and elaborated enough to enable adaptation of the market. The BIM-modeller states: "Yes, if it [the data] is complete, then we [the BIM modelers] can work with this. No, I would never do it on my own. That question must, of course, come from the client" Thereby the guidelines could be used in practice by the constructors of the BIM itself. The modeler mentions that the implementation of the ILS+ in their workflow will not be done voluntarily, due to more work and longer processes, this is highlighted further later in this chapter. The modeller adds: "In the end, of course, there is a kind of proliferation of new ILSs such as the ILS O&E, AEDES, to name but a few. I think that this could also be conceivable, for example, as a kind of extra module to be added to the ILS O&E" For smoother processes and more clear data requirement specifications this ILS+ could be merged with other data specifications on the market. A lot of the properties asked in the ILS+ could be recognized from other ILSs and could be merged in the future.

Important for good implementation of the ILS+ is to create a mechanism or rule set that checks if the data is complete and correct. According to the BIM modeler states the following: "If we are going to use this. The first thing I would do is make a ruleset with which you can check if all the data is in the model [..] this makes it easier and more fun to work, since your data is checked" A ruleset could be used to check if the data is available and aligned with each other. Contrasting and missing data is highlighted by the programme and mistakes could be managed by the BIM modeler. This is not the only structure that could be used according to the modeler: "You can also upload models, for example, a certain platform and then use, for example, FME [Feature Manipulation Engine] to check whether you are asking is included" FME is a data integration platform that enables to connect, check, and transform data of various structures and organisations. This platform could also be used to check if the data is complete and correct. By implementing such model the process becomes more structured and less complex, because the modelers can easily check their progress and completeness of the model.

Another interesting note is that modelling becomes more complex. This is expressed by the following quote: “My experience is that as soon as you start adding a lot of data in models. It becomes really complicated to keep working consistently” During the interview an example was given about copying walls. By copying a wall, the data of the wall is copied too. Then the wall is pasted into another part of a BIM or a different BIM. This should mean that the, for example, address should change and be updated. Rulesets could help with checking this data but changing it is still manual work. Furthermore, what if building objects are modelled in smaller building parts? For example, a window frame is modelled in of jambs and a still, and separate glass plane, instead of one single object. In that case, the required data could not be connected to this object, since it is impossible to connect, for instance, a burglary resistance class to a still. This means that the window should be remodelled into one object to link the correct properties to it. This could lead to a lot of extra work for the modelling parties.

Phase of use

The BIM modeler mentioned: “What is the appropriate stage for execution? That is the definitive design or contractor design, I think. Only contactor design is more often a hotchpotch of supplier aspect models. But then again, that’s the phase when the final data is generated […] I think contractor design and at the very end of that” Most of the data required by the ILS+ is finalized later in the design process. The data could vary during the whole design phase and thereby be useless if recoded earlier. However, the creation of certain aspects, such as the location or Rc-values, will not change after the building permit is awarded and could be stored earlier.

Separate model

During the interview the BIM modeler was doubted if the BIM for the construction phase was sufficient to be transformed into a decommissioning BIM. The following argument was given: “We are now going to focus on what the model is meant for. Well, it turns out that we are going to build it and afterwards you look at whether the model is adequate for, well, disassembly. […] But the same thing happens in the use phase: those maintenance models are so far apart in terms of data and level of detail. They say [the clients], well, you know, just go ahead, and build it [for construction]. And later we make a new one [BIM] for maintenance” This means that the data of the construction BIM should be stored for implementing the ILS+. Thereby whole new models are constructed specified for disassembly and the same process is started as in the maintenance phase. According to the modeler, the transformation of a construction model to a disassembly model could only be checked after a case study. Giving an estimation if the construction model could be used as disassembly model was hard without ever implemented the ILS+.

Pricing

The ILS+ creates a digital model with new property sets and thereby a price. Both respondents mentioned that the investment of storing this data is significant. This is expressed by the BIM modeler: “My first reaction when I saw that was: hey, we’re not going to do that! And: Hey that’s expensive!”

This is due to the high required LOD and the extensive property list, the BIM modeler said further: “A lot of parties first look at the LOD level, because there is a kind of sliding scale price attached to it. And is then linked to a price […] Oh, these are a lot of properties too, so then it becomes even more expensive” This means that the modelling and adding this data will be linked to a relative high price tag. The circular decommissioner highlights this too and recognises a problem: “This product delivers data that all have to be filled in, that costs time and therefore money. But if he himself does not benefit from it, he will not do it in practice” The decommissioner mentioned that the one collecting and storing the data should benefit from storing the data. However, it is not defined what type of benefits the modelling party should have.

Use of data

When the data derived from the ILS+ is used is clear for the BIM modeler: “for disassembly eventually” Further the modeler stated: “That [an asset] will soon be empty and uploading the building parts on a second-hand store, so to speak” The data derived from the ILS+ could be used to create a cash flow in the future by selling the building components for reuse. Thereby the modeler acknowledges that the data derived from implementing the ILS+ is valuable for reusing the building components.

The circular decommissioner mentioned that the data from the ILS+ could be very valuable for them by explaining: “We start by identifying; Which things are in the building? And what can we do with it? And the moment we cannot reuse it, the question is: what is in it? In terms of materials, this is less important, because then we just want to know, for a column, what the dimensions of that column are in order to determine whether we can reuse it. The same applies to a floor. And if we cannot reuse it, we want to know how much concrete is in that column. To know how many tonnes of concrete are we harvesting from a building? So, I think that the ILS+ could potentially be very valuable to us” The analysis of the components could be done off site which results in shorter start-up phase and less risk. This is highlighted by the following argument of the circular decommissioner: “We start with a much larger amount of information and data and that would save us a lot of time. It would save us a lot of time and give us a much better insight into the quantities of a property and how we could reuse parts, so that would be a great profit for us. Another benefit is less risk. Being able to form better prices in offers, you name it”

Building components check in practice

Circular decommissioner mentioned that the ILS+ reduces the overall work but stated that not all work is shortened: “To judge whether we can still do something with an object depends very much on the knowledge and expertise of our people who make an inventory of the building on site, because you can never determine from office or from a drawing. Whether that door, or that window, or that floor is still in good condition is something you will always have to see on location” The data in the ILS+ does not ensure directly that the components are maintained well and thereby physical inspection will always be needed in the future. Keeping the data up to date faces the same problems. That the data is available will not mean that the data is maintained well over the years

Project complexity

The size of the project could be defined as the number of parameters that should be met to complete the project (Vidal & Marle, 2008). Implementing this ILS+ will increase the size of the project since, more deliverables are needed, bigger initial investments, and more objectives that should be realized.

All the demountable components should have a separated LCA, structural calculations and aspect model to provide insight in the reuse options in ensuing lifecycles. This causes a lot of extra manual work during the construction of the models and calculations, since this data is only needed during decommissioning and reapplication. Thereby the initial design stages become more time consuming and costly and is thereby initially unattractive for clients and modelers. The project processes become more complex by more deliverables, higher investments, and more requirements to deliverables.

Furthermore, modelling processes become too since this becomes more difficult to copy and paste of a building component. This is caused by data changes. For example, by copying a wall to a neighbour, the location and address changes without the data recognizing it. Thereby, the data should be checked of all the asked building components. This could be done by rulesets or a platform, but manual checking will always be needed.

23.4. Responsibilities after delivery of the digital models

The data of the ILS+ should be maintained as well. This is highlighted by the circular decommissioner by saying: ‘And what is clearly the most important challenge: how do you ensure that data remains up-to-date and available?” However, the interviewees do not agree with each other about the responsibilities and how this should be managed. The circular decommissioner was very clear by stating: “I think that during the lifetime of the building, the building owner is responsible for it” The BIM modeler said: “I do not really have the answer to that yet” The main issue with this is that there are various mutations that could happen to a building, by, for instance, a change of data and a change in geometry. According to the BIM modeler, the following question should be answered first: “What is a mutation?” Because it is unknown what and how much should be changed in the model and how this could influence future processes of stakeholders. Thereafter, someone could be held responsible for maintaining the digital model, data, and other documents.

23.5. ILS+ process and current work processes summarized

These findings are visualized in more detail in figure 34 and table 7. These diagrams show the differences in data requirements of the researched structures and are validated during the validation interviews. In the coming figures of this paragraph the components walls, floors, and columns are discussed and not the whole building.

Design phases

In figure 34 the development of the different BIMs is illustrated. This figure shows that both the linear and the ILS+ structure start with a rather generic model that still needs a lot of development during the initial design stages. Modular contractors, however, are starting with much higher LOD and develop thereby earlier a much more detailed BIM. During the preliminary and definitive design extra data is added to the models of the linear organisations and the ILS+ structure. After the design phases every structure constructed an LOD-350 BIM. Another interesting note is that the modular organisations also have linked maintenance data to their model. Thereby the data of the modular organisations is the most elaborated compared to the other two structures.

Construction phase

During the construction phases the LOD of all the researched processes remains equal. Thereby the models in this stage store enough data to construct the building. However, table 7 shows that in the construction phase data for permit application is not included anymore, because this reduces the overall files size and simplifies the model. Linear organisations could apply this because this data is obsolete after this phase. Thereby manufactures do not include this data in their aspect models. The other two data structures do include this data, because this could be useful in later stages of the project lifecycle. Further, the linear organisations and the ILS+ structure do not cover maintenance data in their dataset. Thereby the data sets provided could not

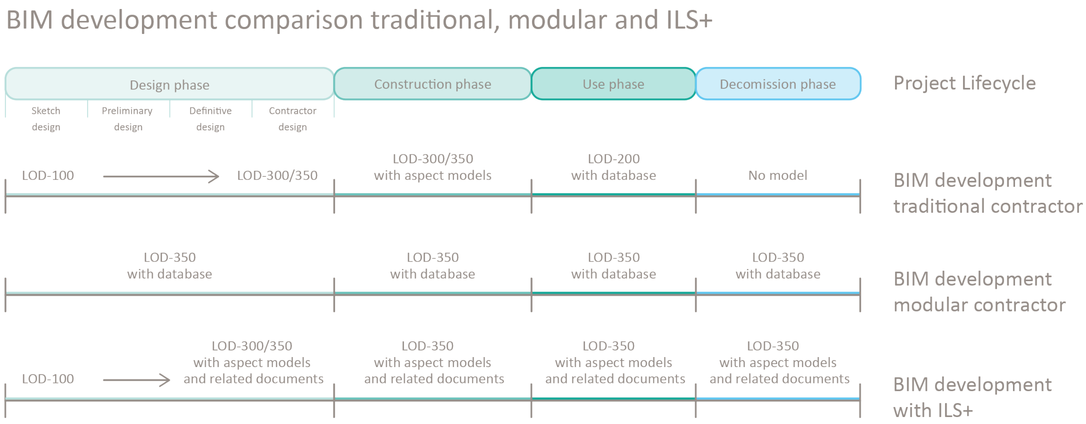

Figure 34: Location of additional documents (Source: Own Illustration)

be used for maintenance purposes.

Use phase

During the use phase the biggest changes differences between the linear organisations and the other structures is identified. The construction BIM used in the previous phase is not used anymore during maintenance activities of the linear organisations, because this data is become obsolete in their coming processes. Thereby a new BIM is constructed with LOD-200, linked to a database with maintenance data. Contrastingly, the ILS+ and the modular process do store all data of previous phases. Thereby there is a lot more knowledge available by the modular organisations and after the ILS+ application in the use phase about the construction of the asset. A drawback of this knowledge level is that both structures require much more data storage compared to the linear structure. The 2D construction drawings, data for permit application, and data for construction stored by the ILS+ and modular structure has no function during this phase. And, in the case of the ILS+, this data could be stored for several years without having a particular use, apart from renovations.

The difference between the modular structure and the ILS+ process is that the data of the modular builders does not need maintenance because the use phase is most of the time shorter than 15 years. Thereby big renovations or big maintenance is not needed before the building is disassembled. The ILS+ structure, on the other hand, does require data maintenance since renovations and maintenance activities require more impactful changes in the building, and could thereby influence processes in the coming phases.

Decommission phase

During the decommission phase there is no specially designed BIM available the linear processes. The maintenance BIM could be used by the decommissioner but contains too limited data and geometry to disassemble the building, especially when it is compared to the modular and ILS+ process. The data stored by the ILS+ and the modular organisations is sufficient to decommission the building without losing the intrinsic material value of the building components. Thereby the materials could be reused in future lifecycles. The decommissioner does not exactly know what is in the building after the lifecycle in the linear process.

As mentioned before, storing the linear construction models into a material passport does not ensure that the building components, or other parts, are suitable for reuse. The cause of this could be missing data, undefined fasteners, missing certifications, and missing calculations. However, it gives decommissioners a better understanding of the construction of the building, it does not help with redeploying building parts.

	Overall building LOD	*2D details available*	*Data for permit application*	*Data for construction*	*Data for maintenanc*
Desgin phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	LOD 100 - LOD 350	Yes	Yes	Yes	Yes
ILS+	LOD 350	Yes	Yes	Yes	No
Construction phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	LOD 350	Yes	No	Yes	No
ILS+	LOD 350	Yes	Yes	Yes	Yes
Maintenance phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	LOD 200	No	No	No	Yes
ILS+	LOD 350	Yes	Yes	Yes	Yes
Decommission phase					
Modular organisation	LOD 350	Yes	Yes	Yes	Yes
Linear organisation	N/A	N/A	N/A	N/A	N/A
ILS+	LOD 350	Yes	Yes	Yes	Yes

Table 8: Comparison ILS+, linear and modular construction data requirements (Source: Own table)

Part 6
Conclusion and discussion

In this chapter the conclusion and discussion of this report is presented. This chapter focuses on answering and elaborating the research questions stated in the first part. In the conclusion the answers to these questions will be given and elaborated. The discussion chapter will reflect on the result in more detail and provide recommendations.

24. CONCLUSION

The presented report aimed to identify the data requirements of a BIM for circular component reuse. The current need for circularity is growing and digital models could help with the analysing and decommissioning the building components. However, the current data requirements of such models and building components were not constructed which resulted in inconsequent and incomplete data storage. In this report, research is presented that aimed to identify the data requirements of component reuse and analysed influences of the availability of that data to the construction process of a BIM. To find an answer to this problem, linear and modular organisation typologies are interviewed and analysed to identify their BIM developments and data requirements. To structure this research four sub-questions are formulated, which will be briefly described before answering the main research question.

Sub- research question 1: What are the capabilities of the IFC scheme?

The IFC is a standardized open data format that could be used by almost every BIM software programme to store data over a longer period and exchange data between stakeholders of a project. Thereby the format is one of the most used and flexible data formats in the built environment. The data from a BIM should be exported to IFC file and thereby the BIM determines the data quality of the IFC. Interviews and mapping the existing IFC 4.3 highlighted the flexibility and the complexness of the scheme but also the completeness. An IFC could contain almost all type of properties. However, documents and mechanisms behind calculations are an exception, here a reference should be made to access the data.

Once the BIM is exported to an IFC, the objects are stored in the entities of the IFC scheme. The IFC scheme is an agglomeration of entities which could all contain specific types of data. Thereby it becomes crucial that the correct entities are chosen to export the BIM objects to. Choosing the correct entities was highlighted by every IFC and BIM expert interviewed during this thesis. Wrong exportation could lead to missing data in the final IFC and thereby data could still be missing for circular reuse of building components. Exportation to an IFC is not difficult but should be guided correctly to ensure that the data from the BIM is secured in the IFC.

Sub- research question 2: What data saves a linear building organisation about their new constructed assets during the phases of a project, and why?'

The data required in a digital model of a linear building organisation is not consistent. Every phase in a project the required data changes because the data has fulfilled a certain purpose. The interviews conducted during this thesis show that data is removed and added in every phase to keep the digital models as compact and manageable as possible. Data of, for instance, type of ventilation grills and burglary resistance classes are very relevant during permit applications and construction designs. However, become useless during the use phase. Every phase has thereby one or more digital models to complete the requirements of that specific phase. The models constructed in earlier phases form the starting points of the models in later phases, but the data behind the models is often omitted. The requirements of every phase are stated by permit applications or requirements of clients.

The requirements set by clients are inconsequent too. Clients use different ILSs added with their own data to specify the capabilities of their BIMs. This makes the digital models in every project differed in terms of LOD and added additional data behind every object. The aim of the model is to provide the user of the BIM advantages during the processes in the undertaken phase. Users of BIM are very diverse and thereby the data in the BIM is very diverse. If data is not asked by the client, it is not added to the BIM. Furthermore, clients often prescribe the BIM basis ILS as data specification, but the clients do not know what data is then added to their model. Furthermore, the BIM basis ILS does not prescribe required properties of an object. This highlights the lack of knowledge of clients of BIM data requirements. An ILS used by a linear organisation defines characteristics based on objects such as a wall of a floor. Thereby the characteristics of the linear construction models relates to the system level described by Durmisevic (2019).

Sub- research question 3: What data saves a modular building organisation about their new constructed assets during the phases of a project, and why?

The data required in a digital model of a modular building organisation is consistent because the data is required in sub-sequent lifecycles and phases. Interviews with modular organisations highlight that all data of building parts is stored in a database to ensure that the data is complete for all phases in the project lifecycle. For example, during the use phases the digital model contains data about the strength classes of the steel, because this data is used during design phases after a project lifecycle. Thereby the organisation uses one main model to construct, maintain, and disassemble their assets. Furthermore, connections between building components are further defined by drawing the fasteners in the 2D construction drawings. This enables the decommissioner to identify the decommissioning strategy in the final phase of the project.

Since the objects of a digital model are directly connected to the database of the organisation, the data requirements set by the modular organisation is constant too. The modular organisations do not look to the requirements set by the undertaken phase, but by the needs of the whole project. This makes their database more elaborate. Furthermore, the modular organisations define characteristics on a low agglomeration level. Such as the environmental impact of a constructed object or the structural characteristics of a constructed object. The modular organisation thereby links characteristics to the component and element level defined by Durmisevic (2019). Thereby reusing the building parts is simplified and quicker.

Sub- research question 4: What process changes are caused by Circular Reuse ILS in the first project lifecycle?

The Circular Reuse ILS highlights that a new main model and aspect models should be constructed to enable circular reuse of components. Thereby properties of older models should be copied into new digital models which makes the model more complex and thereby manging, modelling, and checking the BIM becomes more extensive for the modeler. This is also reflected in the pricing, risk, and the duration of BIM construction, because these will both increase. The construction of a complete BIM for disassembly is thereby more expensive and complex compared to the currently used processes of the linear organisations.

Specified data should be connected to the aspect models. Interviews with modular organisation highlights that all characterises should be added to lower agglomeration levels to be able to reuse it. Thereby structural calculations and LCA calculations should be applied to constructed building components rather than whole objects. In the current linear processes these are based on the whole building or, in case of structural calculations, specified to the most interesting part of the building. The construction of these calculations will change due to the lower agglomeration levels and thus more detailed calculations. This increases the pricing, risk, complexity, and duration during the construction of the BIMs, since more actions are needed to complete the calculations.

During the use phase a new demand is created: data maintenance. After the construction is completed, modifications will occur to the physical in from of renovations. Hence, the digital model should be renovated too. Maintaining construction data is then needed to match the physical building with the stored models retrieved from the ILS+, otherwise the geometry of the digital models does not meet the geometry of physical building components. Maintenance to digital models is not a widely researched field, so minimal guidelines and solutions are already constructed. Therefore, the owner of the data should pay extra attention during this phase.

The disassembly process of a build asset will be much less considering that more data is available before the disassembly activities start. Thereby the decommissioner could make a better assessment of the released building components, disassembly plan and reuse possibilities of the components. Thereby the risk of the process decreases and lower margins of error, exacter pricing, more accurate planning could be realized compared to the current processes. However, physical inspection is still needed. The quality described in the models should always be checked in practice, that does not change.

Main research question: Which data is needed for circular component reuse and how does this data requirement influence the management of a BIM in new construction projects?

This research identified that all phase of a building requires different types of data. Interviews with modular constructor stresses the importance of construction data and drawings during the disassembly of the asset and redeployment in ensuing lifecycles. By using the ILS+, data is stored in correct agglomeration level, complete, uniform, structured, reusable, and interchangeable. The ILS+ defines the required data for reusable building components and enables thereby reuse in future lifecycles.

As described in sub-question 4, the modelling stages become more complex and demanding since more models are required and more properties are needed. This increases the project complexity in the design stages of the project. Also, BIM management in the use phase of a project is more complex since data maintenance problems arise during renovation activities. Disassembly and analysing the released building components for reuse is simplified since more data is available during these stages. Decommissioning and reusing building components contain less risk and results in exacter pricing, quicker disassembly, and less faults during this final stages.

25. DISCUSSION AND RECOMMENDATIONS

This chapter will further elaborate on the ILS+ and the implementation of the ILS+ in practice. All the presented improvement areas are derived from validation interviews and contradicting answers from respondents. The chapter starts with the discussion of the presented ILS+, thereafter the methodology is discussed. Further a recommendation paragraph is added to provide some improvements of the process and ILS+ for future application.

25.1. Discussion

The discussion chapter is separated into two sections. In the section under 18.1.1. discussion functionalities ILS+, the functioning of the ILS+ in practice is further elaborated. These sections provide insights in new versions of the ILS+ and the functioning of the product in practice Implementing this ILS+ brings new challenges in the management of the project process and are therefore discussed. Thereafter a brief discussion is presented to the used methodology and research structure. Here the used methodology is discussed, and improvements are highlighted.

Discussion ILS+

Aim of this research was to provide an information delivery standard for circular component reuse. However, not all building components are included in the current ILS+, such as roof or foundation. Thereby the ILS+ is not fully complete for implementation of application in practice. Furthermore, this ILS+ is a combination between an ILS and a BIM protocol. This could be made explicit more in the report and in the guideline itself. The provided document structure could lead to misunderstanding in the current market.

Furthermore, the provided ILS+ is based on the requirements stated by the interviewees and building degree in 2022. Since regulations could change, it could be that the data required in this ILS+ could become obsolete or is not comprehensive for future reuse. The number of regulations should not be changing to ensure that the data required from this ILS+ stays complete. Thereby implementation of this ILS+ does not guarantee that the components could be reused. This is a major drawback since it could discourage the implementation of the ILS+ and even reusing building parts. Nevertheless, these new regulations and requirements could not be inventoried simply because it is impossible to forecast the developments and requirements of the future. Still, the respondents and literature acknowledge that steps should be made towards circularity and therefore implementation of such data specifications.

Another important aspect is that all data should be made available that is required by the ILS+. As mentioned in the technical decomposition, a building component consist of layers of building parts. Thereby producers of building materials should share the data to ensure that the ILS+ could be completed. Thereby the producers should enable data accessibility to each other and be ensured that the data is stored safely during the use phase of the project. The ILS+ does not take safe data storage into account. Thereby this could be a potential pitfall and documents could not be completed.

Complex processes

The respondents acknowledge that the construction of the digital model requires more and more complex processes. Thereby the already complex and demanding construction phase and contractor design become even more complex. Using digital models form other phases for decommissioning is not validated yet and could thereby lead to a reduced difficulties in terms of project complexity.

Lacking flexibility

One of the difficulties of the current approach is the lack of flexibility during the use phase of the asset. As mentioned by the validation interviewees and the IFC expert, it is almost impossible to make major changes in an IFC. This is caused by the inflexible characteristics of the IFC schema. During the use phase a building will modify, by maintenance, renovation or expanding the asset. These characteristics should be added to the decommission documents, but the IFC makes this impossible. Important is that this could be implemented or changed in the future to ensure that all data remains available and up to date.

Maintaining data

Storing data for deconstruction requires saving data that is useless during the use phase of the building. For example, knowing the burglary resistance class a door is irrelevant for the user of the door. This documentation becomes valuable if the door should be replaced or reused. Thereby storing this construction data is useless for, almost, the whole use phase, which could be several decades. This does not only apply for the properties of an object, but also for the LCA calculations, aspect models, location of and type of the fasteners, and structural calculations. Thereby it is important that the data should be stored safely and to a clearly assigned place. Furthermore, storing that on a platform costs money for the owner of the building. This is a financially unattractive structure since the data is useless for most of the time. Keeping the data available is, of course, crucial in reusing the building components, otherwise the same reuse possibilities are available as in the current linear economy.

The validation respondents do not agree about updating the digital model during the use phase. Here a lack of demand and experiments could be recognized. Due to the limited case studies or experiments in the market these aspects of the circular development in the AEC are underdeveloped. Thereby, implementing this ILS+ is a step towards circular reuse, but not the finish. This ILS+ only works if digital data is properly maintained just as the physical components, otherwise the data, and thereby the component, becomes useless.

Discussion methodology

In the current research structure interviews were used to identify the data needs to construct an information delivery specification. These interviews aimed to identify the data requirements of linear and modular building organisations to reuse components. Thereafter the interviews were analysed to identify the requirements and construct a new structure for circular reuse.

Component level

During this research there is focused on reusing on component level. However, limited research is done to the reusability value of those building components after one lifecycle. Building components are the most circular and environmentally friendly agglomeration to reuse, but the redeployment of those component in a second lifecycle is not researched. Thereby the demand or possibility of reusing building components is overlooked. It could be that, for design reasons, the building components are too big to reuse. Thereby a crucial assumption is done without validation or market research. This is also reflected during interviews with the modular organisations. All modular organisations used a further defined agglomeration level of building parts to construct their building, thereby building elements and products are used. This creates more flexibility in their future design phases. Therefore, it could be that reuse on component level is not preferable in practice and further specification is needed.

Used theories

In this report three theories were discussed to provide a knowledge base that could be used for further elaboration in the report and as input for the interviews. Not all the seps made here where necessary end up with the ILS+.

First, a lot of time and effort is added to the theories of Durmisevic (2006; 2019; 2021). These theories improved the understanding of demountable construction and gave input for the interview questions. However, when is looked to the contribution of these theories in the ILS+, minimal input and data is processed in the guideline. Thereby the theories where less important that initially indicated in this report. It gave comprehensive input for the interview questions, but the theories had nominal impact in the final data requirements. Thereby it could be questioned if these theories should be used as guidance for the interviews.

Second, during the initial stages of this report the presumption was that the IFC scheme should play a more prominent role in the capabilities of storing reuse data. Thereby a lot of research is done to the capabilities and characteristics of the scheme and a whole chapter is committed to this concept. Since the IFC plays such a predominant role in the prescribed data structure, the allocation of a whole chapter could be justifiable. Contrastingly, the interviewed BIM modeler 1, did not know the full potential of IFC too.

Standards are available for exportation to the correct IFC entities and thereby understanding the full capabilities of entities and property set are not needed. Research to fully elaboration of this topic could be debated, since standards already exist, and correct export structures could be found on publicly accessible sites.

A significant part of this research is focused on processes and workflows. However, in the current described theoretical background minimal input is given from that side. It could be that important subjects, problems, and theories were overlooked and thereby the research process is incomplete. The description of the processes could therefore not be seen as comprehensive.

Interviewees

In this report is chosen to interview modular and linear building organisations to see what data both organisations require during their project lifecycle. Thereby the goal was to identify the data requirements of modular builders during the project lifecycle and implement these in linear oriented organisations. The interviewing of modular builders is not a representative view of the whole AEC market since the use of their units limits itself in dwellings and offices. Thereby the research limits itself to those functions. Comparing those with linear organisations, who construct a variety of those functions could be questionable. Thereby more asset typologies should be investigated to ensure that the presented ILS+ is complete.

The processes in the modular building organisations were assumed to be ideal without an analysis of the existing linear processes. Whereas the products of both organisations look like each other, the functions, the processes, business models, construction techniques and sequences, lie far apart. This is underestimated before entering the interviews. Thereby it became difficult to compare the data requirements without looking at the processes and business models. Comparing the two organisation typologies is still relevant since modular construction represents a part of the circular definition presented in part 2 but does not give a comprehensive view of reuse.

Questions during the interview

As mentioned before, the processes, techniques, and business models of modular and linear builders are very different. Thereby the interviews were very different compared to each other, even when the same question list is used. The semi-structured interview approach brought much interesting views on the work processes and data requirements of both organisations. However, since both approaches differ a lot, the focus points during the interviews were very diverse too. Thereby the answers between the organisations were sometimes limited and sometimes elaborate. For instance, during the interviews with the linear oriented organisations much more questions were asked about maintenance LOD and data requirement, since a lot is happening in digital model compared to the construction BIM. The modular organisations, on the other hand, used predefined maintenance activities and checklists to ensure that their building is maintained. Further the interview with modular organisations focusses more on the organisation of data and further improvements of their data structure. Thereby the capabilities of BIM were an important topic in combination with the data storage in external documents.

Validation by experts

During the validation one BIM modeller is interviewed from the final design phases and the contactor design together with a circular decommissioner with a BIM-specialities to validate the ILS+. These two interviewees gave a comprehensive view of the initial ILS+ configuration and mentioned that the structure could be applied in practice. The number of respondents is a bit too low to validate the full process and completeness of the guidelines, since it was impossible for them to oversee all requirements of the ILS+. However, it provides a good starting point for further development of the current data requirement specification. Further, both respondents acknowledge that the process is practical feasible, disregarding willingness of implementation.

Both respondents could imagine that processes become more complicated during the execution of the ILS+, due to more deliverables, properties of the deliverables, and more specified calculations. The BIM modeler noted that it is difficult to oversee how the different models in phases relate to each other and if they could be used for decommissioning. This could potentially reduce the workload enormously since construction (aspect) models could be used for decommissioning too. Thereby the outcome of the process could be simplified after performing experiments.

25.2. Recommendations

In the coming sections recommendations are provided to improve the presented structure and other find research topics. These recommendations are derived from contradictions in interviews and advice given in during the validation interviews.

Data sharing between actors

An interesting argument was given in exploratory interviews: “I’m not willing to share all data […] this could give competitors information about my work processes and my margins” Key in the functioning of this ILS+ is that the data is complete. Otherwise, some steps in application or implementation could not be made or should be tested. This could lead to inefficiencies in the process and, at worst, in obsoletion of the physical building component for reuse. If one stakeholder in the process is not willing to share the data, reusing components becomes much more complicated. More research should be done to this topic to ensure that data is stored safely, so competitors feel free to add all data to building parts and reuse could be facilitated. Questions such as: who is responsible for the data safety? Who has access to the data during the use phase? Could be explored further.

Implementation of the ILS+

The original function of an ILS is to provide data requirements of a digital model. However, the presented ILS+ requires more deliverables than just a digital model. This could lead to more difficulties in implementation of the standard in practice since the current knowledge level in the market is relatively low and confusion could be created. The experienced BIM modeler was confused too when the ILS+ was opened first. Since the BIM modeler is an experienced conductor of BIM processes and implementation, this should be improved and smoothened further for practical use. Therefore, the ILS+ should be separated in requirements of a BIM protocol and a circular reuse ILS itself. An extra advantage of this is that merging with other ILS standards is simplified too, given that the structure is more aligned with existing standards and workflows.

Further, the presented ILS+ should be further validated by case studies. The current described structure could be improved by conducting multiple case studies or experiments. Thereby the new processes, possible new BIM modelling requirements, and unclarities could be further explored and improved. This study provides the first steps towards component reuse in the AEC industry and should be further tested for full implementation. However, the current availability of case studies is too limited to make a comparison.

As mentioned by the BIM modeler, implementing rulesets, or creating a platform to check if the digital model meets the requirements of the ILS+ remain open. This could simplify the implementation of the ILS+ in the market. A Solibi ruleset or a digital platform could easily be constructed and will facilitate better usability of market parties. These checking mechanisms will check if the required data in the ILS+ is presented in the objects of the model, furthermore it overcomes data irregularities.

Market knowledge

The current knowledge of BIM in the AEC industry is rather limited. Thereby the implementation of the ILS+ is validated and could be implemented by the front runners in the market. However, it remains unknown if less experienced BIM organisations could work with this structure. The adoption route to this ILS+, as well as other ILS standards, in the market is not defined. Thereby implementation of ILS standards and BIM should be further researched in the coming years. The current market is making slow improvements and, often, does not know what data and routes are available and needed. An adoption route to market wide BIM implementation and using ILS standards should be made to ensure that data could be managed and stored.

Demand of the market

Both validation interviewees mentioned that the current market for this ILS+ is rather low, due to missing incentives and lack of interest. Furthermore, the BIM modeler argued that the implementation of this ILS+

in their processes is not done voluntarily, because it increases complexity and extents current processes timewise. Thereby a full implementation of this ILS+ in practice is currently far. Recognized is that the constructors of the BIM or owners of the building components should have a bigger stimulus than currently present to implement circular visions into their processes and projects. How this could be achieved and how to overcome barriers is widely researched. However, a definitive suitable answer is still unknow because the market demand is not sufficient.

Increasing flexibility

Maintaining the data is still a fully unknow topic in the construction industry and should therefore be investigated in the future. This is due to a lack of knowledge in the market as well as the limited need for digital maintenance. Current BIMs are often used during the design phases of a project, whereas implementation in maintenance and disassembly phases are still minimal. Thereby keeping data up to date is not as investigated by research as well as the market. Defining when should data be maintained? What is a data mutation? Who is responsible for data maintenance? And how could major data mutations be processed in IFC? are still unanswered questions. Without proper maintenance to the data, circularity becomes much more difficult and almost impossible. Answering these questions will also improve the BIM maintenance models, since data modifications have also influence on those models.

Dynamic link between documents

One of the major drawbacks of this ILS+ is the fixed link between the documents. Since the certifications and calculations are presented in PDF formats. If modifications to the component occur, the calculations should adapt to this. Otherwise, the whole calculation should be executed again, or the component should be tested. How a dynamic link could be created between structural, LCA and certifications is unknown and is a complex problem. Solving this problem will help maintenance modelling parties to ensure that data is processed automatically in every document and thereby reducing the overall chance of manual mistakes.

Processes subsequent lifecycles

This report focuses on constructing a new data structure that enables circular reuse on component level. Herein the BIM processes of the first lifecycle of the components is described and further elaborated. The ILS provides data analysis and disassembly of the components but does describe the influences of predefined building parts on the design phases in subsequent lifecycles. How these processes are influenced by this new data structure remains open after this thesis. Questions such as How does the design change by using predefined building parts? Are new processes needed during the design phases? How could designing from components be stimulated? Should be answered.

Part 7
Reflection

26. REFLECTION

During my thesis project for my Batchelor in Amsterdam, I discovered my interest in the CE and circular construction. I really liked this innovative new way of thinking and started to recognize the application of the concept in practice. My goal was therefore to further develop my circular knowledge in this thesis. Furthermore, I did not have a complete understanding of BIM and corresponding processes because I never anticipated in such projects. After completion of my study, I wanted to know the possibilities and capabilities because BIM is, in my view, involved in the future of all building processes. These two concepts are closely related to the master Management in the build environment because it focusses on changing and managing processes in the built environment.

After the P2 presentations I directly started with interviewing respondents. I really liked this part of the research process because it gave me interesting new insights and knowledge about the investigated topics. Early on I recognized that my research gap, as presented in the P2 presentation, was not the right and I needed to make a change. This resulted in a lot of work and, logically, confusion by my mentors. This deteriorated further because I did not process al the changes in the report. Thereby, the gap between the reported process and approach and my actual progression became (too) big for the mentors to fully understand what I was doing. I did not like the typing and enjoyed the interviewing and exploring more. This caused a lot of confusion, questions, and surprises by my mentors and resulted in feedback that I needed to elaborate my report and process further. During the preparation of the P3 presentation I realized that the report was missing a lot of process and already perceived knowledge. I tried to manage as much as possible by writing bullet points and small pieces of information, so the number questions and the level of confusion was limited. However, I did not manage to complete it, so the report was not finished when it should be handed in.

In the initial stages, Tong provided me with a clear and well-structured example of a thesis. After the feedback, I looked critically to the report structures of my own thesis and the example and noticed that I sometimes elaborate too much and, more often, too less. This helped me to identify the unclarities and missing structure that I was facing in the report. I underestimated the time that it takes to process all the interviews in the report. Thereby interviewing and searching to new structures becomes a more logic step and a lot of change work and writing work stays undone. I learned that I should finish parts of the report and research before next steps are taken. Moreover, that writing and processing information on paper is also making progress, because this enables mentors to give more detailed feedback.

During the interviews I asked the respondents more than initially necessary to complete this thesis, because I believe that this could also result in more elaborate answers. This resulted in an improved understanding of the workflow and data managing structure. However, I also believe that this strategy distracted me from aspects that where more important to do.

Thereby some important tasks, mostly writing, remained undone and a lot of work should be redone and completed. I further believe that this approach made structuring the report much more difficult because I had so much data researched. Thereby following a red line was difficult to me and this is reflected in the finalized report.

The used data collection methods in this report are interviews, mapping, and literature. I believe that these methods brought the best result to answer the main research question. However, using modular builders to identify the data requirements could be seen as questionable, because their work processes differ a lot and their business model is completely different. The modular builders aim to reuse products multiple time to make a financial profit, whereas linear organisations could sell their product once. The main problem is that the linear constructed buildings have a much longer use phase and thereby different functions and maintenance activities going on. This difference is highly underestimated by me. Furthermore, the functions constructed by the modular builders are primarily offices and temporary housing, while linear organisations construct a wider variety of functions. Modular constructors could partly be used to answer the main question. However, more requirements are possible needed if other functions should be added. The used interview group could be improved, and I should discuss these much more elaborate with my mentors to see if the correct persons are interviewed.

The respondent all showed interest in my end-product and sometimes mentioned that they are facing the same problems as addressed in this report. Some recognize the increased interest of clients to build (more) circular and want to know how they could make the first steps towards this. Thereby I realized that the problem is important and is going to be used by organisations or used by them as a starting point. The circular aim of the Dutch government will increase the interest further over the years, since the regulations state a fully circular Netherlands in 2050.

During the past months I found it difficult to sometimes manage the privacy of my respondents, since I could not use the name or relations of the organisation or person. Often these aspects were leading to interesting insights because this elaborated their work processes more. The organisations I have interviewed are not as common compared to the linear contractor organisations, since they all have knowledge about BIM and IFC or modular and temporary construction. I was happy that I started the interviews with explaining the research and asking if they had questions too me. Further the consent form helped me with to stress that information is known and used by me.

All in all, I believe that I learned much of the application of circularity in BIM, IFC and the built environment. Thereby my main predefined goals are met when I complete my thesis.

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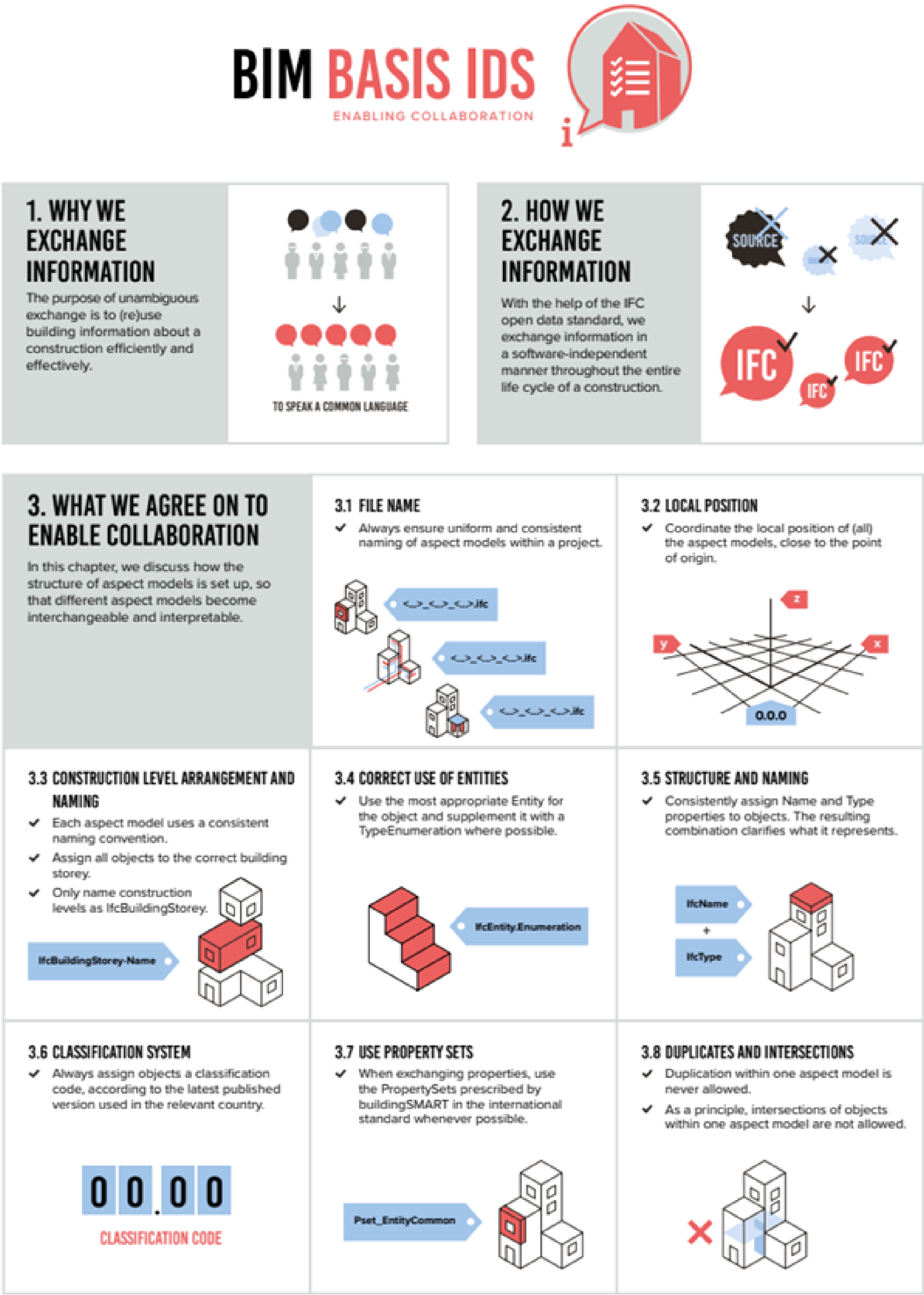
Appendixes

1. BIM BASIS ILS

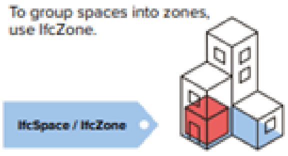


4. WHICH (MINIMUM) INFORMATION IS REQUIRED IN ONE OF THE ASPECT MODELS

Agree on what information is to be provided by whom and when. Start with the topics in this chapter and add to them if necessary.

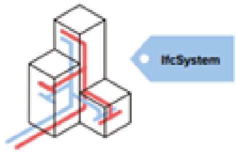
4.1 SPACES

- ✔ Spaces are: volumes and areas, enclosed by real or theoretical boundaries, with a function in a construction.
- ✔ Create IfcSpace from spaces and name the function.
- ✔ To group spaces into zones, use IfcZone.



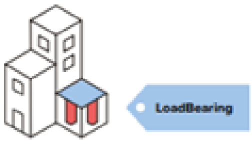
4.2 BUILDING SERVICES RELATED SYSTEMS

- ✔ Group installation objects belonging to the same system in an IfcSystem, when applicable.



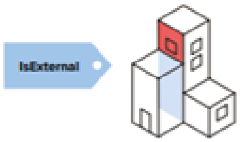
4.3 LOAD-BEARING / NON-LOAD-BEARING

- ✔ Indicate whether the property LoadBearing is TRUE or FALSE for objects, when applicable.



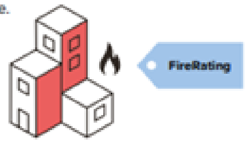
4.4 INTERNAL / EXTERNAL

- ✔ Indicate whether the property IsExtermal is TRUE or FALSE for objects, when applicable.



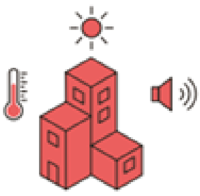
4.5 FIRE SAFETY

- ✔ For objects, when applicable, use FireRating (resistance to fire penetration and spread) values, and use FireRatingR (resistance time to failure).
- ✔ Use the FireRating property for the resistance to fire penetration and spread value.



4.6 BUILDING PHYSICS PROPERTIES

- ✔ Incorporate the relevant building physics properties into the objects.

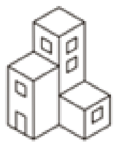


4.7 MATERIAL

- ✔ Assign a material (IfcMaterial) to all objects.
- ✔ In compositions, choose the dominant material.
- ✔ Be cautious with additional properties in the naming of the material.

4.8 PROJECT SPECIFIC

- ✔ Determine project-specific information required for the intended BIM applications and project objectives.



2. INTERVIEW QUESTIONS IFC

Algemene informatie IFC

1. Kunt u kort uitleggen wat IFC is?
2. Hoe is het IFC open standaard informatieschema gestructureerd?
3. Welke diagrammen kunnen worden gebruikt om de IFC weer te geven?
a. Wat zijn de eigenschappen van deze diagrammen?
4. Waarom is de IFC op deze manier gestructureerd?
5. Wat zijn volgens u de sterke en zwakke kanten van de huidige IFC-structuur?

Werking van de IFC

6. Hoe weet een BIM-softwareprogramma welke entiteiten gebruikt moeten worden om een BIM-model om te zetten naar IFC?
   a. En door wie of wat wordt dit bepaald? (Bijv. modelleur, protocol, software, etc.)
   b. En waarom kan dit verschillen?
   c. En welke problemen kan dit opleveren?
7. Hoe weet een BIM-softwareprogramma waar informatie gevonden kan worden in het IFC-schema?
8. Moeten alle enumerated types van een entity worden ingevuld?
9. Met welke relatie entities worden relaties tussen bouwelementen aangegeven?
   a. Kunnen gebouwelementen ook zonder relatie entity worden gekoppeld aan elkaar?
10. Hoe kan gecontroleerd worden dat alle informatie opgeslagen in het IFC-schema?
   a. En hoe kan gecontroleerd worden dat alle informatie ingeladen kan worden?

Uitbreiding van de IFC

11. Hoe kan de IFC-datastructuur worden uitgebreid?
   a. En wat zijn de voor- en nadelen van deze mogelijkheden?
12. Kunnen de entiteiten van de IFC worden aangepast?
   a. Indien ja, hoe?
   b. Indien nee, hoe wordt informatie opgeslagen dat niet in de huidige structuur kan worden opgeslagen?
13. Hoe kunnen de enumerated types van een entity worden aangepast/ uitgebreid?

Model view definition (MVD)

14. Wat is een model view definition (MVD)?
15. Hoe wordt een nieuwe MVD gemaakt?

3. INTERVIEW QUESTIONS LINEAR ORGANISATIONS

Algemene informatie

1. Wat is jullie werkwijze?
2. Hoe delen jullie informatie met andere stakeholders?

Opslaan van informatie tijdens bouwproces

3. Hoe slaan jullie element, materiaal en gebouwconnectie informatie tijdens het bouwproces?
4. Waarom wordt deze methode gebruikt?
5. Welk opslagformat wordt er gebruikt? (Denk aan PDF, een Revit-model, IFC, etc.)
6. Waarom wordt deze opslagformat gebruikt?
7. Hoe gedetailleerd wordt de geometrie gemodelleerd?
8. Wordt alle informatie opgeslagen in een BIM?
    a. Waarom wel/niet? En waar wordt de eventuele overige informatie opgeslagen?
9. Hoe gedetailleerd wordt de data opgeslagen?
    a. En zit er een verschil in detailniveau van onderdelen?
    b. Hoe gedetailleerd is de BIM gedurende de verschillende fase van een project?
10. Hoe weten jullie dat alle benodigde informatie in de BIM/IFC zit?

Archiveren van bouwinformatie

11. Hoe slaan jullie element, materiaal en gebouwconnectie informatie om het te archiveren?
12. Waarom wordt deze methode gebruikt?
13. Heeft het onderhoud van een gebouw invloed op de informatie eisen van een BIM?
    a. Waarom wel/niet?
14. Welk opslagformat wordt er gebruikt?
15. Waarom wordt deze opslagformat gebruikt?
16. Hoe gedetailleerd wordt de geometrie geëxporteerd?
17. Wordt alle informatie opgeslagen in een BIM?
    a. Waarom wel/niet?
18. Hoe gedetailleerd wordt de data opgeslagen?
    a. En zit er een verschil in detailniveau van onderdelen?

4. INTERVIEW QUESTIONS MODULAR ORGANISATIONS

Algemene informatie

1. Wat is jullie werkwijze?
2. Hoe delen jullie informatie met andere stakeholders?

Opslaan van informatie tijdens bouwproces

3. Hoe slaan jullie element, materiaal en gebouwconnectie informatie tijdens het bouwproces?
4. Waarom wordt deze methode gebruikt?
5. Welk opslagformat wordt er gebruikt? (Denk aan PDF, een Revit-model, IFC, etc.)
6. Waarom wordt dit opslagformat gebruikt?
7. Hoe gedetailleerd wordt de geometrie gemodelleerd?
8. Wordt alle informatie opgeslagen in een BIM?
    a. Waarom wel/niet?
9. Hoe gedetailleerd wordt de data opgeslagen?
    a. En zit er een verschil in detailniveau van onderdelen?
    b. Hoe gedetailleerd is de BIM gedurende de verschillende fase van een project?

Archiveren van bouwinformatie

10. Hoe slaan jullie element, materiaal en gebouwconnectie informatie om het te archiveren?
11. Waarom wordt deze methode gebruikt?
12. Welk opslagformat wordt er gebruikt?
13. Waarom wordt dit opslagformat gebruikt?
14. Wordt alle informatie opgeslagen in een BIM?
    a. Waarom wel/niet?
15. Hoe gedetailleerd wordt de data opgeslagen?
    a. Welke verschil in detailniveau van onderdelen?

5. MAPPING STRUCTURE OF THE IFC

The mapping of the IFC is located on the next page.

6. CIRCULAR REUSE ILS+ AND CIRCULAR REUSE ILS+ GUIDELINES

The documents start on the next page.

Circular reuse ILS+ guidelines

Information delivery specification for circular reuse of building components in a BIM

Colofon

May 2022, Delft

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Contents

1. Reading Guide

This manual has a direct link with the excel file "*Circular Reuse ILS+".* The data requirements of a newly constructed building component are described in the excel together with the needed entities and related helplines. The purpose and introduction are presented in the first chapter of this guideline. This chapter explains the need of this data specification and how the data, derived from this ILS, could be used the future. Chapter three describes the origin of this document. This chapter elaborates the process of construction of this data specification and why the required data and documents are more elaborate compared to already existing ILSs in the market. The fourth chapter demonstrates how clients and contracting parties could use this specification in their processes. In the fifth chapter the structure and scope are further defined. This provides insight of the application of the ILS and which documents should contain which data parts. The chapter "guidelines circular reuse" describes which steps should be followed to ensure complete and useable data storage for circular reuse. The excel "*Circular Reuse ILS+"* provides the exact data requirements of the described building components. Chapter 6 will elaborate the reuse Excel in further detail. The document finishes with providing additional links to help with the exportation to IFC and structuring a BIM.

2. Introduction and goal

The implementation of BIM (Building Information Model) plays an important role in digitalizing in the construction industry. Research state that BIM will become the global language of all the construction projects in the future and will have significant role in the development of the sector. One of these developments is the transformation of the current linear economy to a more sustainable circular economy. In the circular economy materials and parts are reutilized in a subsequent lifecycle to reduce the overall environmental impact of the used parts. The government of the Netherlands already adapted this their ambition to be circular in 2050. The construction industry should redeploy building parts of current buildings in buildings of the future to comply with this new transformation. BIM could help with this by providing the data to analyse building parts and development of a disassembly plan. This document describes which data is needed from the building components: wall, column, and floor to redeploy them in subsequent lifecycles. Having this data will help decommissioners to disassemble the building and redeploy these components in a new asset.

The guidelines require contractors to use IFC (Industrial Foundation Classes) and PDF file formats. The IFC is and interoperational data exchange format which is used in the construction industry to share 3D models between stakeholders of a construction project. The open data standard of the IFC makes the file useful for archiving data over the longer term because the data file does not require updates or modifications. PDF has the same qualities as the IFC but is used to present 2D drawings, schedules, and descriptions. Thereby all data could be used by future users during disassembly of the asset.

Goal

The goal of this guideline is to digitalize and structure building and building component data to enable reuse of building components after obsoletion of the asset. This document gives answer to the question: *"How and what data be stored to enable building component reuse?".* The presented ILS+ ensures that newly constructed building components include all required data to be redeployed in the future. With help of the IFC open data standard and PDF, data is exchanged in a software-independent manner throughout the entire lifecycle of a modular constructed asset. By knowing the qualities and characteristics of new developed building components, it becomes viable to create a circular decommissioning plan, quantify and qualify the recoverable materials, and make analysis of redeployment of the components after a lifecycle. Further these properties ensure that all data is presented to meet the latest requirements of the Dutch building degree 2012. The building component described in this ILS+ are the components: wall, column, and floor.

ILS and this ILS+

Current data specifications are also known as an ILS (Information Delivery System, original Dutch name: Informatie Leverings Specificatie) and provide data requirements of a BIM and thereby an IFC. However, research concluded that data in a BIM and IFC is not sufficient to redeploy building components in a flowing asset, since the qualities, calculations and building sequence could not be checked or recognized directly from a digital model. This guideline requires delivering extra documents on top of a digital model and is thereby more elaborate than the already acknowledged ILSs in the market. Therefore, this data specification is called an ILS+ instead of an ILS. The extra documents of this ILS+ are: LCA calculations, structural calculations, and certifications of the building components. These documents are further specified and elaborated in chapter 5.

3. Origin of this document

This document is constructed after a half year of research modular and linear oriented building organisations. This research focusses on the data structure and requirement of both organisations during a project lifecycle. The main question during this research was: *"How and what data be stored to enable efficient data storage for circular building component reuse?"* Both organisations illustrate different kind of structures and requirements. The data structures and requirements are analysed and resulted to this presented structure, and this resulted in this guideline for circular component reuse.

The required properties are needed for reuse of the building components, wall, floor, and column in subsequent lifecycles. These are needed during the analysis of the components for redeployment, the application of a building permit, or more efficient decommission processes. Adding the properties presented in the excel named: "*Circular Reuse ILS+"* and ensures that decommission activities could be completed and redeployed in the Netherlands.

Why building components?
Reusing components is the first step on the circular ladder and is therefore elaborated in this document. By using large building components, bigger emission savings could be realized, and less waste is produced compared to smaller parts. Thereby significant steps are taken towards the implementation of the circular economy in the Netherlands. Using large building parts is also preferable from a financial perspective, since less labour is needed for redeployment of a component. Thereby the value of the building component is higher, and reusing becomes more attractive.

Existing standards
The starting point of this ILS+ are the already existing ILS standards, property sets of buildingSMART and provided BIM structures of the BIMloket. The layout of the ILS+ could be recognized from the BIM Basis ILS, AEDES ILS and the ILS façade 0.9 (original Dutch name: ILS Gevel 0.9). These documents are used because the structure behind these specifications is complete and clear. Further implementation of those specifications in a BIM show similarity with this ILS+ and should thereby facilitate implementation further. The property sets of buildingSMART are already provided sets which ensure that data is stored in a uniform way. This improves the overall implementation an makes all presented data uniform, and thereby recognizable for software and future users. This also applies for using the NAA.K.T. method (Original Dutch name: NAA.K.T. methodiek) for building materials.

Installations
Modular building stimulates separating building functions from each other, in other words, installations and structural components are separated and not interlinked. Separating these functions increases the redeployment and flexibility of the building parts and thereby facilitates more reuse possibilities. During the research, installations were always separated from the structure and the skin components, by adding an extra layer especially designed for the installations. Therefore, this ILS+ does ***not*** include directives for installations itself. This means that the geometry, type, and qualities of installation works are ***not*** included in this ILS. Modifications to the components derived from the installations ***are*** included, such as cut-outs and other modifications.

4. Target Group

The target group of this ILS+ is very diverse. Many stakeholders could use this ILS+ during a project lifecycle. The following sections elaborate the target groups further.

Contracting party

The main users of this ILS+ are the contracting parties with clients with a circular aim. Every contracting party could use this ILS+ if they use BIM in any form during construction of their new assets. This means that the function of these organisations could very diverse, from BIM-modelers till modular contractors. The contracting parties are the main target group of this ILS+ because will spend the most time applying and checking their model with the provided documents and will thereby add the most value in their processes and structures.

The required data in this ILS+ could be completed in the later stages of the project process since most of the required data is generated during the definitive design and construction design phases. In the initial stages, the ILS+ could be used as guideline during the construction to a definitive product. This makes it easy and clear what data should be delivered and at which place it should be stored. Thereby the contracting party can check any time if the deliverables meet the requirements and thereby the specification of the client. The researched objects are formulated clearly, however, a building consist of more that these components and is therefore not directly complete for an overall circular reuse of an asset. Furthermore, the client could add their own requirements on top of this ILS+ and thereby the data could not be complete after applying this ILS+.

This ILS could further be used by contracting parties that are willing to change their linear business model into a circular business model. Thereby the contracting party could use this ILS+ and required documents to structure their data and check if their data supply is complete for redeployment. Thereby the ILS+ could provide a useful starting point of their analysis.

Client

These guidelines provide circular oriented clients to define their data requirements of their digital model in new constructed assets. By using this ILS+ the client is ensured that the data is complete, structured, uniform, and succinct. Every circular oriented client could ask contracting parties with BIM processes and modelling to implement the data requirements of this ILS+ in their models.

The provided structure enables clients to check if all data is complete, uniform, and structured and could be added to the BIM protocol in the beginning of a project lifecycle. During its lifecycle the client could check if all data is generated and definitive. How the checking process is implemented in the project is not included in the ILS+ and should be added to BIM execution plan. Furthermore, the client could add their own additional data requirements to this plan if they need more properties of an asset. Furthermore, the circular value of their asset increases, which could lead to a financially higher asset value in the future.

Future decommissioners

The data added to the digital models will help the decommissioning party significantly. The data will reduce the overall insecurities of the building composition and thereby reduce risk, increase the redeployment value, reduce lead times, and enable better pricing. Thereby, reusing the components is much easier and attractive since processes and data is available, clearer, and structured. By implementing this ILS+, decommissioning becomes more structured and the released building parts could be analysed for new reuse possibilities.

5. Required documents and files

In the current BIM environment, it is unfortunately impossible to store all data into one single decommissioning file. This is caused by the structure of the IFC since this is not capable of including certifications and complete calculations of building components. This results in multiple files which are described in this chapter. To store all data there is chosen to construct two document types: an IFC file and additional PDF documents in form of 2D construction drawings and details, certification, and calculations of the decommissioned components.

General structure

In figure 25 illustrates the required structure of this ILS+. At the top of the illustration the main IFC file is shown. This IFC is a 3D presentation of the whole building and illustrates basic data, geometry, and location of the demountable building components. This model requires LOD-200 or higher, and the dismountable components are modelled separately to be recognizable and identifiable. Basic data is connected to the main IFC to minimize the complexity and size of the file. The required data in this model is presented in the excel "*Circular Reuse ILS+*" in the tab "*DataRequirements*". Every demountable component has a unique ComponentID to identify the component in other models and documents. Important is that the correct ComponentID is used consistently and in all files so data is always linked to the correct digital and physical component.

Figure 25 also illustrates three aspect models related to that main IFC. Every demountable component should have a separate aspect model with all required data from the "*Circular Reuse ILS+*" Excel file and is modelled in LOD-350. The aspect models require a higher LOD and more data because these are used for performance analysis during reuse in ensuing lifecycles. As mentioned before, having complete IFC models does not guarantee that the building component could be reused. The aspect model should therefore be complemented with: 2D construction drawings, structural calculations (if the component could be used structurally), LCA calculations, and performance certifications to enable circular reuse. Furthermore, the ComponentID should be noted in all the documents to recognize the correct building component.

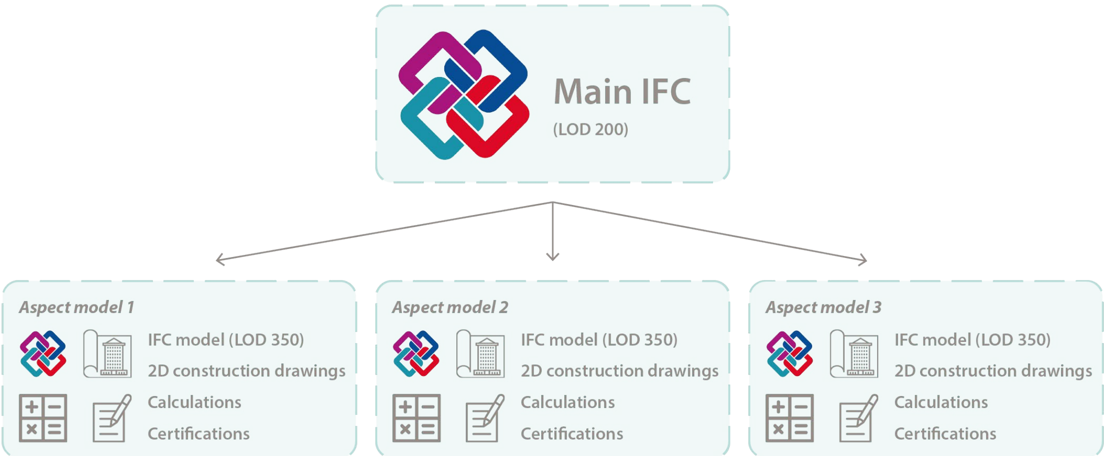


Figure 1: Main IFC and aspect models

Required IFC models

The aspect models are used in ensuing lifecycles for performance analysis and design purposes. They give designers and builders input of the performance of the demountable component and reuse possibilities. Therefore, it important that all demountable components have their own separate aspect IFC, this results in separate models of each individual demountable building component.

Every reusable, for example, wall or floor has thereby a IFC model with all related data and geometry that could be used for performance analysis after a finished lifecycle. In figure 25, three aspect models are presented. However, in practice this number could be a multiple of this, depending on the size of the asset. All the aspect models are represented in the main IFC to localize the components in the whole building. This main IFC is a presentation of the whole building with all demountable components modelled separately. This ensures that the aspect models could be recognisable, and the geometry of the whole building is presented. The following IFC models should be constructed:

- Main IFC
- Aspect model of every demountable component

Other documents

Every aspect model should be linked to drawings, calculations, and certifications to enable reuse of the building component. Organisations that use the building components in subsequent lifecycles need safeguarding that the components work according to specifications and should know how they could be disassembled. Further, some documents are needed during permit applications. Adding these documents to the project information is important because these are used as evidence for virtuous building and execution.

The 2D construction drawings and details

These drawings are all constructive drawings and details that are needed to construct the asset in the first place, these are also needed during decommissioning. These drawings are used to provide future building engineers with enough information to recognize building sequences and know which techniques are needed to disassemble the components from each other. 2D drawings are needed because it creates more insight in the building sequences and connection methods compared to just the IFC files.

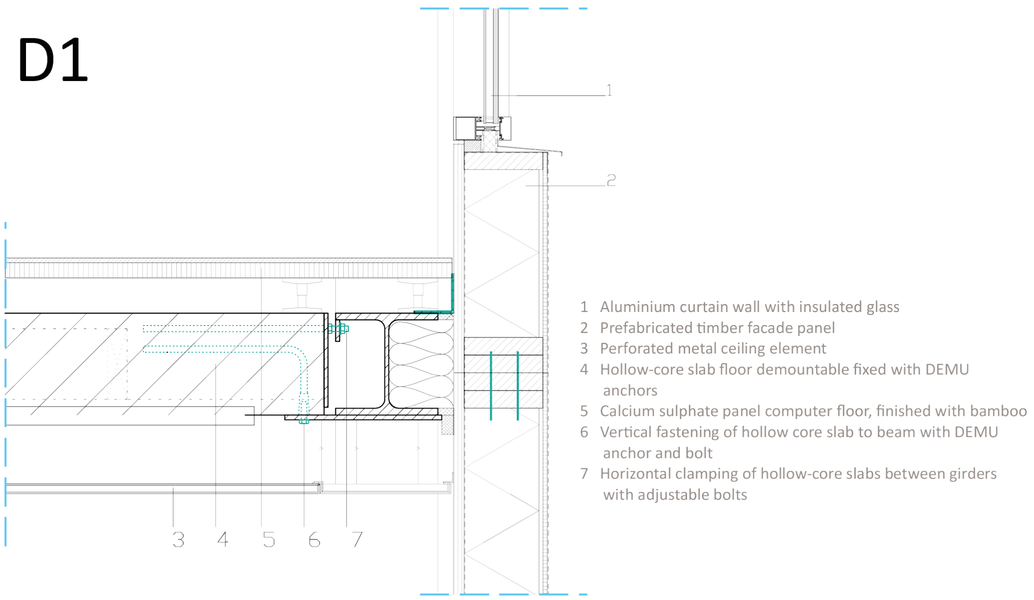


Figure 2: Example of a detail with fasteners (Source: Own illustration adapted from Cepezed (2016)

In the details it is important that fasteners are visualized, this means that the screws, bolds and other connectors are presented. An example of such detail is illustrated in figure 26. The fasteners of the detail are visualized in green. These are not needed in the IFC models because this will increase the overall file size and the IFC becomes too complex. By visualizing the fasteners building engineers of the future could recognize the used connection techniques and disassemble the components to reuse the building. Together with the IFC aspect models and the main IFC, the construction drawings provide enough data to construct a decommissioning plan.

LCA calculation

New buildings larger than 100 square meters require an MPG calculation for application for a building permit. An MPG expresses the environmental impact of the construction materials used in a new built asset and is the sum of all LCAs of an asset. Therefore, the LCA calculation of the component should be added to the documentation of the building component. These numbers ensure that an MPG calculation could be made, and that the component could be used for permit applications in subsequent lifecycles. The inputs of the calculations are the most important aspect since the calculation itself could differ per LCA. An LCA calculation does not have a set structure and the inputs should therefore be explicit to use in subsequent lifecycles. Adding these inputs to an IFC is not preferable since it is impossible to create a dynamic link between the LCA calculations and the IFC. Thereby, manually adding the inputs to the IFC could lead to mistakes and data contamination. Furthermore, adding the whole calculation is simpler and quicker. To calculate an LCA the following data of a component should be explicit from the calculation:

- Abiotic resource depletion (kg Sb-eq.);
- Abiotic fossil resource depletion (MJ);
- Freshwater ecotoxicity (kg 1,4-dichlorobenzene eq.);
- Climate change (kg CO2-eq.);
- Marine aquatic ecotoxicity (kg 1,4-dichlorobenzene eq.);
- Ozone layer depletion (kg CFC-11-eq.) ;
- Terrestrial ecotoxicity (kg 1,4-dichlorobenzene eq.);
- Photochemical oxidation (smog) (kg ethylene-eq.);
- Acidification (kg SO^{2-}eq.);
- Human toxicity (kg 1,4-dichlorobenzene eq.);
- Eutrophication (kg $PO4^{3-}$-eq.).

Furthermore, the NL-SfB code is needed to complete the calculation, but this is already needed for identification. Therefore, this code is added to the excel "*Circular Reuse ILS+".* A link to the LCA calculations could be added to the property "*LCACalculations*" to create a direct link from the IFC to the LCA calculation document. Furthermore, in the description of the LCA, the ComponentID should be added to link the calculation to the correct component.

Structural calculations

To enable redeployment of building component, it should be possible to check the structural calculations. These calculations are required during the application of a permit. In subsequent lifecycles the safety factors and used loads must be able to be controlled per component, otherwise a building permit cannot be awarded. Testing building components after disassembling is often undesirable since it is a time consuming and financially unattractive process. These certifications could not directly be included in the IFC. However, the "*Circular Reuse ILS+"* defines a new property called "*StructuralCalculations*" herein a link to the certification could be added. Thereby a link to the calculations is realized to find the calculations directly from the IFC. Each structural calculation should have a correct ComponentID that links the component to the calculation. The following data should be explicit in the structural calculations:

- Used forces on the component;

- Used load(s) on the component;
- Safety factors;
- Strength of the component in X, Y, and Z direction;
- Used profile;
- Used material, inclusive correlated strength class;
- Weight of the component;
- Function of the component;
- And if applicable: reinforcement ratios.

Performance certification

Certifications of the assembling of the component should be added to ensure that the component performs according to the calculations. The certifications are used by organisations in subsequent lifecycles to ensure that the quality of the building component is aligned with the performance requirements and calculations. This certification could be, for example, an CE certificate, KOMO certification or Bouwgarant certification. Like the LCA and the structural calculations a property set is added to the IFC that requires a link to the certification and is called "*PerformanceCertificate*".

6. Guidelines Circular Reuse ILS+

Nr.	Name	Explanatory notes
1.	Create a new folder	Create a new folder or place to create a project folder. This folder is used to store all project data.
2.	File name	Always ensure uniform and consistent naming of models and documents within a project. Every model should be aligned with the following structure: <projectname>_<discipline>_<aspect>.ifc For example, ResidentialJansen_structure_roof
3.	Construction level arrangement and naming	Each (aspect) model usage the following structure for naming building stories. <number><(optionally)floor letter>space<description>. For example, 00 GroundLevel and 01a FirstFloor. Assign each object is to the correct building story
4.	Modelled correctly	Check the following aspects: - Is the local position of models coordinated close to the point of origin? - Are all fasteners visualized in the details? - Are the components recognisable in the main BIM/IFC? - Does the BIM include all data from the "*Circular Reuse ILS+"*? - Are there are no duplicated components? - Is the model free from intersections between building components? - Are all predefined property sets from the excel "*Circular Reuse ILS+"* added? If one of these questions is answered with "*No"* add extra data or model further or adjust the model.
5.	Name all components	Give all building components a unique ComponentID. This identifier links the location of the component with the technical component data.
6.	Correct use of entities	Use the Entity as described in the "*Circular Reuse ILS+"* (ObjectType tab) for the object
7.	Export the BIM to an IFC	Check if all the previous steps are completed and all data of the "*Circular Reuse ILS+"* excel is added to the models. Then the BIM could be exported the BIM to an IFC. After exportation, place the IFC into the project folder.
8.	Add all certifications and calculations	Add a copy of the required certifications and calculations to the project folder. Make sure that the building components are identified with the ComponentID.
9.	Add all construction drawings	All drawings needed during construction should be stored in the project folder for decommissioning. Ensure that all connections around the building components are added and place these to the project folder
10.	Upload the project folder	Upload the whole project folder to a material platform to ensure that all data is accessible for a decommission stakeholder in the future.

7. Circular Reuse ILS+ Excel

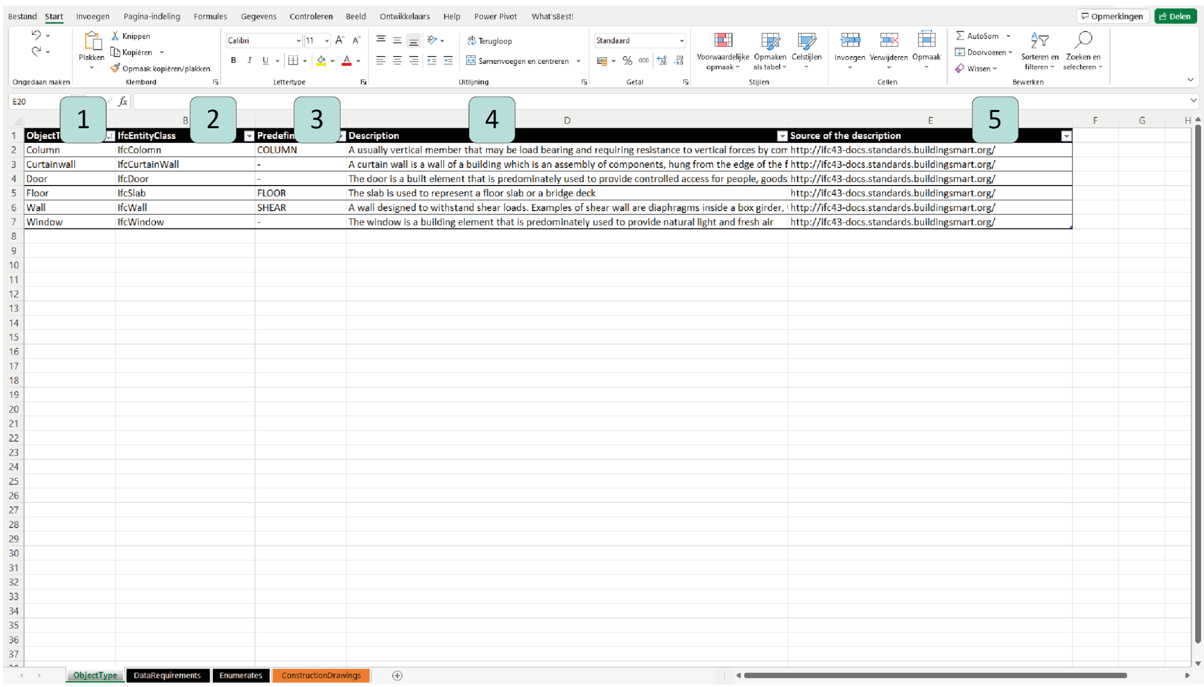
All the required data for reusing building components is structured in the excel "*Circular Reuse ILS+*" and could be used for projects which aim to reuse building components in following lifecycles. In the excel, required data requirements and exportation structured are defined for each object and thereby ensure that data is complete, structured, and uniform. A building engineer is thereby informed about the data requirements for exportation of a BIM in new circular AEC projects. The document becomes useful for the clients as well as the contractors and is based used for exportation to IFC.

The Reusable Component ILS consists of 4 tabs which all have a specific function. These tabs inform the modeler about the required data, correct naming, location, used entities, data typology, and correlated enumerates. The functioning and aim of the tabs are briefly highlighted in the following sections.

ObjectTypes

The tab ObjectTypes identify to which object typology should be exported to which entity. This is important to ensure that all data is stored in the correct place and complete. These characteristics are enough to inform the modeler to export the correct entities and use the correct name in all the files. Further, the modelling software recognises uniform names and can conduct analysis. The ObjectType tab shows a table with the correct names of the objects, the correlated IFC entity, predefined type, and a description of the object and the source of the description.

Since the aspect model and the main model both require different LOD, a lot of object types are included. A higher LOD means, overall, a high variety of building parts that are used. Therefore, this list is extensive. The list is based on the predefined standards of the NLRS. However, the allocation of entities is correct and could therefore be used in other software programmes too.



ObjectT	IfcEntityClass	Predefin	Description	Source of the description
Column	IfcColomn	COLUMN	A usually vertical member that may be load bearing and requiring resistance to vertical forces by com	http://ifc43-docs.standards.buildingsmart.org/
Curtainwall	IfcCurtainWall	-	A curtain wall is a wall of a building which is an assembly of components, hung from the edge of the f	http://ifc43-docs.standards.buildingsmart.org/
Door	IfcDoor	-	The door is a built element that is predominately used to provide controlled access for people, goods	http://ifc43-docs.standards.buildingsmart.org/
Floor	IfcSlab	FLOOR	The slab is used to represent a floor slab or a bridge deck	http://ifc43-docs.standards.buildingsmart.org/
Wall	IfcWall	SHEAR	A wall designed to withstand shear loads. Examples of shear wall are diaphragms inside a box girder,	http://ifc43-docs.standards.buildingsmart.org/
Window	IfcWindow	-	The window is a building element that is predominately used to provide natural light and fresh air	http://ifc43-docs.standards.buildingsmart.org/

Figure 3: ObjectType tab in Circular Reuse ILS+ excel (Source: Own Illustration)

1. ObjectType: The name of the object in the BIM;
2. ifcEntityClass: The name of the entity that the object should be exported to;

3. PredefinedType: The predefined type is a further specification of the object occurrence;
4. Description: A description of the object occurrence;
5. Source of the description: The source of the object description.

DataRequirements

There is a lot of data that should be included to the components to enable decommission. All identified data requirements are presented in this tab and therefore this tab is the most important and detailed tab of the excel. This tab informs which properties should be included in the IFC to enable circular reuse. The used property sets are derived from the buildingSMART preformulated property sets and from other ILSs. These are used to minimize the number of new property sets and thereby increase the recognisability and uniformity of the data. However, these current property sets are not sufficient to describe all data, therefore a custom property set is created called "*Pset_Circular_Reuse_ILS+*".

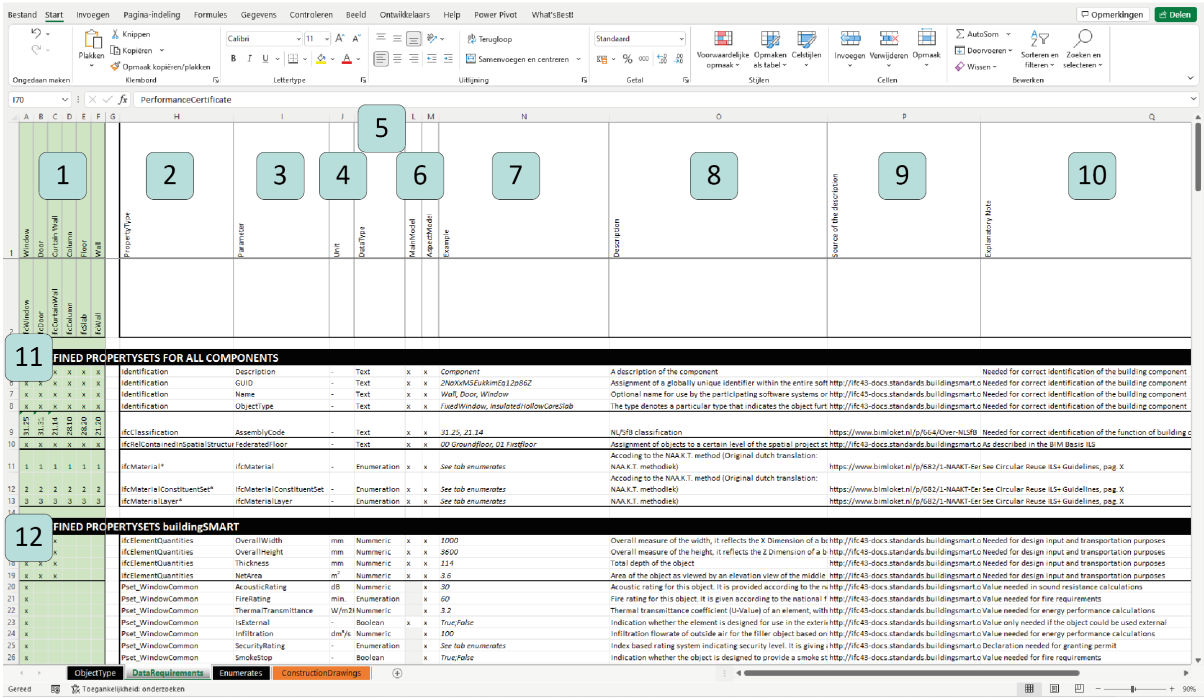


Figure 4: DataRequirements tab in Circular Reuse ILS+ excel (Source: Own Illustration)

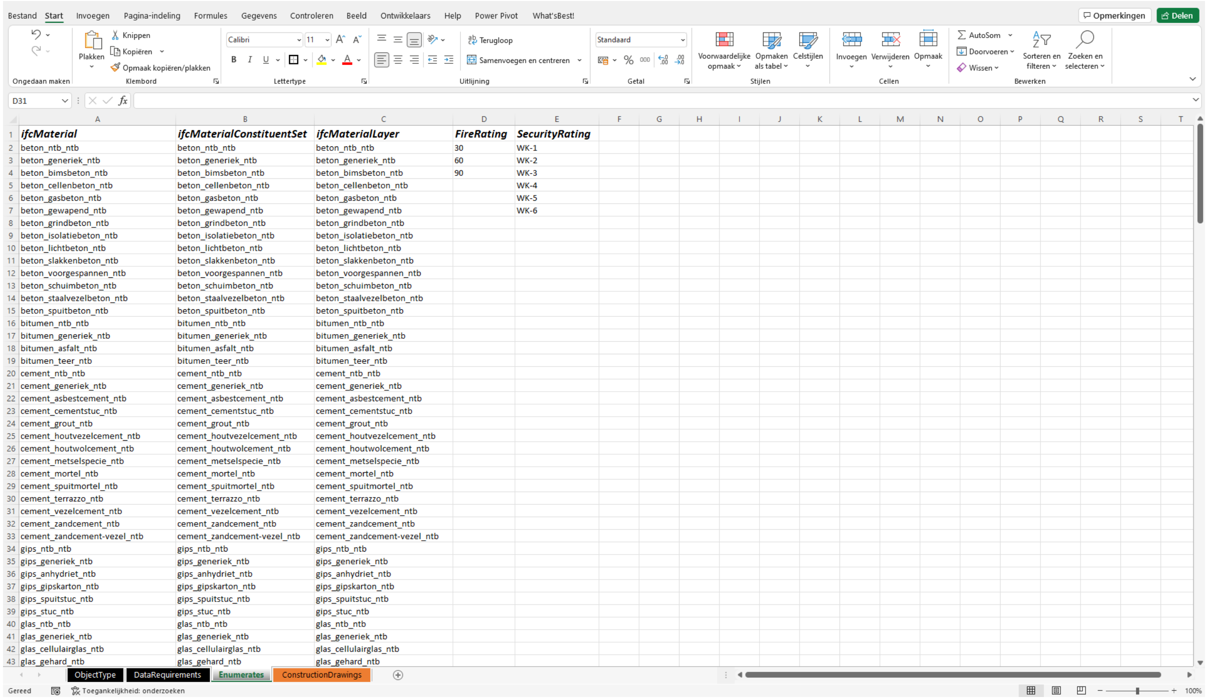
1. ObjectTypes: The researched object types are presented here. When an X is in a cell the property should be added to the object properties;
2. PropertyType: This column informs to what property set the data should be exported.
3. Parameter: The parameter shows the name of the property. The name "*parameter*" is derived from other ILS standards;
4. Unit: the unit of the data;
5. DataType: The form of the data;
6. MainModel and AspectModel: These columns show in what model the data should be stored. An X in a cell means that the property should be included in the model;
7. Example: An example of the data in the IFC;
8. Description: A description of the property;
9. Source of the description: The source of the property description;
10. Explanatory note: A brief explanatory note why the property is needed for circular reuse;
11. Predefined property sets for all components: Required standard property sets for all components;

12. Predefined property sets buildingSMART: Required buildingSMART property sets.

Materials of the objects should be added to the IFC too, this could be done with use of three different property sets. The use of the property set depends on the composition of the component. The ifcMaterial is used for homogeneous objects, this means that only a single material is used in the object. If a multitude of materials is used in the object, the ifcMaterialConstituentSet should be used. This could be used for a multitude of material and could be assigned to parts of a building component. The last option is the ifcMaterialLayerSet. In this entity different layers of one object could have a specified name and thickness. Important is that the NAA.K.T. method is used for naming the materials. This standardized naming structure ensures uniform and clear naming of materials. This simplifies recognisability and findability of the materials. A guide to implement the NAA.K.T. method could be found in chapter 8.

Enumerates

Some of the Parameters have an enumeration as datatype. This means that a value of a predefined list should be filled in for a specific property and ensures that organisations use the same data name in models. In this tab these parameters are presented, and the building modeler should use one of these enumerations during the naming of materials, fire rating and security rating. The names presented here are derived from the NAAK.T. method.



	A	B	C	D	E
1	***ifcMaterial***	***ifcMaterialConstituentSet***	***ifcMaterialLayer***	***FireRating***	***SecurityRating***
2	beton_ntb_ntb	beton_ntb_ntb	beton_ntb_ntb	30	WK-1
3	beton_generiek_ntb	beton_generiek_ntb	beton_generiek_ntb	60	WK-2
4	beton_bimsbeton_ntb	beton_bimsbeton_ntb	beton_bimsbeton_ntb	90	WK-3
5	beton_cellenbeton_ntb	beton_cellenbeton_ntb	beton_cellenbeton_ntb		WK-4
6	beton_gasbeton_ntb	beton_gasbeton_ntb	beton_gasbeton_ntb		WK-5
7	beton_gewapend_ntb	beton_gewapend_ntb	beton_gewapend_ntb		WK-6
8	beton_grindbeton_ntb	beton_grindbeton_ntb	beton_grindbeton_ntb		
9	beton_isolatiebeton_ntb	beton_isolatiebeton_ntb	beton_isolatiebeton_ntb		
10	beton_lichtbeton_ntb	beton_lichtbeton_ntb	beton_lichtbeton_ntb		
11	beton_slakkenbeton_ntb	beton_slakkenbeton_ntb	beton_slakkenbeton_ntb		
12	beton_voorgespannen_ntb	beton_voorgespannen_ntb	beton_voorgespannen_ntb		
13	beton_schuimbeton_ntb	beton_schuimbeton_ntb	beton_schuimbeton_ntb		
14	beton_staalvezelbeton_ntb	beton_staalvezelbeton_ntb	beton_staalvezelbeton_ntb		
15	beton_spuitbeton_ntb	beton_spuitbeton_ntb	beton_spuitbeton_ntb		
16	bitumen_ntb_ntb	bitumen_ntb_ntb	bitumen_ntb_ntb		
17	bitumen_generiek_ntb	bitumen_generiek_ntb	bitumen_generiek_ntb		
18	bitumen_asfalt_ntb	bitumen_asfalt_ntb	bitumen_asfalt_ntb		
19	bitumen_teer_ntb	bitumen_teer_ntb	bitumen_teer_ntb		
20	cement_ntb_ntb	cement_ntb_ntb	cement_ntb_ntb		
21	cement_generiek_ntb	cement_generiek_ntb	cement_generiek_ntb		
22	cement_asbestcement_ntb	cement_asbestcement_ntb	cement_asbestcement_ntb		
23	cement_cementstuc_ntb	cement_cementstuc_ntb	cement_cementstuc_ntb		
24	cement_grout_ntb	cement_grout_ntb	cement_grout_ntb		
25	cement_houtvezelcement_ntb	cement_houtvezelcement_ntb	cement_houtvezelcement_ntb		
26	cement_houtwolcement_ntb	cement_houtwolcement_ntb	cement_houtwolcement_ntb		
27	cement_metselspecie_ntb	cement_metselspecie_ntb	cement_metselspecie_ntb		
28	cement_mortel_ntb	cement_mortel_ntb	cement_mortel_ntb		
29	cement_spuitmortel_ntb	cement_spuitmortel_ntb	cement_spuitmortel_ntb		
30	cement_terrazzo_ntb	cement_terrazzo_ntb	cement_terrazzo_ntb		
31	cement_vezelcement_ntb	cement_vezelcement_ntb	cement_vezelcement_ntb		
32	cement_zandcement_ntb	cement_zandcement_ntb	cement_zandcement_ntb		
33	cement_zandcement-vezel_ntb	cement_zandcement-vezel_ntb	cement_zandcement-vezel_ntb		
34	gips_ntb_ntb	gips_ntb_ntb	gips_ntb_ntb		
35	gips_generiek_ntb	gips_generiek_ntb	gips_generiek_ntb		
36	gips_anhydriet_ntb	gips_anhydriet_ntb	gips_anhydriet_ntb		
37	gips_gipskarton_ntb	gips_gipskarton_ntb	gips_gipskarton_ntb		
38	gips_spuitstuc_ntb	gips_spuitstuc_ntb	gips_spuitstuc_ntb		
39	gips_stuc_ntb	gips_stuc_ntb	gips_stuc_ntb		
40	glas_ntb_ntb	glas_ntb_ntb	glas_ntb_ntb		
41	glas_generiek_ntb	glas_generiek_ntb	glas_generiek_ntb		
42	glas_cellulairglas_ntb	glas_cellulairglas_ntb	glas_cellulairglas_ntb		
43	glas_gehard_ntb	glas_gehard_ntb	glas_gehard_ntb		

Figure 5: Enumerates tab in Circular Reuse ILS+ excel (Source: Own Illustration)

ConstructionDrawings

This tab illustrates which drawings should be added to the project to deconstruct the asset. It is important that all drawings required for construction are also presented during the deconstruction phase. Therefore, they should be added to the project folder too. In the detail drawings it should be explicit how the joint could be decommissioned. This means that the mechanical fastener should be modelled. In case of a chemical fastener, a description or note should be explicit how the joint can be disassembled without damaging building parts.

8. Other helpful documents and links

Exportation help

For help with exportation the BIMloket provides some helpful guidelines for exportation. These documents could help with the exportation from native BIM software to an IFC file.

Link to the guidelines (most of them are in Dutch):
https://www.bimloket.nl/p/363/Handleidingen

Used standards

NAA.K.T. method

The NAA.K.T method is an structured method to describe building materials and their characteristics.This structure aims to provide an unambiguous description of building materials and their appearance. NAA.K.T. is an abbreviation of NAAm_Kenmerk_Toepassing (translation: name_characterisic_application). This ensures that all materials and appearances of materials are described in a uniform method, which helps software to understand the provided description.

Link to the NAA.K.T. material naming:
https://www.bimloket.nl/p/682/1-NAAKT-Eenduidige-materiaalbenaming

ObjectType	IfcEntityClass	PredefinedType	Description	Source of the description
Column	IfcColomn	COLUMN	A usually vertical member that may be load bearing and requiring resistance to vertical forces by compression	http://ifc43-docs.standards.buildingsmart.org/
Curtainwall	IfcCurtainWall	-	A curtain wall is a wall of a building which is an assembly of components, hung from the edge of the floor/roof	http://ifc43-docs.standards.buildingsmart.org/
Door	IfcDoor	-	The door is a built element that is predominately used to provide controlled access for people, goods, animals	http://ifc43-docs.standards.buildingsmart.org/
Floor	IfcSlab	FLOOR	The slab is used to represent a floor slab or a bridge deck	http://ifc43-docs.standards.buildingsmart.org/
Wall	IfcWall	SHEAR	A wall designed to withstand shear loads. Examples of shear wall are diaphragms inside a box girder, typically (	http://ifc43-docs.standards.buildingsmart.org/
Window	IfcWindow	-	The window is a building element that is predominately used to provide natural light and fresh air	http://ifc43-docs.standards.buildingsmart.org/

Window	Door	Curtain Wall	Column	Floor	Wall	PropertyType	Parameter	Unit	DataType	MainModel	AspectModel	Example	Description	Source of the description	Explanatory Note
ifcWindow	ifcDoor	ifcCurtainWall	ifcColumn	ifcSlab	ifcWall					LOD-200	LOD-350				
PREDEFINED PROPERTYSETS FOR ALL COMPONENTS															
x	x	x	x	x	x	Identification	Description	-	Text	x	x	*Component*	A description of the component		Needed for correct identification of the building component
x	x	x	x	x	x	Identification	GUID	-	Text	x	x	*2NaXxM5EukkimEq12p86Z*	Assignment of a globally unique identifier within the entire software v	http://ifc43-docs.standards.buildingsmart.org/	Needed for correct identification of the building component
x	x	x	x	x	x	Identification	Name	-	Text	x	x	*Wall, Door, Window*	Optional name for use by the participating software systems or users.	http://ifc43-docs.standards.buildingsmart.org/	Needed for correct identification of the building component
x	x	x	x	x	x	Identification	ObjectType	-	Text	x	x	*FixedWindow, InsulatedHollowCoreSlab*	The type denotes a particular type that indicates the object further.	http://ifc43-docs.standards.buildingsmart.org/	Needed for correct identification of the building component
31.25	31.31	21.14	28.10	23.20	21.20	ifcClassification	AssemblyCode	-	Text	x	x	*31.25, 21.14*	NL/SfB classification	https://www.bimloket.nl/p/664/Over-NLSfB	Needed for correct identification of the function of building component
x	x	x	x	x	x	ifcRelContainedInSpatialStructure	FederatedFloor	-	Text	x	x	*00 Groundfloor, 01 Firstfloor*	Assignment of objects to a certain level of the spatial project structur	http://ifc43-docs.standards.buildingsmart.org/	As described in the BIM Basis ILS
1	1	1	1	1	1	ifcMaterial*	ifcMaterial	-	Enumeration	x	x	*See tab enumerates*	Accoding to the NAA.K.T. method (Original dutch translation: NAA.K.T	https://www.bimloket.nl/p/682/1-NAAKT-Eendu	See Circular Reuse ILS+ Guidelines, pag. X
2	2	2	2	2	2	ifcMaterialConstituentSet*	ifcMaterialConstituentSet	-	Enumeration	x	x	*See tab enumerates*	Accoding to the NAA.K.T. method (Original dutch translation: NAA.K.T	https://www.bimloket.nl/p/682/1-NAAKT-Eendu	See Circular Reuse ILS+ Guidelines, pag. X
3	3	3	3	3	3	ifcMaterialLayer*	ifcMaterialLayer	-	Enumeration	x	x	*See tab enumerates*	Accoding to the NAA.K.T. method (Original dutch translation: NAA.K.T	https://www.bimloket.nl/p/682/1-NAAKT-Eendu	See Circular Reuse ILS+ Guidelines, pag. X
PREDEFINED PROPERTYSETS buildingSMART															
x	x	x				ifcElementQuantities	OverallWidth	mm	Nummeric	x	x	*1000*	Overall measure of the width, it reflects the X Dimension of a boundir	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
x	x	x				ifcElementQuantities	OverallHeight	mm	Nummeric	x	x	*3600*	Overall measure of the height, it reflects the Z Dimension of a boundi	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
x	x	x				ifcElementQuantities	Thickness	mm	Nummeric	x	x	*114*	Total depth of the object	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
x	x	x				ifcElementQuantities	NetArea	m^2	Nummeric	x	x	*3.6*	Area of the object as viewed by an elevation view of the middle plane	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
x						Pset_WindowCommon	AcousticRating	dB	Nummeric		x	*30*	Acoustic rating for this object. It is provided according to the national	http://ifc43-docs.standards.buildingsmart.org/	Value needed in sound resistance calculations
x						Pset_WindowCommon	FireRating	min.	Enumeration		x	*60*	Fire rating for this object. It is given according to the national fire safe	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
x						Pset_WindowCommon	ThermalTransmittance	W/m2K	Nummeric		x	*3.2*	Thermal transmittance coefficient (U-Value) of an element, within the	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
x						Pset_WindowCommon	IsExternal	-	Boolean		x	*True;False*	Indication whether the element is designed for use in the exterior (TR	http://ifc43-docs.standards.buildingsmart.org/	Value only needed if the object could be used external
x						Pset_WindowCommon	Infiltration	dm^3/s	Nummeric		x	*100*	Infiltration flowrate of outside air for the filler object based on the are	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
x						Pset_WindowCommon	SecurityRating	-	Enumeration		x	*See tab enumerates*	Index based rating system indicating security level. It is giving accordi	http://ifc43-docs.standards.buildingsmart.org/	Declaration needed for granting permit
x						Pset_WindowCommon	SmokeStop	-	Boolean		x	*True;False*	Indication whether the object is designed to provide a smoke stop (TF	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
x						Pset_WindowCommon	GlazingAreaFraction	m2	Nummeric		x	*0.5*	Fraction of the glazing area relative to the total area of the filling elem	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
x						Pset_DoorWindowGlazingType	SolarTransmittance	W/m2	Nummeric		x	*0.65*	The ratio of incident solar radiation that directly passes through a syst	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
x						Pset_ManufacturerTypeInformation	PerformanceCertificate	-	Text		x	*Link to the performance certificate of the manufacture*	Manufacturer's performance certificate	http://ifc43-docs.standards.buildingsmart.org/	Certification needed for facilitation of reuse
	x					Pset_DoorCommon	AcousticRating	dB	Nummeric		x	*30*	Acoustic rating for this object. It is provided according to the national	http://ifc43-docs.standards.buildingsmart.org/	Value needed in sound resistance calculations
	x					Pset_DoorCommon	FireRating	min.	Enumeration		x	*60*	Fire rating for this object. It is given according to the national fire safe	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
	x					Pset_DoorCommon	ThermalTransmittance	W/m2K	Nummeric		x	*3.2*	Thermal transmittance coefficient (U-Value) of an element, within the	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
	x					Pset_DoorCommon	IsExternal	-	Boolean		x	*True;False*	Indication whether the element is designed for use in the exterior (TR	http://ifc43-docs.standards.buildingsmart.org/	Value only needed if the object could be used external
	x					Pset_DoorCommon	Infiltration	dm^3/s	Nummeric		x	*100*	Infiltration flowrate of outside air for the filler object based on the are	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
	x					Pset_DoorCommon	SecurityRating	-	Enumeration		x	*See tab enumerates*	Index based rating system indicating security level. It is giving accordi	http://ifc43-docs.standards.buildingsmart.org/	Declaration needed for granting permit
	x					Pset_DoorCommon	SmokeStop	-	Boolean		x	*True;False*	Indication whether the object is designed to provide a smoke stop (TF	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
	x					Pset_DoorCommon	FireExit	-	Boolean		x	*True;False*	Indication whether this object is designed to serve as an exit in the ca	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
	x					Pset_DoorCommon	SelfClosing	-	Boolean		x	*True;False*	Indication whether this object is designed to close automatically after	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
	x					Pset_DoorCommon	GlazingAreaFraction	m2	Nummeric		x	*0.5*	Fraction of the glazing area relative to the total area of the filling elem	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
	x					Pset_DoorWindowGlazingType	SolarTransmittance	W/m2	Nummeric		x	*0.65*	The ratio of incident solar radiation that directly passes through a syst	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
	x					Pset_ManufacturerTypeInformation	PerformanceCertificate	-	Text		x	*Link to the performance certificate of the manufacture*	Manufacturer's performance certificate	http://ifc43-docs.standards.buildingsmart.org/	Certification needed for facilitation of reuse
		x				Pset_CurtainWallCommon	AcousticRating	dB	Nummeric		x	*30*	Acoustic rating for this object. It is provided according to the national	http://ifc43-docs.standards.buildingsmart.org/	Value needed in sound resistance calculations
		x				Pset_CurtainWallCommon	FireRating	min.	Enumeration		x	*60*	Fire rating for this object. It is given according to the national fire safe	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
		x				Pset_CurtainWallCommon	ThermalTransmittance	W/m2K	Nummeric		x	*3.2*	Thermal transmittance coefficient (U-Value) of an element, within the	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
		x				Pset_CurtainWallCommon	IsExternal	-	Boolean		x	*True;False*	Indication whether the element is designed for use in the exterior (TR	http://ifc43-docs.standards.buildingsmart.org/	Value only needed if the object could be used external
		x				Pset_ManufacturerTypeInformation	PerformanceCertificate	-	Text		x	*Link to the performance certificate of the manufacture*	Manufacturer's performance certificate	http://ifc43-docs.standards.buildingsmart.org/	Certification needed for facilitation of reuse
			x			Pset_ColumnCommon	Slope	°	Nummeric	x	x	*90*	Slope angle - relative to horizontal (0.0 degrees).	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
			x			Pset_ColumnCommon	IsExternal	-	Boolean		x	*True;False*	Indication whether the element is designed for use in the exterior (TR	http://ifc43-docs.standards.buildingsmart.org/	Value only needed if the object could be used external
			x			Pset_ColumnCommon	ThermalTransmittance	W/m2K	Nummeric		x	*3.2*	Thermal transmittance coefficient (U-Value) of an element, within the	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
			x			Pset_ColumnCommon	LoadBearing	-	Boolean		x	*True;False*	Indicates whether the object is intended to carry loads (TRUE) or not (	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input in subsequent lifecycle
			x			Pset_ColumnCommon	FireRating	min.	Nummeric		x	*60*	Fire rating for this object. It is given according to the national fire safe	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
			x			Pset_ManufacturerTypeInformation	PerformanceCertificate	-	Text		x	*Link to the performance certificate of the manufacture*	Manufacturer's performance certificate	http://ifc43-docs.standards.buildingsmart.org/	Certification needed for facilitation of reuse
			x			Qto_ColumnBaseQuantities	Length	mm	Nummeric	x	x	*2500*	The length of the object. Not taking into account any cut-out's or othe	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
			x			Qto_ColumnBaseQuantities	CrossSectionArea	mm	Nummeric	x	x	*250*	Total area of the cross section (or profile) of the object.	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
			x			Qto_ColumnBaseQuantities	NetWeight	kg	Nummeric		x	*1000*	account possible processing features (cut-out's, etc.) or openings	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
				x		Pset_SlabCommon	AcousticRating	dB	Nummeric		x	*30*	Acoustic rating for this object. It is provided according to the national	http://ifc43-docs.standards.buildingsmart.org/	Value needed in sound resistance calculations
				x		Pset_SlabCommon	FireRating	min.	Enumeration		x	*60*	Fire rating for this object. It is given according to the national fire safe	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
				x		Pset_SlabCommon	IsExternal	-	Boolean		x	*True;False*	Indication whether the element is designed for use in the exterior (TR	http://ifc43-docs.standards.buildingsmart.org/	Value only needed if the object could be used external
				x		Pset_SlabCommon	ThermalTransmittance	W/m2K	Nummeric		x	*3.2*	Thermal transmittance coefficient (U-Value) of an element, within the	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
				x		Pset_SlabCommon	LoadBearing	-	Boolean		x	*True;False*	Indicates whether the object is intended to carry loads (TRUE) or not (	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input in subsequent lifecycle
				x		Pset_ManufacturerTypeInformation	PerformanceCertificate	-	Text		x	*Link to the performance certificate of the manufacture*	Manufacturer's performance certificate	http://ifc43-docs.standards.buildingsmart.org/	Certification needed for facilitation of reuse
				x		Qto_SlabBaseQuantities	Width	mm	Nummeric	x	x	*1200*	The width of the object. Only given, if the object has constant thickne	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
				x		Qto_SlabBaseQuantities	Length	mm	Nummeric	x	x	*2500*	The length of the object. Only provided if rectangular.	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
				x		Qto_SlabBaseQuantities	Depth	mm	Nummeric	x	x	*250*	The depth of the object. Depth (one direction of the non-projected fo	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
				x		Qto_SlabBaseQuantities	NetWeight	kg	Nummeric		x	*1000*	account possible processing features (cut-out's, etc.) or openings	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
					x	Pset_WallCommon	AcousticRating	dB	Nummeric		x	*30*	Acoustic rating for this object. It is provided according to the national	http://ifc43-docs.standards.buildingsmart.org/	Value needed in sound resistance calculations
					x	Pset_WallCommon	FireRating	min.	Enumeration		x	*60*	Fire rating for this object. It is given according to the national fire safe	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
					x	Pset_WallCommon	IsExternal	-	Boolean		x	*True;False*	Indication whether the element is designed for use in the exterior (TR	http://ifc43-docs.standards.buildingsmart.org/	Value only needed if the object could be used external

Window	Door	Curtain Wall	Column	Floor	Wall	PropertyType	Parameter	Unit	DataType	MainModel	AspectModel	Example	Description	Source of the description	Explanatory Note
ifcWindow	ifcDoor	ifcCurtainWall	ifcColumn	ifcSlab	ifcWall					LOD-200	LOD-350				
					x	Pset_WallCommon	ThermalTransmittance	W/m2K	Nummeric		x	*3.2*	Thermal transmittance coefficient (U-Value) of an element, within the	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
					x	Pset_WallCommon	LoadBearing	-	Boolean		x	*True;False*	Indicates whether the object is intended to carry loads (TRUE) or not (	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input in subsequent lifecycle
					x	Pset_ManufacturerTypeInformation	PerformanceCertificate	-	Text		x	*Link to the performance certificate of the manufacture*	Manufacturer's performance certificate	http://ifc43-docs.standards.buildingsmart.org/	Certification needed for facilitation of reuse
					x	Qto_WallBaseQuantities	Length	mm	Nummeric	x	x	*2500*	The length of the object. Along center line (even if different to the wa	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
					x	Qto_WallBaseQuantities	Width	mm	Nummeric	x	x	*250*	The width of the object. Only given, if the object has constant thickne	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
					x	Qto_WallBaseQuantities	Height	mm	Nummeric	x	x	*3600*	Characteristic height. Total nominal height of the wall. It should only l	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
					x	Qto_WallBaseQuantities	NetWeight	kg	Nummeric		x	*1000*	account possible processing features (cut-out's, etc.) or openings	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input and transportation purposes
NEW PROPERTYSETS CIRCULAR REUSE ILS															
x	x	x				Pset_Circular_Reuse_ILS+	LoadBearing	-	Boolean		x	*True;False*	Indicates whether the object is intended to carry loads (TRUE) or not (	http://ifc43-docs.standards.buildingsmart.org/	Needed for design input in subsequent lifecycle
x	x	x				Pset_Circular_Reuse_ILS+	Waterproofness	Pa	Nummeric		x	*300*	Waterproofness, expressed in Pa. Threshold value in accordance with	ILS_Gevel_0.9	Value only needed if the object could be used external
x	x	x				Pset_Circular_Reuse_ILS+	NetWeight	kg	Nummeric		x	*1000*	Total net weight of the object without add-on parts, taking into account possible processing features (cut-out's, etc.) o		Needed for design input and transportation purposes
		x				Pset_Circular_Reuse_ILS+	Infiltration	dm^3/s	Nummeric		x	*100*	Infiltration flowrate of outside air for the filler object based on the are	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
		x				Pset_Circular_Reuse_ILS+	SmokeStop	-	Boolean		x	*True;False*	Indication whether the object is designed to provide a smoke stop (TR	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
		x				Pset_Circular_Reuse_ILS+	GlazingAreaFraction	m2	Nummeric		x	*0.5*	Fraction of the glazing area relative to the total area of the filling elem	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
		x				Pset_Circular_Reuse_ILS+	SolarTransmittance	W/m2	Nummeric		x	*0.65*	The ratio of incident solar radiation that directly passes through a syst	http://ifc43-docs.standards.buildingsmart.org/	Value needed for energy performance calculations
		x				Pset_Circular_Reuse_ILS+	SecurityRating	-	Enumeration		x	*See tab enumerates*	Index based rating system indicating security level. It is giving accordi	http://ifc43-docs.standards.buildingsmart.org/	Declaration needed for granting permit
		x				Pset_Circular_Reuse_ILS+	FireExit	-	Boolean		x	*True;False*	Indication whether this object is designed to serve as an exit in the ca	http://ifc43-docs.standards.buildingsmart.org/	Value needed for fire requirements
			x			Pset_Circular_Reuse_ILS+	AcousticRating	dB	Nummeric		x	*30*	Acoustic rating for this object. It is provided according to the national	http://ifc43-docs.standards.buildingsmart.org/	Value needed in sound resistance calculations
			x	x	x	Pset_Circular_Reuse_ILS+	AcousticRatingContact	dB	Nummeric		x	*30*	Contact acoustic rating for this object. It is provided according to the national building code.		Value needed in sound resistance calculations
			x	x	x	Pset_Circular_Reuse_ILS+	StructuralCalculations	-	Text		x	*Link to the structural calculations of the component*			
x	x	x	x	x	x	Pset_Circular_Reuse_ILS+	ThermalResistance	(m2*K)/W	Nummeric		x	*3.5*	Thermal Resistance of a building object, the Rc-value	https://www.joostdevree.nl/shtmls/r-waarde.sh	Value needed for energy performance calculations
x	x	x	x	x	x	Pset_Circular_Reuse_ILS+	ColourOutside	-	Text		x	*DarkGray, Ral-9001*	Colour outside, expressed in RAL	ILS_Gevel_0.9	Value only needed if the object could be used external
x	x	x	x	x	x	Pset_Circular_Reuse_ILS+	LCACalculations	-	Text		x	*Link to the LCA calculations of the component*			
x	x	x	x	x	x	Pset_Circular_Reuse_ILS+	BagPandId	-	Nummeric	x	x	492100000030559	Addresses and Buildings ID Register (Basisregistratie Adressen en Geb	https://bagviewer.kadaster.nl	Needed for correct identification of the building component

1 IfcMaterial is a homogeneous or inhomogeneous substance that can be used to form elements (physical products or their components).
http://ifc43-docs.standards.buildingsmart.org/IFC/RELEASE/IFC4x3/HTML/lexical/IfcMaterial.htm

2 IfcMaterialConstituentSet is a collection of individual material constituents, each assigning a material to a part of an element.
http://ifc43-docs.standards.buildingsmart.org/IFC/RELEASE/IFC4x3/HTML/lexical/IfcMaterialConstituentSet.htm

3 IfcMaterialLayerSet is a designation by which materials of an element constructed of a number of material layers is known and through which the relative positioning of individual layers can be expressed.
http://ifc43-docs.standards.buildingsmart.org/IFC/RELEASE/IFC4x3/HTML/lexical/IfcMaterialLayer.htm

ifcMaterial	*ifcMaterialConstituentSet*	*ifcMaterialLayer*	*FireRating*	*SecurityRating*
beton_ntb_ntb	beton_ntb_ntb	beton_ntb_ntb	30	WK-1
beton_generiek_ntb	beton_generiek_ntb	beton_generiek_ntb	60	WK-2
beton_bimsbeton_ntb	beton_bimsbeton_ntb	beton_bimsbeton_ntb	90	WK-3
beton_cellenbeton_ntb	beton_cellenbeton_ntb	beton_cellenbeton_ntb		WK-4
beton_gasbeton_ntb	beton_gasbeton_ntb	beton_gasbeton_ntb		WK-5
beton_gewapend_ntb	beton_gewapend_ntb	beton_gewapend_ntb		WK-6
beton_grindbeton_ntb	beton_grindbeton_ntb	beton_grindbeton_ntb		
beton_isolatiebeton_ntb	beton_isolatiebeton_ntb	beton_isolatiebeton_ntb		
beton_lichtbeton_ntb	beton_lichtbeton_ntb	beton_lichtbeton_ntb		
beton_slakkenbeton_ntb	beton_slakkenbeton_ntb	beton_slakkenbeton_ntb		
beton_voorgespannen_ntb	beton_voorgespannen_ntb	beton_voorgespannen_ntb		
beton_schuimbeton_ntb	beton_schuimbeton_ntb	beton_schuimbeton_ntb		
beton_staalvezelbeton_ntb	beton_staalvezelbeton_ntb	beton_staalvezelbeton_ntb		
beton_spuitbeton_ntb	beton_spuitbeton_ntb	beton_spuitbeton_ntb		
bitumen_ntb_ntb	bitumen_ntb_ntb	bitumen_ntb_ntb		
bitumen_generiek_ntb	bitumen_generiek_ntb	bitumen_generiek_ntb		
bitumen_asfalt_ntb	bitumen_asfalt_ntb	bitumen_asfalt_ntb		
bitumen_teer_ntb	bitumen_teer_ntb	bitumen_teer_ntb		
cement_ntb_ntb	cement_ntb_ntb	cement_ntb_ntb		
cement_generiek_ntb	cement_generiek_ntb	cement_generiek_ntb		
cement_asbestcement_ntb	cement_asbestcement_ntb	cement_asbestcement_ntb		
cement_cementstuc_ntb	cement_cementstuc_ntb	cement_cementstuc_ntb		
cement_grout_ntb	cement_grout_ntb	cement_grout_ntb		
cement_houtvezelcement_ntb	cement_houtvezelcement_ntb	cement_houtvezelcement_ntb		
cement_houtwolcement_ntb	cement_houtwolcement_ntb	cement_houtwolcement_ntb		
cement_metselspecie_ntb	cement_metselspecie_ntb	cement_metselspecie_ntb		
cement_mortel_ntb	cement_mortel_ntb	cement_mortel_ntb		
cement_spuitmortel_ntb	cement_spuitmortel_ntb	cement_spuitmortel_ntb		
cement_terrazzo_ntb	cement_terrazzo_ntb	cement_terrazzo_ntb		
cement_vezelcement_ntb	cement_vezelcement_ntb	cement_vezelcement_ntb		
cement_zandcement_ntb	cement_zandcement_ntb	cement_zandcement_ntb		
cement_zandcement-vezel_ntb	cement_zandcement-vezel_ntb	cement_zandcement-vezel_ntb		
gips_ntb_ntb	gips_ntb_ntb	gips_ntb_ntb		
gips_generiek_ntb	gips_generiek_ntb	gips_generiek_ntb		
gips_anhydriet_ntb	gips_anhydriet_ntb	gips_anhydriet_ntb		
gips_gipskarton_ntb	gips_gipskarton_ntb	gips_gipskarton_ntb		
gips_spuitstuc_ntb	gips_spuitstuc_ntb	gips_spuitstuc_ntb		
gips_stuc_ntb	gips_stuc_ntb	gips_stuc_ntb		
glas_ntb_ntb	glas_ntb_ntb	glas_ntb_ntb		
glas_generiek_ntb	glas_generiek_ntb	glas_generiek_ntb		
glas_cellulairglas_ntb	glas_cellulairglas_ntb	glas_cellulairglas_ntb		
glas_gehard_ntb	glas_gehard_ntb	glas_gehard_ntb		
glas_gewapend_ntb	glas_gewapend_ntb	glas_gewapend_ntb		
glas_helder_ntb	glas_helder_ntb	glas_helder_ntb		
glas_kwartsglas_ntb	glas_kwartsglas_ntb	glas_kwartsglas_ntb		
glas_opaal_ntb	glas_opaal_ntb	glas_opaal_ntb		
glas_spiegelend_ntb	glas_spiegelend_ntb	glas_spiegelend_ntb		
grondstof_ntb_ntb	grondstof_ntb_ntb	grondstof_ntb_ntb		
grondstof_generiek_ntb	grondstof_generiek_ntb	grondstof_generiek_ntb		
grondstof_aarde_ntb	grondstof_aarde_ntb	grondstof_aarde_ntb		
grondstof_bimszand_ntb	grondstof_bimszand_ntb	grondstof_bimszand_ntb		
grondstof_grind_ntb	grondstof_grind_ntb	grondstof_grind_ntb		
grondstof_kalk_ntb	grondstof_kalk_ntb	grondstof_kalk_ntb		
grondstof_klei_ntb	grondstof_klei_ntb	grondstof_klei_ntb		
grondstof_leem_ntb	grondstof_leem_ntb	grondstof_leem_ntb		
grondstof_lucht_ntb	grondstof_lucht_ntb	grondstof_lucht_ntb		
grondstof_silt_ntb	grondstof_silt_ntb	grondstof_silt_ntb		
grondstof_split_ntb	grondstof_split_ntb	grondstof_split_ntb		
grondstof_turf_ntb	grondstof_turf_ntb	grondstof_turf_ntb		
grondstof_water_ntb	grondstof_water_ntb	grondstof_water_ntb		
grondstof_zand_ntb	grondstof_zand_ntb	grondstof_zand_ntb		
hout_ntb_ntb	hout_ntb_ntb	hout_ntb_ntb		
hout_generiek_ntb	hout_generiek_ntb	hout_generiek_ntb		
hout_accoya_ntb	hout_accoya_ntb	hout_accoya_ntb		
hout_azobe_ntb	hout_azobe_ntb	hout_azobe_ntb		
hout_balsa_ntb	hout_balsa_ntb	hout_balsa_ntb		
hout_bangkirai_ntb	hout_bangkirai_ntb	hout_bangkirai_ntb		
hout_berken_ntb	hout_berken_ntb	hout_berken_ntb		
hout_beuken_ntb	hout_beuken_ntb	hout_beuken_ntb		
hout_bilinga_ntb	hout_bilinga_ntb	hout_bilinga_ntb		
hout_board_ntb	hout_board_ntb	hout_board_ntb		
hout_clt_ntb	hout_clt_ntb	hout_clt_ntb		
hout_douglas_ntb	hout_douglas_ntb	hout_douglas_ntb		
hout_ebben_ntb	hout_ebben_ntb	hout_ebben_ntb		
hout_eiken_ntb	hout_eiken_ntb	hout_eiken_ntb		

ifcMaterial	ifcMaterialConstituentSet	ifcMaterialLayer	FireRating	SecurityRating
hout_esdoorn_ntb	hout_esdoorn_ntb	hout_esdoorn_ntb		
hout_essen_ntb	hout_essen_ntb	hout_essen_ntb		
hout_gemodificeerd_ntb	hout_gemodificeerd_ntb	hout_gemodificeerd_ntb		
hout_grenen_ntb	hout_grenen_ntb	hout_grenen_ntb		
hout_hardboard_ntb	hout_hardboard_ntb	hout_hardboard_ntb		
hout_hardhout_ntb	hout_hardhout_ntb	hout_hardhout_ntb		
hout_houtspaan_ntb	hout_houtspaan_ntb	hout_houtspaan_ntb		
hout_houtvezel_ntb	hout_houtvezel_ntb	hout_houtvezel_ntb		
hout_houtwol_ntb	hout_houtwol_ntb	hout_houtwol_ntb		
hout_kersen_ntb	hout_kersen_ntb	hout_kersen_ntb		
hout_lariks_ntb	hout_lariks_ntb	hout_lariks_ntb		
hout_mahonie_ntb	hout_mahonie_ntb	hout_mahonie_ntb		
hout_masonite_ntb	hout_masonite_ntb	hout_masonite_ntb		
hout_mdf_ntb	hout_mdf_ntb	hout_mdf_ntb		
hout_meranti_ntb	hout_meranti_ntb	hout_meranti_ntb		
hout_merbau_ntb	hout_merbau_ntb	hout_merbau_ntb		
hout_multiplex_ntb	hout_multiplex_ntb	hout_multiplex_ntb		
hout_noten_ntb	hout_noten_ntb	hout_noten_ntb		
hout_okoume_ntb	hout_okoume_ntb	hout_okoume_ntb		
hout_osb_ntb	hout_osb_ntb	hout_osb_ntb		
hout_populieren_ntb	hout_populieren_ntb	hout_populieren_ntb		
hout_spaanplaat_ntb	hout_spaanplaat_ntb	hout_spaanplaat_ntb		
hout_triplex_ntb	hout_triplex_ntb	hout_triplex_ntb		
hout_vuren_ntb	hout_vuren_ntb	hout_vuren_ntb		
hout_wenge_ntb	hout_wenge_ntb	hout_wenge_ntb		
hout_ceder_ntb	hout_ceder_ntb	hout_ceder_ntb		
hout_zaagsel_ntb	hout_zaagsel_ntb	hout_zaagsel_ntb		
hout_zachtboard_ntb	hout_zachtboard_ntb	hout_zachtboard_ntb		
hout_zachthout_ntb	hout_zachthout_ntb	hout_zachthout_ntb		
isolatie_ntb_ntb	isolatie_ntb_ntb	isolatie_ntb_ntb		
isolatie_generiek_ntb	isolatie_generiek_ntb	isolatie_generiek_ntb		
isolatie_eps_ntb	isolatie_eps_ntb	isolatie_eps_ntb		
isolatie_fenolhars_ntb	isolatie_fenolhars_ntb	isolatie_fenolhars_ntb		
isolatie_glaswol_ntb	isolatie_glaswol_ntb	isolatie_glaswol_ntb		
isolatie_geexpandeerd-perliet_ntb	isolatie_geexpandeerd-perliet_ntb	isolatie_geexpandeerd-perliet_ntb		
isolatie_hardschuim_ntb	isolatie_hardschuim_ntb	isolatie_hardschuim_ntb		
isolatie_mineralewol_ntb	isolatie_mineralewol_ntb	isolatie_mineralewol_ntb		
isolatie_mineraal_ntb	isolatie_mineraal_ntb	isolatie_mineraal_ntb		
isolatie_resolschuim_ntb	isolatie_resolschuim_ntb	isolatie_resolschuim_ntb		
isolatie_siliperliet_ntb	isolatie_siliperliet_ntb	isolatie_siliperliet_ntb		
isolatie_pir_ntb	isolatie_pir_ntb	isolatie_pir_ntb		
isolatie_pur_ntb	isolatie_pur_ntb	isolatie_pur_ntb		
isolatie_solperlite_ntb	isolatie_solperlite_ntb	isolatie_solperlite_ntb		
isolatie_steenwol_ntb	isolatie_steenwol_ntb	isolatie_steenwol_ntb		
isolatie_xps_ntb	isolatie_xps_ntb	isolatie_xps_ntb		
kunststof_ntb_ntb	kunststof_ntb_ntb	kunststof_ntb_ntb		
kunststof_generiek_ntb	kunststof_generiek_ntb	kunststof_generiek_ntb		
kunststof_abs_ntb	kunststof_abs_ntb	kunststof_abs_ntb		
kunststof_aeryl_ntb	kunststof_aeryl_ntb	kunststof_aeryl_ntb		
kunststof_dpc_ntb	kunststof_dpc_ntb	kunststof_dpc_ntb		
kunststof_elastomere-foam_ntb	kunststof_elastomere-foam_ntb	kunststof_elastomere-foam_ntb		
kunststof_ep_ntb	kunststof_ep_ntb	kunststof_ep_ntb		
kunststof_epoxyhars_ntb	kunststof_epoxyhars_ntb	kunststof_epoxyhars_ntb		
kunststof_hard-kunststof_ntb	kunststof_hard-kunststof_ntb	kunststof_hard-kunststof_ntb		
kunststof_hdpe_ntb	kunststof_hdpe_ntb	kunststof_hdpe_ntb		
kunststof_hmpe_ntb	kunststof_hmpe_ntb	kunststof_hmpe_ntb		
kunststof_hpl_ntb	kunststof_hpl_ntb	kunststof_hpl_ntb		
kunststof_ldpe_ntb	kunststof_ldpe_ntb	kunststof_ldpe_ntb		
kunststof_loodvervanger_ntb	kunststof_loodvervanger_ntb	kunststof_loodvervanger_ntb		
kunststof_pe_ntb	kunststof_pe_ntb	kunststof_pe_ntb		
kunststof_pmma_ntb	kunststof_pmma_ntb	kunststof_pmma_ntb		
kunststof_pvac_ntb	kunststof_pvac_ntb	kunststof_pvac_ntb		
kunststof_pa_ntb	kunststof_pa_ntb	kunststof_pa_ntb		
kunststof_pc_ntb	kunststof_pc_ntb	kunststof_pc_ntb		
kunststof_pctfe_ntb	kunststof_pctfe_ntb	kunststof_pctfe_ntb		
kunststof_plexiglas_ntb	kunststof_plexiglas_ntb	kunststof_plexiglas_ntb		
kunststof_polyesterhars_ntb	kunststof_polyesterhars_ntb	kunststof_polyesterhars_ntb		
kunststof_polyester_ntb	kunststof_polyester_ntb	kunststof_polyester_ntb		
kunststof_pp_ntb	kunststof_pp_ntb	kunststof_pp_ntb		
kunststof_ps_ntb	kunststof_ps_ntb	kunststof_ps_ntb		
kunststof_ptfe_ntb	kunststof_ptfe_ntb	kunststof_ptfe_ntb		
kunststof_pu_ntb	kunststof_pu_ntb	kunststof_pu_ntb		
kunststof_pvc_ntb	kunststof_pvc_ntb	kunststof_pvc_ntb		
kunststof_zacht-kunststof_ntb	kunststof_zacht-kunststof_ntb	kunststof_zacht-kunststof_ntb		
kunststof_silicagel_ntb	kunststof_silicagel_ntb	kunststof_silicagel_ntb		

ifcMaterial	***ifcMaterialConstituentSet***	***ifcMaterialLayer***	***FireRating***	***SecurityRating***
kunststof_siliconen_ntb	kunststof_siliconen_ntb	kunststof_siliconen_ntb		
metaal_ntb_ntb	metaal_ntb_ntb	metaal_ntb_ntb		
metaal_generiek_ntb	metaal_generiek_ntb	metaal_generiek_ntb		
metaal_aluminium_ntb	metaal_aluminium_ntb	metaal_aluminium_ntb		
metaal_brons_ntb	metaal_brons_ntb	metaal_brons_ntb		
metaal_chroom_ntb	metaal_chroom_ntb	metaal_chroom_ntb		
metaal_gietijzer_ntb	metaal_gietijzer_ntb	metaal_gietijzer_ntb		
metaal_goud_ntb	metaal_goud_ntb	metaal_goud_ntb		
metaal_ijzer_ntb	metaal_ijzer_ntb	metaal_ijzer_ntb		
metaal_koper_ntb	metaal_koper_ntb	metaal_koper_ntb		
metaal_lood_ntb	metaal_lood_ntb	metaal_lood_ntb		
metaal_messing_ntb	metaal_messing_ntb	metaal_messing_ntb		
metaal_platina_ntb	metaal_platina_ntb	metaal_platina_ntb		
metaal_rvs_ntb	metaal_rvs_ntb	metaal_rvs_ntb		
metaal_soldeersel_ntb	metaal_soldeersel_ntb	metaal_soldeersel_ntb		
metaal_staal_ntb	metaal_staal_ntb	metaal_staal_ntb		
metaal_tin_ntb	metaal_tin_ntb	metaal_tin_ntb		
metaal_titanium_ntb	metaal_titanium_ntb	metaal_titanium_ntb		
metaal_zilver_ntb	metaal_zilver_ntb	metaal_zilver_ntb		
metaal_zink_ntb	metaal_zink_ntb	metaal_zink_ntb		
natuursteen_ntb_ntb	natuursteen_ntb_ntb	natuursteen_ntb_ntb		
natuursteen_generiek_ntb	natuursteen_generiek_ntb	natuursteen_generiek_ntb		
natuursteen_asbest_ntb	natuursteen_asbest_ntb	natuursteen_asbest_ntb		
natuursteen_basalt_ntb	natuursteen_basalt_ntb	natuursteen_basalt_ntb		
natuursteen_gneiss_ntb	natuursteen_gneiss_ntb	natuursteen_gneiss_ntb		
natuursteen_graniet_ntb	natuursteen_graniet_ntb	natuursteen_graniet_ntb		
natuursteen_gravel_ntb	natuursteen_gravel_ntb	natuursteen_gravel_ntb		
natuursteen_hardsteen_ntb	natuursteen_hardsteen_ntb	natuursteen_hardsteen_ntb		
natuursteen_kristallijn-gesteente_ntb	natuursteen_kristallijn-gesteente_ntb	natuursteen_kristallijn-gesteente_ntb		
natuursteen_kwartsiet_ntb	natuursteen_kwartsiet_ntb	natuursteen_kwartsiet_ntb		
natuursteen_lei_ntb	natuursteen_lei_ntb	natuursteen_lei_ntb		
natuursteen_marmer_ntb	natuursteen_marmer_ntb	natuursteen_marmer_ntb		
natuursteen_poreus-gesteente_ntb	natuursteen_poreus-gesteente_ntb	natuursteen_poreus-gesteente_ntb		
natuursteen_puimsteen_ntb	natuursteen_puimsteen_ntb	natuursteen_puimsteen_ntb		
natuursteen_sedimentgesteente_ntb	natuursteen_sedimentgesteente_ntb	natuursteen_sedimentgesteente_ntb		
natuursteen_trachiet_ntb	natuursteen_trachiet_ntb	natuursteen_trachiet_ntb		
natuursteen_zandsteen_ntb	natuursteen_zandsteen_ntb	natuursteen_zandsteen_ntb		
ntb_ntb_ntb	ntb_ntb_ntb	ntb_ntb_ntb		
organisch_ntb_ntb	organisch_ntb_ntb	organisch_ntb_ntb		
organisch_generiek_ntb	organisch_generiek_ntb	organisch_generiek_ntb		
organisch_bamboe_ntb	organisch_bamboe_ntb	organisch_bamboe_ntb		
organisch_hennep_ntb	organisch_hennep_ntb	organisch_hennep_ntb		
organisch_jute_ntb	organisch_jute_ntb	organisch_jute_ntb		
organisch_katoen_ntb	organisch_katoen_ntb	organisch_katoen_ntb		
organisch_kurk_ntb	organisch_kurk_ntb	organisch_kurk_ntb		
organisch_leer_ntb	organisch_leer_ntb	organisch_leer_ntb		
organisch_mais_ntb	organisch_mais_ntb	organisch_mais_ntb		
organisch_papier_ntb	organisch_papier_ntb	organisch_papier_ntb		
organisch_plantaardige-vezel_ntb	organisch_plantaardige-vezel_ntb	organisch_plantaardige-vezel_ntb		
organisch_riet_ntb	organisch_riet_ntb	organisch_riet_ntb		
organisch_stro_ntb	organisch_stro_ntb	organisch_stro_ntb		
organisch_vegetatie_ntb	organisch_vegetatie_ntb	organisch_vegetatie_ntb		
organisch_vilt_ntb	organisch_vilt_ntb	organisch_vilt_ntb		
organisch_vlas_ntb	organisch_vlas_ntb	organisch_vlas_ntb		
organisch_wol_ntb	organisch_wol_ntb	organisch_wol_ntb		
rubber_ntb_ntb	rubber_ntb_ntb	rubber_ntb_ntb		
rubber_generiek_ntb	rubber_generiek_ntb	rubber_generiek_ntb		
rubber_butyl_ntb	rubber_butyl_ntb	rubber_butyl_ntb		
rubber_epdm_ntb	rubber_epdm_ntb	rubber_epdm_ntb		
rubber_hard-rubber_ntb	rubber_hard-rubber_ntb	rubber_hard-rubber_ntb		
rubber_linoleum_ntb	rubber_linoleum_ntb	rubber_linoleum_ntb		
rubber_natuurrubber_ntb	rubber_natuurrubber_ntb	rubber_natuurrubber_ntb		
rubber_neopreen_ntb	rubber_neopreen_ntb	rubber_neopreen_ntb		
rubber_polysulfide_ntb	rubber_polysulfide_ntb	rubber_polysulfide_ntb		
rubber_schuimrubber_ntb	rubber_schuimrubber_ntb	rubber_schuimrubber_ntb		
rubber_tpve_ntb	rubber_tpve_ntb	rubber_tpve_ntb		
samengesteld_element_ntb	samengesteld_element_ntb	samengesteld_element_ntb		
samengesteld_product_ntb	samengesteld_product_ntb	samengesteld_product_ntb		
steenachtig_ntb_ntb	steenachtig_ntb_ntb	steenachtig_ntb_ntb		
steenachtig_generiek_ntb	steenachtig_generiek_ntb	steenachtig_generiek_ntb		
steenachtig_baksteen_ntb	steenachtig_baksteen_ntb	steenachtig_baksteen_ntb		
steenachtig_calciumsilicaat_ntb	steenachtig_calciumsilicaat_ntb	steenachtig_calciumsilicaat_ntb		
steenachtig_geexpandeerde-klei_ntb	steenachtig_geexpandeerde-klei_ntb	steenachtig_geexpandeerde-klei_ntb		
steenachtig_kalksteen_ntb	steenachtig_kalksteen_ntb	steenachtig_kalksteen_ntb		
steenachtig_kalkzandsteen_ntb	steenachtig_kalkzandsteen_ntb	steenachtig_kalkzandsteen_ntb		

ifcMaterial	*ifcMaterialConstituentSet*	*ifcMaterialLayer*	*FireRating*	*SecurityRating*
steenachtig_keramisch_ntb	steenachtig_keramisch_ntb	steenachtig_keramisch_ntb		
steenachtig_kunststeen_ntb	steenachtig_kunststeen_ntb	steenachtig_kunststeen_ntb		
steenachtig_porisosteen_ntb	steenachtig_porisosteen_ntb	steenachtig_porisosteen_ntb		
steenachtig_porselein_ntb	steenachtig_porselein_ntb	steenachtig_porselein_ntb		

Construction drawings	Extra	Required	Explanatory note	Examples
Elevations		All elevations that were needed (	A vertical 2D elevation that represents the outside of an asset	NorthElevation, SouthElevation, IndoorGardenElevation
FloorPlans		All plans that were needed durin	A horizontal 2D elevation that represents vertical bound spaces	GroundFloor, FirstFloor, TopFloor
RoofPlans		All plans that were needed durin	A horizontal 2D elevation that represents the top of the constructed asset	RoofPlan
Sections		All sections that were needed du	A vertical 2D elevation through the building that represents vertical bound spaces and construction	SectionA-A, SectionB-B, Section1-1
Details	Fastners should be drawn/modeled. Disassembly of (	All details that were needed duri	A 2D drawing of a joint between two or more builiding parts which make explicit how the asset is constructed	DetailA, DetailB
SitePlan		A site plan	A hoiontal 2D elevation that represents the outside of an asset and the surrounding space	SitePlan