A Process Map for Applying BIM to Design for Deconstruction

Dutch Pavilion at Expo 2020 Dubai Case Study

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by

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Preface

Before you lies the research report titled 'A Process Map for Applying BIM to Design for Deconstruction - Dutch Pavilion at Expo 2020 Dubai Case Study'. This thesis was written in fulfillment of the requirements for the degree of Master of Science (MSc) for the master program Construction, Management and Engineering (CME) at the Faculty of Civil Engineering & Geosciences at Delft University of Technology. This research report provides information on the topic of design for deconstruction of buildings and regarding the implementation of building information modeling into this process.

Writing this research study had its own ups and downs. Without the help of some persons this research would not have been possible. Therefore, I would like to thank the following people:

Firstly, I would like to thank Alexander Koutamanis, for his support through my thesis; from the point I started to find my topic, during the hardships in the middle of the project, and helping me find the way until the end. I would like to thank Henk Jonkers, for his kind and supportive attitude towards me, and his precise feedback in every step. I would like to thank Rajiv Hotchandani, for helping me connecting this research to practice, and making it possible to happen. I would like to thank Paul Chan for being a great chairman to this thesis, and for all the valuable and friendly conversations with me.

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Summary

Construction industry is the biggest waste producer industry in the world. Circular economy, as a replacement of linear economy, introduces methods to increase the recovery of materials' value by returning them back to cycles of construction. One of the aspects of circular economy is deconstruction of buildings. Deconstruction's goal is to eliminate demolition and minimize waste. Design for Deconstruction (DfD) is the practice of designing and planning buildings to facilitate their deconstruction. To achieve this goal, availability of design information is vital in construction and deconstruction of a building. BIM provides a suitable environment for interoperability of different information through different phases of a building lifetime, and between different participants. However, lack of standards for using BIM, in addition to lack of awareness of its capabilities for DfD hinder the utilization of BIM. This research tries to contribute to solving this problem, by answering the research question:

> *What is the process map showing the sequences of activities of Building Information Modeling (BIM) for the process of Design for Deconstruction (DfD)?*

To answer this question, desk research is done to build the theoretical foundation on the research topic. By doing the literature review, deconstruction requirements are identified; a set of principles on DfD are gathered, and capabilities and benefits of BIM are explored. On the other hand, to have a complete viewpoint form practice, case study method is selected. By comparing the current use of BIM and the theoretical framework, a process map will be introduced to apply BIM to DfD.

Gathering data from the case study project, the Dutch Pavilion at Expo 2020 Dubai, leads to findings on how BIM is used for the purpose of DfD and why it is used or not used. The main findings from the case study are as follows: [1] DfD is mostly approached as selection of materials and components to be reusable; [2] the segmentation of the design project was a barrier to proper DfD process; [3] BIM capabilities for DfD are not utilized in the project, mainly due to lack of familiarity, lack of planning, and lack of requirement from the client; [4] BIM is mostly comprehended and used as a 3D modeling tool; [5] BIM is approached as a separate layer to design process, meaning that the modeling takes place after the design is final.

To improve the design process and to fill in the gaps of the current process, a set of steps are proposed to take place, which can be divided to pre-design phase and design phase. The former phase consists of BIM planning, and specifying the information on components to be added to the model. Also, by involving the construction/deconstruction stakeholders in the early stages of the project, the deconstruction specifications can be established. The latter consists of modeling the geometric and non-geometric information of the building, and finally simulating the construction and deconstruction processes to test the deconstructability of the building. Based on these steps a process map is designed, using Business Process Model and Notation (BPMN). The process map illustrates the essential activities required for DfD, integrated with the sequences of building information modeling.

To validate the results, the process map is applied to the case study project, and examples of the outputs are produced to be discussed in an expert panel session. The conclusions on evaluation of the process map are as follows: [1] the process map improved the design process and the quality of the product (the building) regarding circularity aspects; [2] by making the BIM process clear, it will be utilized more; [3] however, there was no agreement on how it will impact the project cost and time; experts on BIM coordination and project management agreed that it will reduce the time of the project, and by decreasing the risks of design errors, it will decrease the costs of the project. On the other hand, there was no clear agreement from other experts.

In conclusion, deconstruction aims for recovery of materials value, and DfD facilitates it through planning and designing. The role of BIM in this process is important, since information modeling and accessibility of it for the related stakeholders at the end of a building's lifetime are necessary to achieve the highest value recovery of a building. Therefore, the integration of DfD and BIM is beneficial for the circularity in the built environment. To fulfill this, it is vital to approach BIM as a new philosophy of working in AEC, and DfD as a new design process. Having these perspectives enable utilizing the benefits of both for the built environment.

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Introduction

In this chapter, the outline of the project is introduced. The context of the research topic is discussed, following by identification of the research problem. Finally, the research design is presented.

1.1. Design for Deconstruction

The largest percentage in production of waste in the world, belongs to the construction industry (Akanbi, Oyedele, Akinade, Ajayi, Davila Delgado, Bilal & Bello, 2018), at the same time, using the resources is leading to resource scarcity. Recently, there are attempts to address this issue in the construction sector. Circular economy's perspective, as a replacement of linear economy, is getting increasing attention; according to The Building Agenda of the Netherlands, the whole sector of construction should be circular by 2050 (DeBouwagenda, 2017). Circular economy can be defined as "an economic and industrial system where material loops are closed and slowed and value creation is aimed for at every chain in the system" (Leising, Quist & Bocken, 2018). The main idea of circular economy comes from the nature, where the waste of each cycle is the nutrient of another cycle. Therefore, (to some extent) circularity can address the problem of resource scarcity and waste production. The main principles of circular economy are asserted as increase of materials' productivity, elimination of waste, maintain the environmental and economic value of materials, and studying the flows of material and energy, and thinking in systems to enable closed-loop processes where waste is an input (Adams et al., 2017). The most common framework in the definitions of circularity is identified as reduce, recycle, reuse (3R framework) (Kirchherr et al., 2017). Although these concepts have been applied to other products from other industries, they are applied to a lesser extent to buildings (Minunno, O'Grady, Morrison, Gruner & Colling, 2018).

Figure 1.1 illustrates the difference of linear and circular economy concept in the built environment. To apply circular economy to buildings, deconstruction (or disassembly) is introduced as a replacement for demolition. Deconstruction is defined as an aspect of the circular economy regarding buildings' end of life, which maximizes material reuse, and its goal is elimination of demolition, and ensuring the materials' recovery (Adams et al., 2017; Akanbi et al., 2018). Deconstruction helps to segregate different materials and components and reuse or recycle them to superior utilization options (Schultmann, 2008). Deconstruction has two stages; planning and deconstruction process, and continued use of the deconstructed materials in other buildings (Thomsen, Schultmann & Kohler, 2011). To achieve this, the information of the building's composition and construction methods are required. In addition, to be able to measure reuse potential of building elements, their disassembly is required to be known (Durmisevic, Beurkens, Adrosevic & Westerdijk, 2017). By looking at the deconstruction of the existing buildings, it is realized that deconstruction of most structures would be much easier if it would have been considered in the design phase (Tingley, 2013). Design decisions have consequences on the entire service life of a building and its materials (Durmisevic & Brouwer, 2015). Therefore, to achieve deconstruction, the building should be designed and built correspondingly. Design for Deconstruction (DfD) or Design for Disassembly refers to the technical and managerial procedures developed to make the reuse of structural and non-structural components of a building at the end of its service life (Akbarnezhad, Ong & Chandra, 2014). It can be defined as the practice to facilitate deconstruction processes through planning and design (Rios, Chong & Grau, 2015). Therefore, DfD aims for designing buildings in a way to ensure that they can be dismantled to their components and materials to maximize the reusability of buildings' elements and minimize waste generation (Macozoma, 2001). In this way, DfD plays an important role in the circularity of the built environment, and designers have the biggest potential influence on the future level of materials' reuse (Crowther, 2018b).

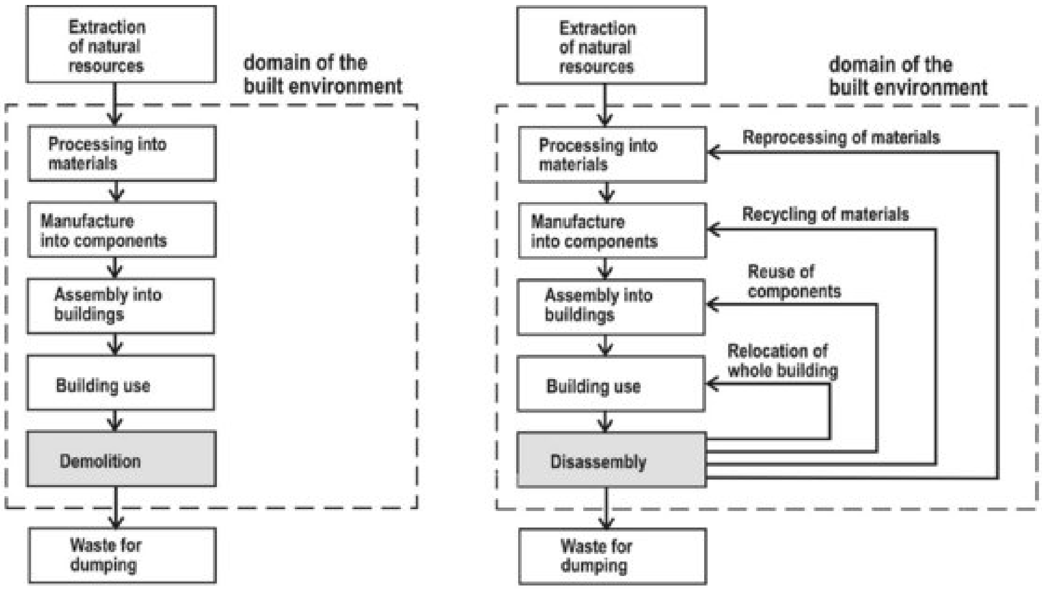

Figure 1.1: Linear building process (left) and circular building process (right) (Crowther, 2018a)

1.2. Problem Statement

In reality, buildings' design, construction, and deconstruction take place in different stages in time, and most probably by different stakeholders. Although deconstruction of a building might happen decades after the design of the building, design information should be available in this stage, to recover the highest possible value of the building (Aguiar, R. & Femke, 2019); the building requires to be documented in detail, with additional information such as connections and material descriptions(Hechler, Larsen & Nielsen, 2012). Therefore, the information flow between different parties and different stages of a project is the important link connecting design to deconstruction. The two main aspects of information for DfD are: [1] availability of the information throughout the lifetime of the building; [2] different input and needs from different stakeholders. Based on these characteristics, BIM is asserted to be beneficial for DfD; there are plenty of research studies that demonstrate the advantages of using BIM for this purpose. Deconstruction of buildings is not guaranteed by designing them for deconstruction only, but a strong integration of BIM and DfD is important for effective end-of-life management of buildings, which must start from the design stage (Akinade, Oyedele, Omoteso, Ajayi, Bilal, Owolabi, Alaka, Ayris & Henry Looney, 2017). BIM enables optimum design and coordination between multidisciplinary participants of a project (Chong, Lee & Wang, 2017), and it has capabilities for the shift towards circular economy in the built environment, having the following strengths (Aguiar et al., 2019):

- A BIM model can contain a lot of information; however, it is vital that models be simplified and contain essential information, to facilitate navigation;

- BIM models can be used for maintenance; however, it is important to keep the models up-to-date;
- The costs of a good BIM model is made in the design phase; however, this means a reliable information database is there for the whole lifecycle of the building.

On the other hand, there are research studies which state that there are practical issues that hinder the complete utilization of BIM in the design processes and deconstruction planning in practice. Although it is known that BIM can eliminate unbudgeted change by 40%, and reduce the time of project by 7% (Liu, Xie, Tivendale & Liu, 2015), fear of too low success and big failure is a barrier for using BIM by project participants in AEC (Migilinskas, Popov, Juocevicius & Ustinovichius, 2013). Industry can be stuck in a status-quo loop (Figure 1.2), which occurs when lack of knowledge and awareness of BIM results in a lack of confidence and motivation to adopt BIM-based collaboration, and reflectively, it leads the level of knowledge about BIM to remain low (Singh et al., 2011). The lack of information about the strict BIM implementation standards and rules for each participant is mentioned as an obstacle in BIM implication (Migilinskas et al., 2013). Lack of enough familiarity with BIM capabilities, lack of protocols (Sun, Jiang, Skibniewski, Man & Shen, 2015), and lack of standardization for BIM processes (Salman, Khalfan & Tayyab, 2012) are identified as limitation factors of using BIM. Among the attempts for providing guidelines for the processes in BIM, Computer Integrated Construction Research Program (2011) has identified 25 BIM uses and created a process map for each. There is no related process maps for DfD although. It is asserted that for deconstruction-related functionalities, there are no process maps (addressing functional issues) and interaction maps (addressing organizational issues) for information exchange in BIM (Volk, Stengel & Schultmann, 2014). Since there are no standard protocols for BIM, firms adopt their own standards, and this can lead to inconsistencies in a project (Salman et al., 2012).

Figure 1.2: Status-quo cycle inhibiting technology adoption and enhancement (Singh et al., 2011).

In sum, most of the previous research studies have two main focuses; first, stating the benefits and capabilities of BIM for DfD, and second, the barriers of using BIM. However, it is not clear how BIM can be applied to DfD. Therefore, in this research, it is tried to explore how BIM should be applied to DfD process. To bridge the theory and practice, it is vital to see problems from both perspectives, and not treat theory as the *correct* and practical issues as the *incorrect*. Hence, considering the practical issues that hinder the use of BIM properly is important in this research.

1.3. Research Objectives and Questions

To contribute to solving this problem, the research objective and questions will be as follows:

1.3.1. Research Objective

The research objective is to contribute to the development of BIM use for the process of design for deconstruction in practice, by providing guidance on how BIM can be applied to DfD. Providing guidance on use of BIM is the most required support on BIM based on the designers' opinion (Chan, 2014). A high level map that shows the sequences and interactions between different participants of the project allows team members to clearly understand how to apply BIM to DfD. Therefore, a framework is advantageous, based on the following reasons:

- Standardization of using BIM;

- Decrease the complexity and increase the utilization of BIM in AEC industry;
- Maximize the added value of BIM for DfD; hence, circularity of buildings.

From an academic point of view, the research will contribute to the practical implementation of circularity to buildings. In addition, providing practical insight to the theoretical aspects of BIM helps in its development.

From the industrial point of view, the research will help the practitioners to further involve BIM in practice. By moving the market and governments towards circularity in the built environment, DfD gets more attention, and this research will help the application of BIM to DfD.

1.3.2. Research Question

Based on what was discussed, the main research question is formed as follows:

> *What is the process map showing the sequences of activities of Building Information Modeling (BIM) for the process of Design for Deconstruction (DfD)?*

1.3.3. Research Sub-questions

In order to address the research question, a set of sub-questions is designed to be answered in the research. Having the answers to these questions is required to address the main research question. The sub-questions are as follows:

1. *What are the principles of DfD?*
   This sub-question gathers the general categories of design decisions that have impact on the deconstruction of a building.
2. *How is BIM used for the purpose of DfD in practice?*
   This sub-question inspects the current process that takes place for using BIM in practice. Since the research question has a practical characteristic, having input from the practical point of view is necessary.
3. *Why is BIM used or not used for the purpose of DfD in practice?*
   This sub-question investigates the reasons of using or not using BIM in practice, which helps to understand the barriers of using BIM, and addressing them in any solutions.
4. *In which ways is it possible to utilize BIM for the DfD purposes?*
   By comparison the capabilities of BIM, and barriers and problems in practice, this sub-question inspects the possible ways to improve the use of BIM in practice, with the goal of information incorporation for DfD purposes.
5. *What are the essential sequences of the process of information modeling, that can clarify the application of BIM to DfD?*
   This sub-question identifies the activities and sequence of them that should be taken in the design stage of the building, in order to exchange the required information for deconstruction of the building to the next user of this information.

1.4. Methodology

Research design is the logic that links the data to be collected to the research questions (Yin, 2003). In this section, the research design is discussed; first, the research methods are introduced. Then, the process of data gathering and analysis to answer the research questions is clarified.

Combining different qualitative methods, bring stronger evidence to the research (Maruster & Gijsenberg, 2013). In this research, desk research and case study are the main methods. The aim of the desk research is to build knowledge on the available theories in the topics of deconstruction, design for deconstruction, and BIM. By doing a state-of-the-art literature review, an analytical framework will be formed. Literature review makes the foundation of the research; therefore, it has a high level of importance.

The second method is case study. Case study is an up-closed and in-depth empirical approach, which investigates a current phenomenon in the real-life (Yin, 2003). In other words, case study can provide an in-depth observation and insight to the research (Verschuren & Doorewaard, 2010). The research has a practice-oriented nature; therefore, a case study is a proper choice. Investigating a real project regarding DfD and BIM approaches, brings new insight to the research topic, and improves the effectiveness of the research results. Observation on location, conducting interview with the experts involved in the project, and studying all sorts of documents provide a profound insight into the various processes and the reason why they develop in a specific way (Verschuren & Doorewaard, 2010).

Flyvbjerg (2006) asserts that atypical or extreme cases often reveal more information than typical or average cases. He adds that the importance of clarifying deeper causes behind a given problem and its consequences is more from both an understanding-oriented and an action-oriented perspective. Although single case studies might have lower potential for generalization, they contribute to the collective process of knowledge accumulation in a given field (Flyvbjerg, 2006).

The selection of single-case design in this research is based on two rationales for this method. One of them is when the case represents an extreme case or unusual case. Another rationale for a single-case study is the revelatory case, which happens when there is an opportunity for the researcher to observe and analyze a phenomenon that was previously inaccessible (Yin, 2018). Single case study enables the researcher to provide in-depth and holistic insight to the practical process of circular projects. By getting involved in the process of a circular project and observing closely the design process, managerial decisions that are made, and use of BIM, a holistic insight can be added to the research. This is advantageous regarding the data that can be gathered, and the depth of studying the case. The theoretical and practical knowledge gained through these steps, make it possible to compare the research studies, and what happens in practice, and analyze the gaps in the process of using BIM for the purpose of DfD. By taking these into account, a single case study is selected for the research. Chapter 3 presents the reasons for the choice of the case.

In addition to above-mentioned methods, action research will be also used in the research to investigate the outcomes of the process map, applied to the case study.

1.5. Data Gathering and Analysis

For the theoretical part, the data will be gathered from publications in scientific journals, conference papers, textbooks and other articles. The knowledge sources include information in the form of available insights and theories. By doing the literature review, the theoretical framework of the research is prepared, by means of which the case study will be analyzed.

In terms of case study, Yin (2003) has mentioned some conditions that increase the quality of the case study method as follows:

- Using of multiple data sources, to increase validity;
- Pattern matching in data analysis, to increase internal validity;
- Combining theories with the single case study, to increase external validity;
- Relying on case study protocol in data collection.

Triangulation eliminates chance as much as possible, therefore, this strategy is used to strengthen the single case study (Verschuren & Doorewaard, 2010). The data will be gathered through documentation, archival records, interviews, direct observations, participant observation, and physical artifacts (Yin, 2003). By convergence of different sources of data to the same evidence, the strategy of triangulation is achieved and the reliability of data is improved (K. Yin, 2015). Information is collected from project database and the professionals involved in the project. This is done through interviews and informal talks during the presence of the researcher in the company. During this period, direct observations are recorded, and the gathered data will be verified by the people involved in the project. In addition, a case study protocol is used, which has a series of topics with hints and inquiries that enable the researcher to get the potential measures and sources of evidence while leaving room for discovery of unforeseen occurrences (K. Yin, 2015).

The data will be analyzed by the theoretical framework. By the comparison of the findings from practice, and literature, the process map is developed. In the end, the process map will be applied on the same case, and the results will be validated by discussing them with an expert panel. Figure 1.3 illustrates the flow diagram of the research strategy.

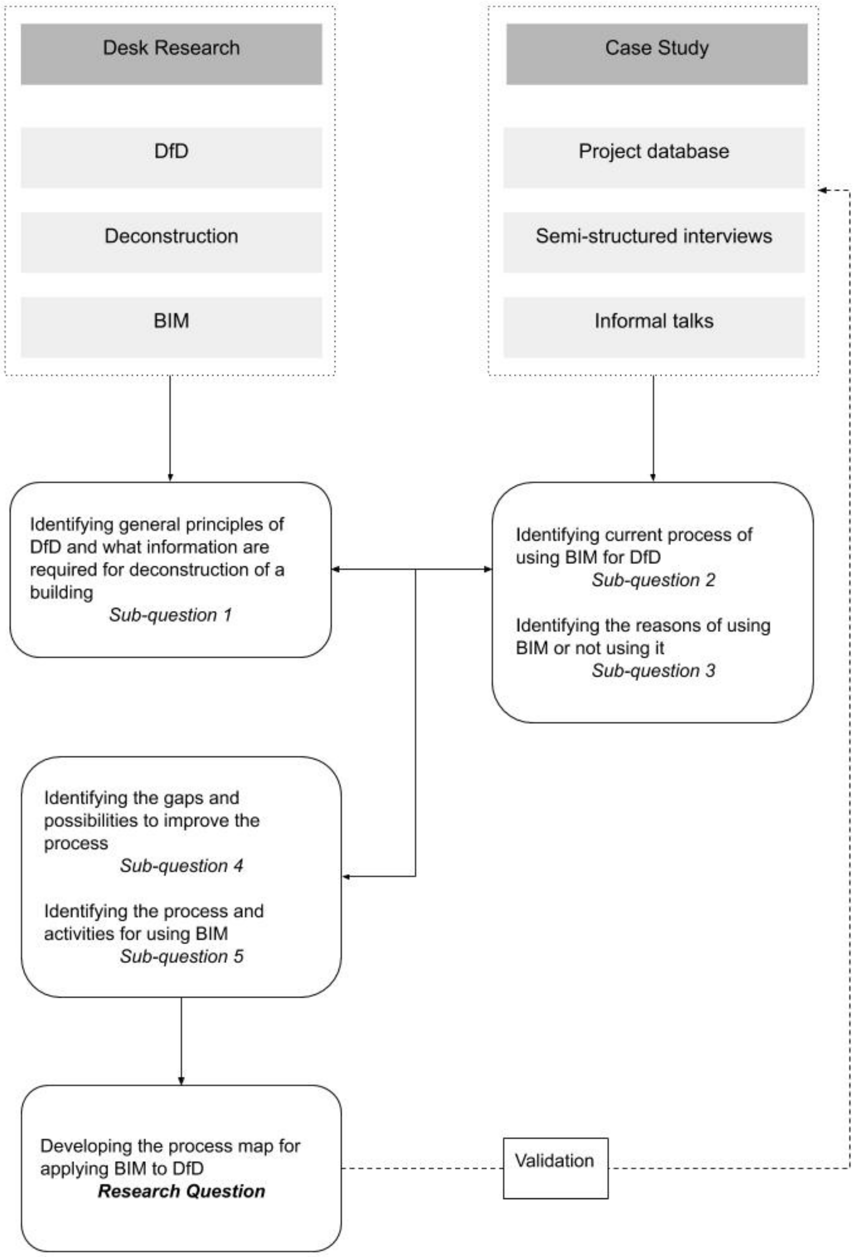

Figure 1.3: Research Strategy (own illustration)

2

Literature Review

This chapter provides an overview of literature on the related topics to the thesis. The literature on circularity in the built environment, deconstruction, design for deconstruction, and BIM is reviewed considering the research objectives and questions. In order to provide this information, this part relies on desk research.

2.1. Circular Economy in the Built Environment

Circular economy is defined as an intentionally restorative industrial economy whose goal is to use renewable energy, to minimize the use of toxic chemicals, and eliminates waste by design. Circular economy can be described as an economic system that changes the end-of-life scenario of products (Kirchherr et al., 2017). Figure 2.1 shows an elaboration of the 9R framework, which contains different strategies defined and practiced for this purpose. The preferred order for the future of the materials in the circular economy is based on retention of optimal value in the physical environment; the shorter the cycle, the better (van Sante, 2017):

1. Reuse: the same product, with the same function;
2. Repair: repaired product, with the same function;
3. Re-manufacture: part of the product, with the same function;
4. Recycle: material reuse as:
   (a) Up cycling (high quality reuse): reuse the material for the same product and function;
   (b) Down cycling (low quality reuse): reuse the material for a simpler product.

The most efficient method to decrease the environmental impacts of the construction industry is the strategy of repair of buildings and reuse them (Carvalho Machado, Artur de Souza & De Souza Veríssimo, 2018). However, this strategy is not always possible to be taken. To move from the building scale, to components and materials' scale, other aspects should be considered; the recovery of building materials depend on how it was designed and constructed, and on the deconstruction technique applied at the building's end of life (Carvalho Machado et al., 2018). For instance, reuse of materials should be considered regarding the function and life span of the building (Rijkswaterstaat, 2015). Therefore, in order to restore the value of the buildings' materials and components after the end of its service lifetime, it is vital to take these aspects into account from the beginning of the building's design. The different aspects of circular economy in different stages of a building's life cycle are demonstrated in Table 2.1. The best stage to consider circularity is early stages of project, which leads to the lowest time and cost required, and the highest potential influence (look at Figure 2.2).

Life cycle stage	Circular economy aspect
Design	Design for Deconstruction Design for adaptability and flexibility Design for standardization Design out waste Design for modularity Specify reclaimed materials Specify recycled materials
Manufacture and supply	Eco-design principles Use less materials/optimize material use Use less hazardous materials Increase the lifespan Design for product disassembly Design for product standardization Use secondary materials Take-back schemes Reverse construction
Construction	Minimize waste Produce reused materials Produce recycled materials Off-site construction
In use and refurbishment	Minimize waste Minimal Maintenance Easy repair and upgrade Adaptability Flexibility
End of life	Deconstruction Selective demolition Reuse of products and components Closed-loop recycling Open-loop recycling
All stages	management of information including metrics and datasets.

Table 2.1: Circular economy aspects across a building's life cycle (Adams et al., 2017).

Circular economy is a change in perspective, therefore, it has influence on all the processes and decisions. It requires change in different aspects of problem solving approaches. It changes how we design and build, at the same time, how we collaborate and make business (Aguiar et al., 2019). To achieve this systemic change in the built environment, in addition to changes in design culture, it is important to involve the entire value network in the processes and collaboration (Debacker, Manshoven, Peters, Ribeiro & Weerdt, 2017). In addition, it is vital to store building information (related to current, past and possible future scenarios) in a centralized digital way (Debacker et al., 2017) These considerations increase the role that BIM can play in circular economy, which will be elaborated further in the next sections.

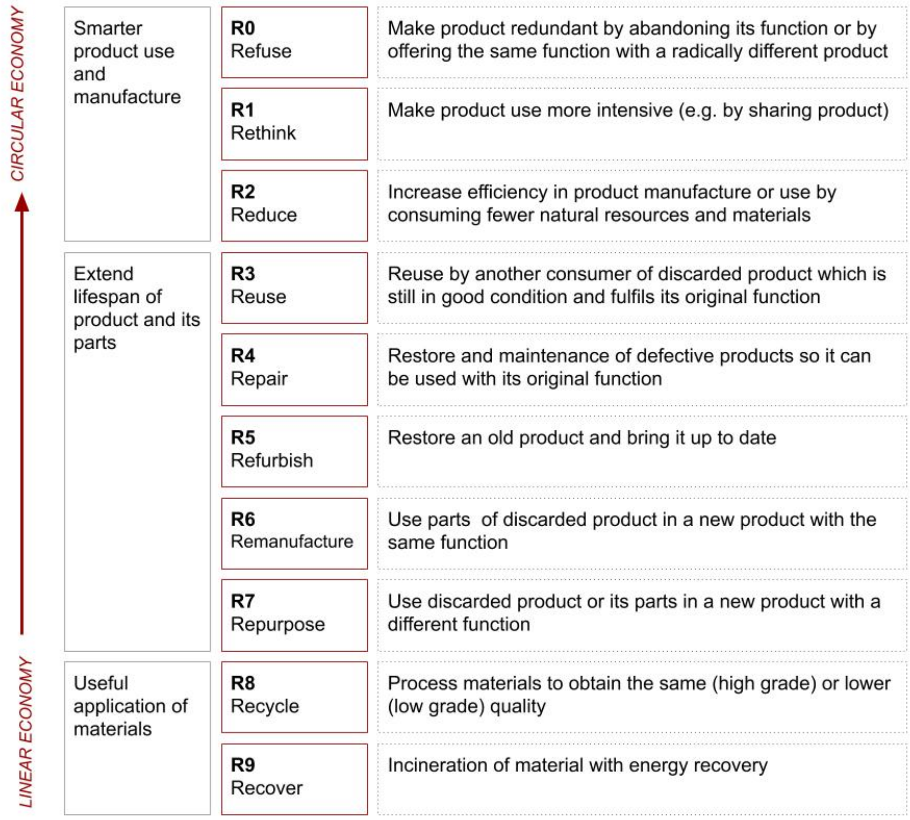

Figure 2.1: 9R Framework (Kirchherr et al., 2017).

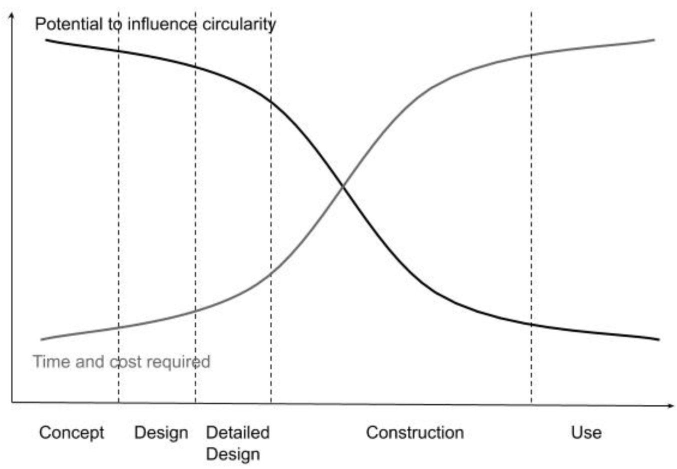

Figure 2.2: Time to influence of circularity in the projects in the built environment

2.2. Deconstruction

Deconstruction is defined as a building end-of-life scenario, which enables the recovery of building components (Akinade, Oyedele, Ajayi, Bilal, Alaka, Owolabi, Bello, Jaiyeoba & Kadiri, 2017). It is a process of systematically dismantling buildings for the purpose of waste decrease and generation a supply of secondary materials which are suitable for reuse or recycling (Macozoma, 2001). Durmisevic et al. (2017) assert that deconstruction is the foundation for high reuse potential and and high transformation capacity of buildings. At the same time, in practice, the end of a building is usually not considered through its design stage (Rios et al., 2015). Thus, the importance of deconstruction for the shift towards circular economy in the built environment is high, in addition to considering deconstruction at the design stage of the buildings. As a substitute for demolition, the choice of deconstruction introduces trade-offs, which should be considered (Macozoma, 2001):

- Time and employment: deconstruction takes more time, however, it provides more employment opportunities.
- Labour and salvage: deconstruction has a higher cost regarding labour, however, it can be offset by the value recovery of the salvage.
- Disposal and diversion: diversion of waste has environmental benefits, however, disposal is easier.
- Avoided cost and incurred cost: deconstruction requires costs in design, however, it avoids costs of waste transport and virgin material procurement costs.

A typical deconstruction can be assumed as the reverse of construction (Queheille, Taillandier & Saiyouri, 2019). Crowther (2002) asserts that if a controlled and sequential deconstruction takes place, the construction and deconstruction sequences could be the reversal of each other. Typically, deconstruction starts with removing all interior non-structural elements, and then, layer by layer removal of structural elements, in a way that the building is structurally sound at every stage of deconstruction (Guy, Shell & Esherick, 2006). Table 2.2 shows the stages and components they contain in the deconstruction (Aidonis, Xanthopoulos, Vlachos & Iakovou, Aidonis et al.).

Deconstruction Stage	Products
1	Heating components Doors Windows Shutters Sanitary devices Electrical devices
2	Floor covering Roof covering Wall covering
3	Electrical installations Sanitary installations Plumbing installations Heating installations
4	Roof frame
5	walls Insulation materials
6	Floors Stairs Reinforced concrete walls Foundation

Table 2.2: Deconstruction stages and products(Aidonis, Xanthopoulos, Vlachos & Iakovou, Aidonis et al.)

However, this typical definition of deconstruction is not the case in all buildings. Every building has unique characteristics, therefore, every demolition project is unique (Michael, 2018). As a result, a more detailed and comprehensive approach to deconstruction is required. Vliet (2018) has divided twenty five influential factors on disassembly to three main categories, and by assessing their weights, introduced the most important factors, which are presented in Table 2.3. The technical factors provide the technical requirements; the process-based factors provide preconditions; and the financial-based factors provide the drivers for disassembly.

Category	Factor	Description
Technical factors	Independency:	decoupling components
	Type of relational pattern:	how products are connected to each other; horizontal and vertical hierarchies
	Assembly sequence:	sequence of assembly determines sequence of disassembly
	Assembly shape:	geometry of product boundaries
	Method of fabrication:	whether a product or assembly is prefabricated or built on site
	Type of connection:	whether the connections are mechanical or adhesive
	Accessibility to connection:	physical access to connections without demolishing
Process-based factors	Disassembly instructions:	documentation of instructions and as-built drawings
	Disassembler expertise:	knowledge and experience in practice
	Number of operations:	indicates the complexity of disassembly; increases the costs
	Deconstruction safety:	guarantee of safety is required for disassembly process
Financial-based factors	Disassembly costs:	financial feasibility of disassembly, by considering the residual value of materials

Table 2.3: Influential factors on disassembly (Vliet, 2018)

Before planning for the deconstruction phase, which can be called a project itself, an analysis and estimation is required. Planning for deconstruction depends on the level of the intended value recovery of the building. This can be determined as a complete building disassembly, or partial disassembly (Sanchez & Haas, 2018), and as the disassembly level from system (building) level, sub-system level, component level, and material level (Durmisevic, 2019). Here, the design of the building plays an important role. Existing building without considerations on deconstruction, do not enable complete disassembly. On the other hand, if the buildings are designed for this purpose, the level of disassembly can increase. However, it is not practical to consider it as the whole building level (Guy et al., 2006). Construction planning is usually based on trade packages, which are usually related to a particular type of building component (such as structure, electrical systems, etc.). However, the deconstruction process depends on its goal; if its goal is component reuse, then the disassembly process will be the reversal of the construction. If its goal is material reuse, then the order of disassembly is not necessarily related to these trade packages (Crowther, 2002).

Deconstruction should be economically and environmentally advantageous over demolition. Therefore, it should be analyzed considering the cost, time, and environmental impact. Costs of deconstruction is mainly distributed between labor, transport and equipment; however, the costs of demolition is based on disposal costs (Coelho & De brito, 2013).

Disassembly planning is defined by Sanchez & Haas (2018, p.1000) as *"finding an optimal and feasible path for disassembly under given constraints"*. Figure 2.3 illustrates a generic classification of disassembly planning methods for buildings. Relocation and reallocation of machinery and labor must be planned to avoid logistics problems such as over-crowdedness, collisions, and unnecessary displacements (Sanchez & Haas, 2018). In the essence, disas-

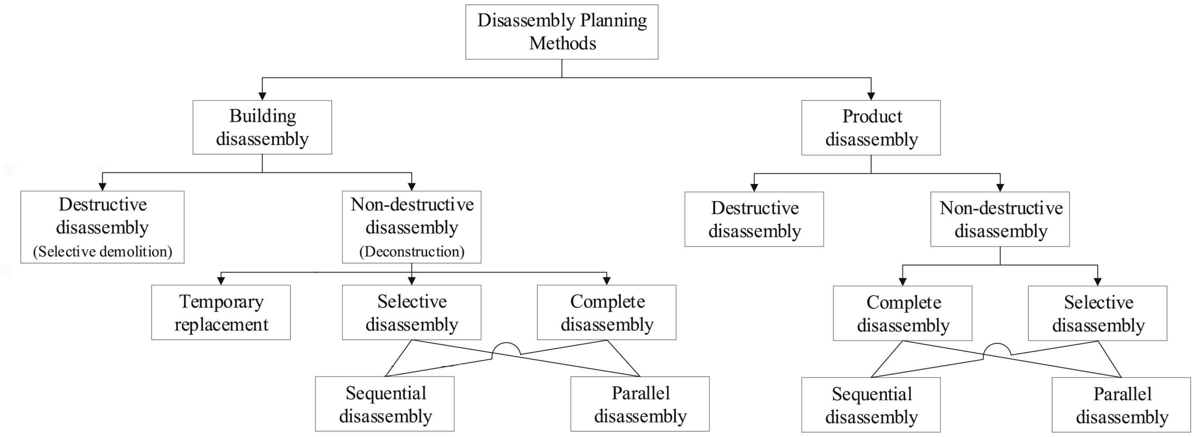

Figure 2.3: Disassembly planning categories (Sanchez & Haas, 2018)

sembly planning includes two main steps; modeling disassembly, and generating sequences (Smith, Smith & Chen, 2012).

Having the building information is important for all the three phases of deconstruction project; analysis, planning, and deconstruction (controlling the project). Usually, the original building documentation is missing, or they are not updated through the use of the building (Ge, Livesey, Wang, Huang, He & Zhang, 2017), and this will make the deconstruction complicated (Michael, 2018). Recently, the use of BIM for deconstruction projects is getting more attention (Volk, 2018).

2.3. Design for Deconstruction

It is known that through strategies such as DfD, material reuse maximizes (Densley Tingley, 2013). Therefore, DfD is getting more attention in AEC industry. Design phase is an important stage in a building lifetime. Actions in every stage, have impact on products and their value recovery potential (Luscuere, 2017). DfD has different impacts on the lifetime of a building. However, designers have the most important role to change the huge waste production of construction and demolition, which is done by DfD (Rios et al., 2015). Figure 2.4 shows how the design process can identify the added value to the project regarding cost of changes and effects of them. DfD should be considered as an additional element that can enrich the design process, rather than an extra constraint (Kanters, 2018).

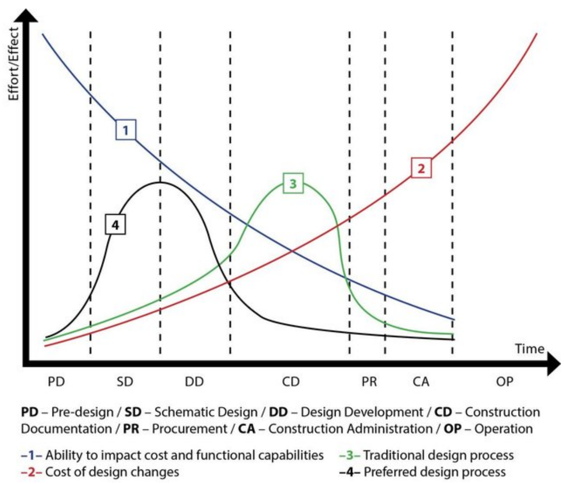

Figure 2.4: Value added, cost of changes, and current compensation distribution for design services (Talebi, 2014)

Although there are no official guidelines for DfD (Macozoma, 2001), scholars have identified and introduced principles for it. The key principles of DfD are as follows:

1. Information gathering of materials and methods of deconstruction;

2. Design connections in an accessible and easy to dismantle way;

3. Separation of non-recyclable, non-reusable, and non-disposal systems, components, and materials;

4. Design for standardization of components and dimensions;

5. Design with reflection of labor practices, productivity, and safety (Rios et al., 2015).

Identification of connections as barriers for building materials recovery, points out the importance of this aspect in design of buildings for deconstruction (Escaleira, Amoêda & Cruz, Escaleira et al.). The model of Durmisevic (look at Figure 2.5) shows indicators of a reversible building, which are based on independence and exchangeability of building products (Durmisevic et al., 2017). Durmisevic (2019) divides the decisions for DfD in three levels as follows:

1. Material levels,

2. hierarchy and arrangement of parts,

3. physical integration of parts.

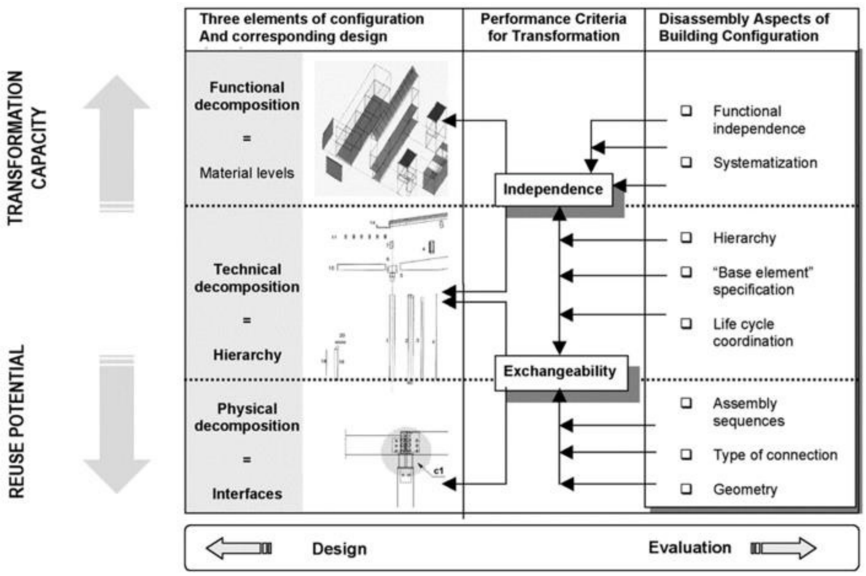

Figure 2.5: Model of Durmisevic (Durmisevic, 2019)

Akinade et al. (2017) have identified the critical success factors for effective recovery of materials through DfD and divided them to material, design, and human related factors. Use of layering approach, and modular construction are among the design related factors. Adequate communication among teams is identified as a critical success in human related category. On the other hand, among the major barriers for high reuse of building elements, Durmisevic et al. (2017) has named lack of valid data about the technical composition of the buildings and lack of decision making support for the preparation of disassembly as two of them. Studies show that the main hindrance of deconstruction of buildings is that buildings are designed without considering the end of life and the process of recovery of the materials (Rios et al., 2015).

DfD in its nature, requires transfer of information through time and through different stakeholders. In addition to construction of a building which is designed for deconstruction, the information should be available for the end of its service life. Otherwise, the building cannot be either deconstructed to the highest degree that has been designed, or deconstructed with optimal cost and time. This can be because of passage of time, unknown life span of a building and future use of it, change of its users and owners, and the need of manuals and information on disassembly of the building. Material passport, for instance, is a tool that makes the information available to all stages, by documenting and tracking the full circular potential of elements of a building (Luscuere, 2017). The other fact that gives the information management a key role in DfD is the multidisciplinary nature of it in DfD. For the best collaboration of the different disciplines in a project, the way of communication and exchange of information is critical.

The building should be designed in a way to be deconstructable. However, that is not adequate to ensure deconstruction. For instance, since deconstruction takes much more time than demolition, time is a hindrance to implementation of deconstruction. Therefore, DfD techniques can (and should) reduce the time for deconstruction (Rios et al., 2015). One goal of DfD is asserted to be *"to expedite the understanding and viability of a disassembly sequence for either building elements or the entire building"* (Guy et al., 2006). Therefore, simultaneous planning of deconstruction along with construction planning, as an aspect of DfD, provides directions for the deconstruction phase (Guy et al., 2006).

DfD can help solving the technical aspects of deconstruction. However, in addition to them, lack of legislation for reuse of building materials, and time and cost limits for the clients and designers are also major barriers for this purpose (Kanters, 2018). The fact that the main benefits of DfD will be achieved in the future, causes no incentives for the designers (Macozoma, 2001), which should be compensated in other ways, such as subsidies based on sustainability of the buildings' design.

By reviewing the literature over DfD, the principles of DfD could be categorized as in Table 2.4.

Category	Sub-category	Principle
Product-related	Material design	design for locally produced building materials(Chini & Schultmann, 2002) use recycled and recyclable materials elimination of hazardous materials minimization of the number of types of materials elimination of secondary finishes to materials (Crowther, 2001) consider durability of materials use lighter materials (Carvalho Machado et al., 2018) separation of components' functionality separation of recyclable and non-recyclable items (Kissi, Ansah, Ampofo & Boakye, 2019)
	Component design	minimize the number of different types of components increase modularity in design (Crowther, 2001) consider transportability of components (Denis, Vandervaeren & Temmerman, 2018) separation of long-lived components from short-lived separation of building systems (structural, electrical, mechanical, etc.) (Kissi et al., 2019)
	Interface design	minimize number of connectors use mechanical connections minimize number of connectors' types design joints for repeatable usage (Crowther, 2001) accessibility of components (Denis et al., 2018) reduce complexity (Carvalho Machado et al., 2018)
Process-related	Construction planning	use prefabrication, mass production, and pre-assembly sequential access to building layers(Morgan & Stevenson, 2005) life cycle coordination (Durmisevic, 2019) facilitate the separation of building's layers (Carvalho Machado et al., 2018) Use technologies compatible with standard building practice (Kissi et al., 2019)
	Deconstruction planning	allow for parallel deconstruction (Crowther, 2001) consider the safety of the job during deconstruction identify disassembly points and disassembly procedures provide identification and categorization of dismantled construction materials (Carvalho Machado et al., 2018) consider the logistics of deconstruction (machinery and storage) (Carvalho Machado et al., 2018) allow for tolerance during deconstruction process (Kissi et al., 2019) define DfD strategies for the building at the design stage (Morgan & Stevenson, 2005)
	Information management	Provide inventory of material reusability thorough documentation of materials and methods (Kissi et al., 2019) keep the as-built drawing updated distribute the updated deconstruction plan

Table 2.4: Principles of Design for Deconstruction gathered from the literature

2.4. BIM for DfD

BIM is defined in different ways. According to the U.S. National BIM standard, BIM is a shared knowledge resource, and a digital representation of a facility's physical and functional characteristics, which both together form a reliable basis for decision making in its lifecycle (Chen, Lu, Peng, Rowlinson & Huang, 2015). This definition emphasizes more on BIM as a product, however, Sacks, Eastman, Lee & Teicholz (2018, p.14), define it as a "modeling technology and associated set of processes to produce, communicate, and analyze building models", which has an emphasis on the process rather than the product. Siebelink, Hans & Arjen (2019, p.1) give a comprehensive definition of BIM; *"BIM should be seen as an object-based and multidisciplinary approach aimed at facilitating collaboration between parties and the integration of object-related information over the entire life cycle of an asset. This function is supported by IT, through which building objects are often captured in 3D representations"*. BIM can be identified as a boundary object. Vidal (2006) define boundary object as an artifact that serves as an intermediary in the communication of persons or groups who collaborate in work, and it has the ability to carry multiple meanings, which enables different parties to have an interactive conversation (Romme & Endenburg, 2006). However, they are both adaptable to local needs, and at the same time, robust enough to sustain the common identity globally (Barrett & Oborn, 2010). The properties of boundary objects develop respectively to the different types of knowledge boundaries existing in a project (Barrett & Oborn, 2010). According to the National Building Information Modeling Standard (NBIMS), BIM is categorized in three ways: [1] as a product; [2] as an IT-enabled, open standards-based deliverable, and a collaborative process; and [3] as a facility lifecycle management requirement (Sacks et al., 2018, p.14). BIM is a powerful tool for solving the problems regarding the fragmentation of project's lifecycle. However, it is not broadly implemented in all the phases yet (Galic et al., 2014). Figure 2.6 illustrates BIM in project's lifecycle.

The uses of BIM are categorized into five basic purposes: gathering, generating, analyzing, communicating and realizing (Kreider & Messner, 2013). In addition to 3D visualization, using comprehensive databases provided by BIM for construct, manage, demolish, and reuse building components are getting more attention (Akbarnezhad et al., 2014). One of the BIM uses is transforming, which is a subcategory of BIM uses under the category of communication, and it is defined as translation of information to be received by another process. This step takes place when the information is required to be communicated to the next user of that information (Kreider & Messner, 2013). Based on the BIM maturity levels, level 3 BIM represents full multidisciplinary collaboration by means of using a single project model, which is accessible to all parties. Its benefit is elimination of conflicting information Sacks et al. (2018, p.16). In spite of these benefits, it is not possible to assert that they are advantageous to all projects to the same extent. In fact, actual benefits, returns, and investments on BIM vary in each project (Barlish & Sullivan, 2012).

In addition to the design benefits through multidisciplinary collaboration, using BIM benefits engineers by eliminating rework and increasing the productivity Sacks et al. (2018, p.199). It helps early stakeholders involvement, by enabling contractors and fabricators to collaborate by design team from early stages, which helps both parties (Sacks et al., 2018). Multidisciplinary design reviews are also a benefit of BIM. This includes special features such as clash detecting and version comparison (Sacks et al., 2018), which helps the change management.

Poor information management is one of the reasons hindering the reuse of building components (Aguiar et al., 2019). In addition, integrating the right information is extremely important, because of high amount of information produced during the life cycle of a building (Aguiar et al., 2019).

Although sustainable design and construction using BIM has been the focus of attention, less effort has been put on using BIM in the deconstruction stage of a building (Akbarnezhad et al., 2014). BIM has capabilities to store building design and construction process documentation, which makes it possible to simulate the assembly and disassembly processes (Akinade et al., 2017). For instance, BIM 7D provides detailed information on exact location for each building element, and the material specifications, therefore, it has benefits for Design for Deconstruction (Kanters, 2018). The use of BIM to simulate the process and se-

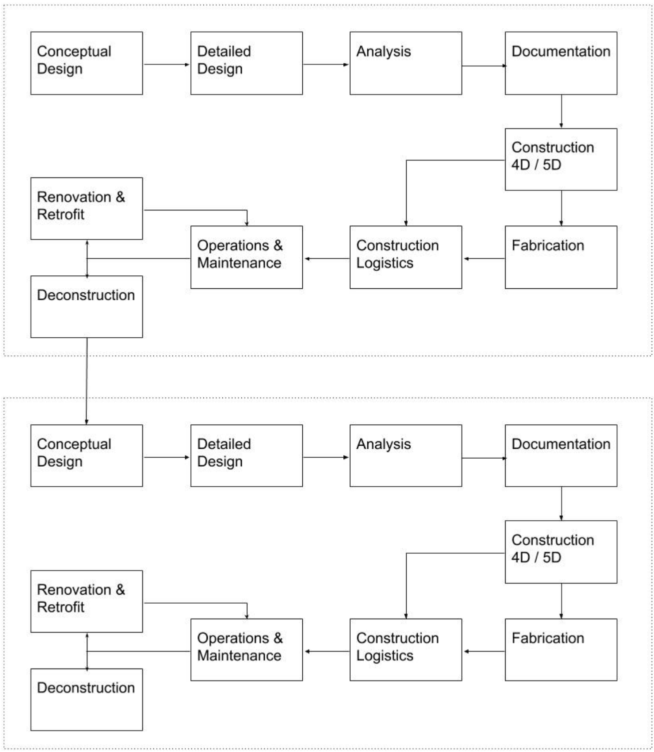

Figure 2.6: BIM in project lifecycle (Galic et al., 2014)

quence of building disassembly is asserted as the most important success factor of DfD in the deconstruction phase (Akinade et al., 2017). A building project needs design of the product (the building) and the process (construction process), therefore, the result will be a coherent and integrated product and process design (Sacks et al., 2018).

BIM is not only a technology change, but also a process change (Eastman, 2011). To effectively use BIM, it is required that changes take place to every aspect of a firm's business (Sacks et al., 2018, p.29). To use BIM to its fullest, it is critical that stakeholders determine what BIM model promotes circular design best: A life cycle model updated during the construction and operation of the building; Or a circular model, made in advance, ensuring the accessibility and reliability of the required information (Aguiar et al., 2019). BIM models can contain a lot of information, which is a strength of BIM, however, it also makes the navigation harder. Therefore, simplification, and containing only the essential information is vital (Aguiar et al., 2019).

The meaning of BIM is not clear when speaking in practical terms, therefore, for using BIM in an effective and efficient way, it is required to clarify it (Aguiar et al., 2019). Using BIM requires proper planning, otherwise it can lead to little or no added value and causes increased costs or delays. A team must find the level that BIM is implemented in a project, in which the value is maximized and the cost is minimized. BIM planning should happen in the early stages of the project (Computer Integrated Construction Research Program, 2011). BIM Execution Plan (BEP) specifies the levels of detail required at each stage, in addition to the mechanisms for model sharing or exchange (Sacks et al., 2018, p.28). This ranges from the organizational levels to technical aspects; for instance, for having the integration of applications and work flows between different disciplines in a project, it is required that an approach is selected (Sacks et al., 2018, p.18). If different modeling tools are used by the different project team members, complexity and the likelihood of errors increase (Sacks et al., 2018, p.28). Computer Integrated Construction Research Program (2011) introduced the guide for creating a BIM Project Execution Plan, with the four main steps as follows:

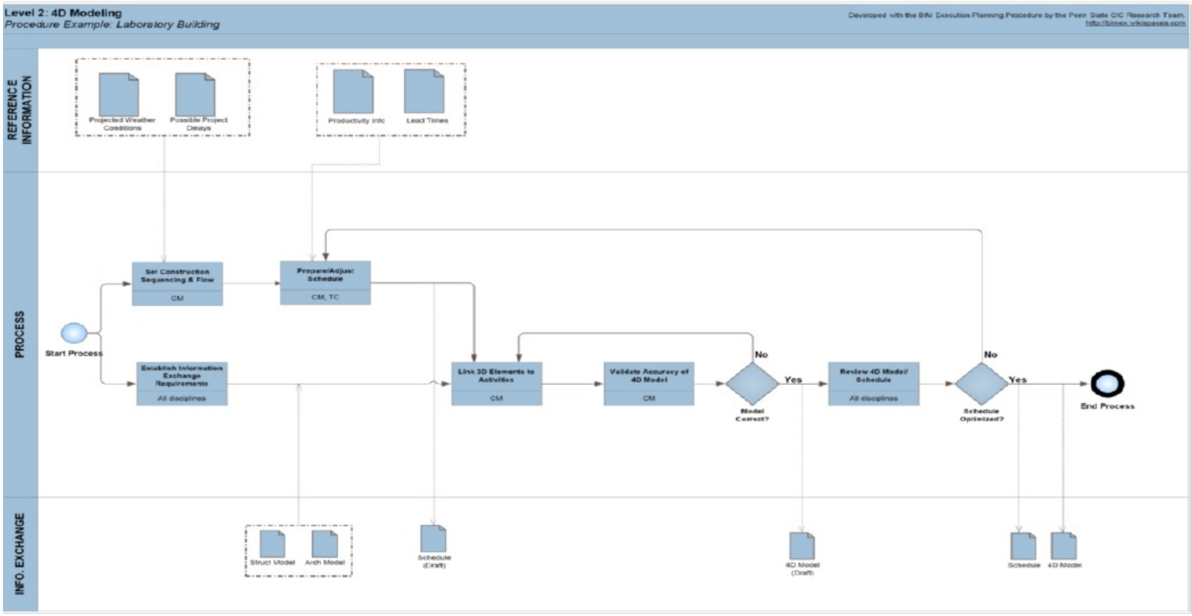

Figure 2.7: BIM process map for 4D modeling (Computer Integrated Construction Research Program, 2011).

1. Identify BIM goals and uses;
2. Design BIM project execution process;
3. Develop information exchanges;
4. Define supporting infrastructure for BIM implementation.

A BIM framework is defined as a theoretical structure that simplifies complicated aspects of BIM and explains them by identifying concepts and their relationships (Succar, 2009). A BIM framework should be extensive enough to cover all relevant BIM issues; on the other hand, it should be succinct enough to systematically present the key issues only (Jung & Joo, 2011). Descriptive frameworks describe characteristics of an existing phenomenon, while prescriptive frameworks prescribe methodologies to follow (Kassem, Iqbal & Dawood, 2013). BIM protocols provide conditions or steps to reach a goal, and they are in represented in either textual or graphical format, such as process maps or flowcharts (Kassem et al., 2013). Computer Integrated Construction Research Program (2011) has identified 25 BIM uses. The purpose of creating these BIM uses guide is a better communication of the purposes and methods for implementing BIM throughout the project (Kreider & Messner, 2013). For each BIM use, they developed a process map, which demonstrates the sequence of activities for that use (Computer Integrated Construction Research Program, 2011). Although there is no process maps for DfD. A process map to clarify the sequence of activities for DfD and explicitly demonstrates the deliverables during the project can be helpful. Figure 2.7 illustrates an example of these process maps. The process map is based on Business Process Modeling Notation (BPMN), whose notations are provided in Appendix A.

BIM tools for specific functions, object-oriented parametric design tools, and interoperability improve the traditional design processes, however, some architects see the complexity and cognitive load of BIM as barriers for supporting the conceptual design stage (Sacks et al., 2018). These gaps include support for intuitive and creative thinking processes, fast assessment and feedback based on simulation and analysis tools, and allowing more informed design. This weakness, however, has been identified by its developers and some free-form tools have been added to BIM applications such as Revit (Sacks et al., 2018, p.193).

The use of BIM for DfD is identified as follows (Minunno et al., 2018):

1. as a collaborative way to enable interconnectivity of information added to the model by different people;

2. facilitates fostering methodical deconstruction methods, with faster deconstruction time;
3. enables assessment of economical advantages of deconstruction and comparison to demolition at the end of the building's service life.

Based on what was discussed about DfD, it is known that simultaneous planning of construction and deconstruction is required. In addition, geometric information on interfaces, and non-geometric information on assembly and disassembly processes are required. Information of materials, components, and systems are required, that analysis of deconstruction benefits and environmental impact can take place in the future. BIM has capabilities for all these functions. Construction planning and evaluation is possible through BIM, and since deconstruction can be assumed as the reversal of construction with adjusting the constraints, the same functions can be used. Simulation and visualization of the construction and deconstruction process, controlling them, and finally analysis of deconstruction feasibility and strategy finding are BIM uses for DfD.

3

Case Study Design

In this chapter, the case study design is discussed. Firstly, the case study selection is explained, following by describing the selected case study. Subsequently, the case study protocol is introduced.

3.1. Case Study Selection

Although deconstruction is not a new concept in construction industry, it is mostly applied to existing buildings, and mostly for the recycling purposes. In fact, DfD is not broadly practiced in the built environment yet. The goal of the case study was to explore DfD and how BIM can apply to it. The selection of the case is based on the following criteria:

1. The project must be a building design project which applies DfD with the circularity ambition.
2. The size of the project should be small, so it would be possible to analyze the design process and manipulate the design process at the end. The small size of the project, also makes it possible to have a deep insight into the processes and reasons behind using BIM or not using it properly, in order to improve its implication and address its barriers in practice.
3. The project should be ongoing in the design phase. This enables the researcher to closely observe the processes and be involved in the project, to have a deeper understanding of what happens and why.
4. The researcher should have access to the information of the project, and have access to involving participants of the project.

3.1.1. Project of Dutch Pavilion at Expo 2020 Dubai

World's fairs always introduce new ambitions in architecture and construction methods and techniques. One of the three main focuses of the Expo 2020 Dubai is sustainability and circular economy in the built environment. Since the Expo is trying to have the state-of-the-art experience in construction, the high standards and requirements should be applied to the design and construction of the pavilion buildings.

The Dutch pavilion in Expo 2020 Dubai is an ongoing project. Witteveen+Bos is the engineering consultant of the project. The scope of the project is design, realization, maintenance and removal of the Dutch Pavilion in Expo 2020 Dubai. The design and construction of the building should be based on the requirements of the Expo. Regarding sustainability, the buildings should be aligned with LEED Gold certificate requirements, and regarding circularity, and according to the guidelines of the Expo, the pavilions *"must be designed to redeploy, recycle, or return back to the manufacturer 75 percent of construction materials"* (Expo2020Dubai, 2016). The organization structure of the project is illustrated in Figure 3.1.

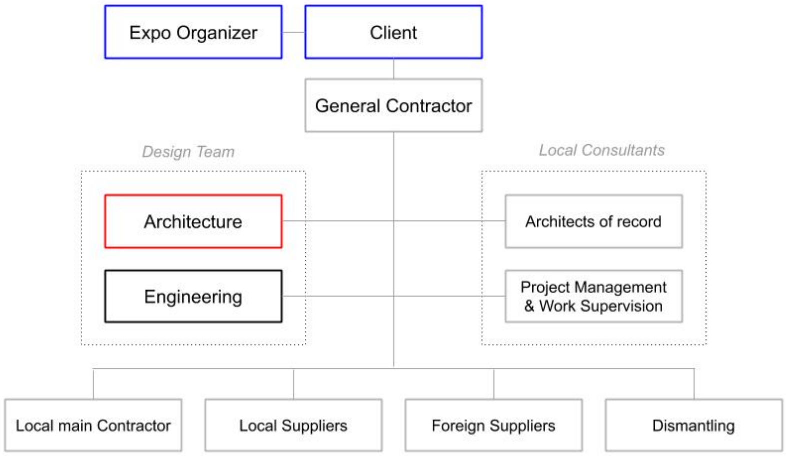

Figure 3.1: Organization Structure of the Project

The building is designed to be fully circular; its construction starts in Summer 2019, and after the Expo event, it will be deconstructed completely, and the components and materials used in the building will be returned to other construction cycles. The main idea of the building is to use available local materials with high recovery potential. Therefore, the materials and components of the building will be procured or rented from the second-hand local suppliers, and they will be reused and recycled after the deconstruction. The structure of the building is based on steel foundation, sheet piling for construction of the walls, and sand from the excavation, which fills inside of the load-bearing walls (look at Figure 3.2 and 3.3).

The case study project fulfills the above-mentioned criteria, although it has some unique characteristics, which are important to be mentioned. Since, it is a pavilion for exposition, it has a known end-of-life, which is not typically the case for other buildings. In addition, because of the nature of the Expo, the project has serious constraints on budget and time. Therefore, it can be assumed not so typical. However, the high standards and principles pursued by Expo Dubai, and its goal to achieve circularity to a high extent, makes it a valuable case to be studied. There are not many available projects that are considering DfD as the basis of their design. Because of the pavilion's temporary nature, and consideration of disassembly at the end of its lifecycle, it can provide new insight on DfD. In addition, the collaboration (between architects, engineers, contractors and sub-contractors) can be closely followed and the quality of using BIM in this project can be identified; how it is used, where it is not used properly, and why. This process will lead to a holistic observation of using BIM for DfD and transferring the required information for this purpose. It is also important to mention that the goal of this research is to study the application of BIM to the main process of DfD in the design stage. Therefore, the essence of BIM, as building information modeling, and the essence of DfD, to consider deconstruction in design of a building, are the necessities of this study.

Figure 3.2: Dutch Pavilion at Expo 2020 Dubai, V8 Architects, 2019

Figure 3.3: Dutch Pavilion at Expo 2020 Dubai, V8 Architects, 2019

3.2. Case Study Protocol

Good case studies have the advantage of multiple sources of evidence (Yin, 2011). To have a guide through the data collection procedure, and to increase the reliability of the research, it is vital to have a case study protocol. Case study protocol deals with the problem of documentation in detail, and helps to develop a case study database (Yin, 2018). The case study protocol of this research is shown in Table 3.1.

Overview of the case study	**Objectives**	*Study approaches towards circularity in practice; Study design for deconstruction processes in practice; Study BIM role in design, construction planning, and deconstruction planning of a circular project; Identify trade-offs and issues for using BIM for DfD.*
	Relevant readings	*circularity, DfD, Deconstruction, BIM.*
	Role of protocol	*Guideline for the data collection procedures (design interview questions, document analysis, observations categorization); Guideline for the data analysis.*
Data collection procedures	**Data collection plan**	*Data is gathered by the reseracher through the period of Feb to July 2019, through her presence in the offices of Witteveen+Bos.*
	Format for the data	*Text, audio files, images, BIM files (proprietary and non-proprietary file formats)*
	Logistical reminders	*Consider delays for conducting interviews; Consider the project schedule.*
Protocol questions	**Main questions**	*What is the DfD process in the project?; How BIM is used in the project?; Why is BIM used or not used in this way?*
	Potential sources of evidence	*Project documentation; Interviews with the involved participants; Observations during the presence in the organization.*
Outline of the report	**Presentation of results**	*Results of the case study, as a part of the researcher's master thesis, will be presented in the final thesis report.*
	Bibliographic information	*References will be presented in the final thesis report.*

Table 3.1: Case Study Protocol

3.3. Data Collection

In case study research, data sources are as follows: documentation, archival records, interviews, direct observations, participant observation, and physical artifacts. No single source is completely advantageous in comparison to other sources, since they are highly complementary (Yin, 2018). Appendix B demonstrates the strengths and weaknesses of each of these data sources. To maximize the benefits of these six sources of data, K. Yin (2015) introduces the following principles to be applied to a case study:

1. Use multiple sources of evidence;
2. Create a case study database;
3. Maintain a chain of evidence (look at Figure 3.4).

In this research, the data is collected from the conducted interviews, project database, and researcher's observations and informal talks, which are elaborated as follows.

3.3.1. Interviews

When the research objective involves understanding the experiences, processes, and attitudes, interviews are useful (Rowley, 2012). In case studies, interviews are closer to guided conversations rather than structured queries (Yin, 2018). To ensure this, semi-structured interview design is selected for this research. Semi-structured interview is a versatile and flexible, and the most popular interview design, which have the following characteristics (Kallio et al., 2016):

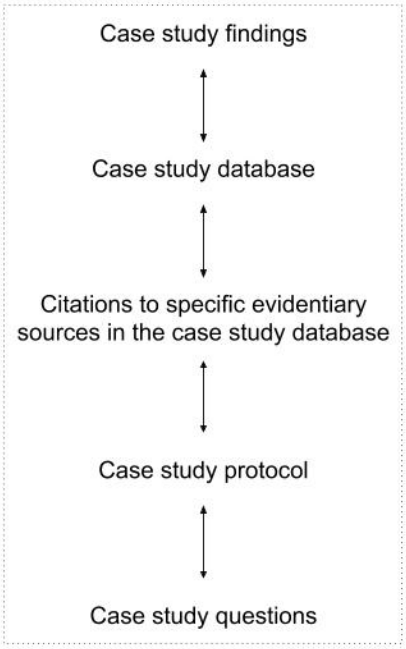

Figure 3.4: Maintaining the chain of evidence in a case study (Yin, 2018)

- Open-endedness allows participants to contribute as much detailed information as they want;
- Rich in qualitative data;
- Difficult to extract similar codes from interviews;
- Reduces researcher's biases in the research.

Therefore, two tasks should be considered throughout a case study interview; following the line of inquiry based on protocol, and conducting an unbiased conversation. The interview guide offers a structure for steering the discussion, but should not be followed strictly (Kallio et al., 2016). It contributes to the credibility of the semi-structured interview, as a research method. Appendix C shows the framework for development of the semi-structured interview guide, which is used in this research.
To design interview questions, it is important to ensure that they:

- Have no implicit assumptions;
- Do not include more than one question in one;
- Do not invite for yes or no replies;
- Are not vague or general;
- Are not invasive (Rowley, 2012).

Questions may have a few sub-questions, which ensure that the interviewee has explored the main question sufficiently (Rowley, 2012). In addition, the researcher should have a strategy to select qualified candidates who provide credible information to the study (Turner III, 2010). Table 3.2 demonstrates the interview protocol.

The interview questions will be as follows:

1. General information

General	**Case study**	*Dutch Pavilion in Expo 2020 Dubai*	
	Interview design	*semi-structured*	
	Interviewees	*project leader; project manager; BIM manager; architectural designer; structural engineer; MEP engineer; contractor.*	
Logistics	**Expected number of interviews**	*8 to 10*	
	Expected duration of an interview	*45 to 60 minutes*	
Data collection	**Questions format**	*open-ended questions*	
	Data gathering	*audio recording of the interviews*	
	Data analysis	*analysis in QDA Miner 5*	
Main objectives of interview questions		***Part A** - general information*	*To identify the role and responsibilities of the interviewee in the project.*
		***Part B** - circularity*	*To identify the meaning of circular economy concepts (circularity in general, deconstruction, and design for deconstruction(DfD)) for practitioners; To identify the gaps between the meanings of the concepts in practice and literature.*
		***Part C** - approaches*	*To identify the practitioners' approach towards DfD in this project.*
		***Part D** - processes*	*To identify how BIM was used in this process; To identify why BIM is used or not used; To analyze trade-offs.*

Table 3.2: Interview Protocol

   (a) What is your role and what are your responsibilities in the project?

2. Circularity
   (a) What do you think circularity means?
   (b) What do you think planning means?
   (c) What do you think planning for construction means?
   (d) What do you think deconstruction means?
   (e) What do you think Design for Deconstruction (DfD) means?

3. Approaches in the project
   (a) How have you approached this project based on circularity?
   (b) How have you approached the planning for construction in this project?
   (c) How have you approached DfD in this project?

4. Process and BIM
   (a) What were the challenges in this process?
   (b) How did you overcome these challenges?
   (c) What do you think BIM is?
   (d) How did you involve BIM in this project?
   (e) Why did you use or not use BIM in this project?
   (f) What have you learned from this project applicable to other projects?

5. Specific questions (varies based on their role and expertise)

3.3.2. Documentation

Document analysis is usually used combined with other data sources, to fulfill the triangulation of evidences (Bowen, 2009). Documents can verify the findings from other sources, they can enable the researcher to track the changes and development, and they provide contextual information, complementary data, extra questions. To have a guideline for collection and data analysis from documents of the project, a protocol is designed. The protocol identifies the categories that information divide to after the content analysis, based on the research questions (Bowen, 2009). In the case study database, the result of document analysis will be stored under "document selected" and "data analyzed" columns. The document protocol is shown in Table 3.3.

Data collection	**Types**	*Expo requirements; standards and regulations; contracts; design models and documents.*		
Data analysis	**Categories**	*general information of the project*	*project description*	
			project requirements	*design requirements*
				construction requirements
				deconstruction requirements
		design process	*design for deconstruction*	*approaches and principles*
				construction planning
				deconstruction planning
			information modeling	*BIM planning*
				BIM use

Table 3.3: Document Analysis Protocol

3.3.3. Direct Observations

The observations can vary from formal to informal data collection activities (Yin, 2018). Therefore, it ranges from attending meetings of the project to informal talks with the involved people in the project. The variety of data collected in these sources is higher than other two sources. Thus, it is important to design a plan for this purpose. Table 3.4 demonstrates the observations protocol.

Objective		*direct observation as a complementary data source to fulfill triangulation of evidences, based on the case study ogjectives (look at case study protocol); to observe the processes of project regarding DfD and use of BIM in the project.*	
Data collection	**Input**	*What*	*meetings (internal meetings and between companies); informal talks with participants;*
		When	*during the presence of the researcher in the organization of the project*
		Where	*company offices, other organizations' offices*
	Recording data	*filednotes*	*descriptive information (describe physical setting, social environment, participants, exact quotes and comments)*
			reflective content (own questions, insight, thoughts)

Table 3.4: Direct Observation Protocol

4
Findings

This chapter provides the findings from the case study research. The findings are based on data gathered from the interviews, direct observations, and related documentation. The data is gathered based on the case study protocol which is elaborated in chapter 3.

4.1. Thematic Content Analysis

Thematic Content Analysis (TCA) is a descriptive presentation of qualitative data (Anderson, 2007). This method is used to present the data gathered from the case study. The researcher should interpret the data that was gathered through interviews. This is done by compiling data into groups of information, known as themes or codes. Themes or codes are defined as consistent phrases, expressions, or ideas that were common among the interviewees (Turner III, 2010). Findings from interviews should be presented under headings reflecting themes that guided the analysis of data. Themes should also align with the research objectives (Rowley, 2012). After transcribing the interviews and approval of the interviewees on the transcripts, for the analysis of the data gathered from the conducted interviews, first a set of themes and codes are defined based on the case study objectives. In addition to the interviews, the documents of the project and the researcher's direct observations are sources of data. Therefore, to facilitate the integrated process of data analysis, a qualitative data analysis software is used. For this purpose, the data gathered from the case study is analyzed in QDA Miner 5. Appendix D provides the interview schedule.

4.1.1. General Understanding

Since theoretical concepts are not approached in practice homogeneously, and for some cases such as BIM, there are multiple definitions, it is vital to find the general understanding and definitions of the practitioners from the themes of the research. Therefore, during the interviews, it was important to see what the participants of the project define DfD (as an aspect of circularity) and BIM, and how their point of view was reflected in the project.

Circular Economy in the Built Environment

Although most of the interviewees were aware of the concept of circularity and importance of it in the future of the built environment, they asserted that it is not considered in their projects usually. Their definitions had differences based on their roles and education. In their definitions, the core concept of circularity was reuse and recycle of materials and components.

However, DfD was not a well-known concept, mainly due to the fact that deconstruction is not generally considered as a plausible future in construction of buildings. It is mostly implemented for the structure of the existing buildings, or temporary buildings. Therefore, DfD is also mainly appreciated as the choice of structural systems, and main material. It was asserted by the interviewees that this project was the first time to consider DfD.

BIM

To identify the role and uses of BIM in practice, first the definition of BIM and the use of it in their projects were discussed with the interviewees; how they define it and what benefits and issues they attribute to it.

- There was no mutual and consistent definition for BIM in the organizations; some had a more comprehensive definition, and some defined it more as 3D modeling tools. *"BIM is a fashionable word for doing something complex. I can have an Excel sheet with parameters and then it can be BIM. I can make a complex model for infrastructure, and coded, then it is also BIM. But few lines in Excel with parameters, that is also BIM. It is company related or project required, makes what it will be. The term BIM is just too big. It is Building information model"*(Interviewee 3, personal communication, 22 May 2019). *"The basis is 3D design, but in a way you can define components and apply features in the model, so you can easily see which components has what features or all the features of the components that are used. You can add much more during construction, you can use it for 4D planning. During use, you can use BIM for maintenance. So you can also define maintenance meantime between maintenance moments"* (Interviewee 1, personal communication, 22 May 2019). *"It is the matter of information put in a 3D model"* (Interviewee 7, personal communication, 20 June 2019).

- There were different focus points and expectations of BIM uses, based on the role of the practitioners, such as communication, information input and output, 3D modeling. *"For me, it is more an update. For my work, I need a lot of mass balances, and get the masses of different materials, and BIM makes it easier for me to get an updated view on it during the design process"* (Interviewee 4, personal communication, 24 May 2019). *"we never want to be blocked by software, it is not in the library so you cannot make it"*; *"I had two meetings for the tower project about which LOD (Level of Development)*(look at Appendix E) *we are going to work in. If it is LOD 200, then why should we work in Revit, it could be just meshes"* (Interviewee 7, personal communication, 20 June 2019).

- There were no clear plans for using BIM features, which causes missing some advantages of BIM. *"I think Navisworks is a very good instrument, but not common to use in our group. So we usually check only the PDF's"*. (Interviewee 1, personal communication, 22 May 2019).

- Time for learning is a barrier for using BIM properly, however, it can be beneficial afterward. In addition, it can decrease the work load. *"So then the better is to check the Navisowkrs. I agree it is better than PDF's. It is the matter of learning to work with Navisworks and lack of time"* (Interviewee 1, personal communication, 22 May 2019); *"I think regarding time it can be better (to use BIM). If everyone is constantly doing it right, and then we can get rid of all the drawings, reports. Now we have to put a lot of effort in reports. But with a BIM, you can have all the calculations. All the input and specifications, and then it can save time"*(Interviewee 2, personal communication, 22 May 2019). *"people learn it (Rhinoceros 3D) really fast and easy , so almost everybody here can work in it, even one who does not know, after two weeks can make models in it. After three or four months they can do almost anything in it. But for a BIM guy, we need training and it takes time to get efficient in it and make profound models"* (Interviewee 7, personal communication, 20 June 2019).

- Multidisciplinary collaboration in BIM platforms has benefits for coordination and design review, however, it is not always used. *"We used Navisworks check in a group in a meeting, and then the benefit is that if changes are made others can react clearly on the change"*(Interviewee 1, personal communication, 22 May 2019). *"There were times in that project, that people around the table (saw the 3D) said "Ah, is that the detail we are discussing?!". So there is really a value in that. All the parties need to work in 3D from the start, and then there is benefit"*; *"We have a lot of projects, for example, we used BIM for communication with clients. We have several examples that we used data from these models to provide extra information to the client"* (Interviewee 8, personal communication, 21 June 2019).

4.1.2. Design of the Dutch Pavilion Project

After discussion on the general meanings of the research themes, the experience of the Dutch Pavilion project was discussed with the practitioners. To study DfD processes in practice, and study BIM role in design, construction planning, and deconstruction planning of a circular project, it is tried to focus on the design of the project (DfD), and the processes (BIM) of the project.

Circularity of the Dutch Pavilion Project

For the purpose of circularity of the project, the main decisions were made in the beginning of the tender phase by the architects. *"One of the first thoughts we had when starting the project, was that we are in the sustainability part of the Expo, so we should do something for that"* (Interviewee 7, personal communication, 4 March 2019). However, not specifically based on a set of standards or guidelines; *"purely from our minds"* (Interviewee 7, personal communication, 4 March 2019). After the tender phase, and in the technical design phase, the sustainability aspects also were checked. *"(We did a) BREEAM-NL quick scan ...also indicators derived from the material circularity index from the Ellen MacArthur Foundation, like reusability, recyclability, bio-based "* (Interviewee 4, personal communication, 24 May 2019). The aspects of circularity that were considered through the planning and design of the building can be listed as follows:

- Minimize the use of materials and waste; The main structure is formed by two walls coupled by struts at roof level. The walls consist of a steel frame founded on a steel foundation, with a cladding of sheet piles on both sides. The walls are filled with sand coming from the excavation between both walls (Structural Package Content-Concept Design, Witteveen+Bos, 2019). *"Our first idea was to make a hole in the ground, so you don't have to construct anything, if you make a hole, it is there already, but then we found out, that it is not so easy to make a hole. Then we thought what if we make a hole, and use sheet piles. And Witteveen+Bos proved that it is possible"* (Interviewee 7, personal communication, 4 March 2019).

- Use of reusable materials and consideration of the future use of the structural materials and components. *"the second thought which was important concerning circularity, was that we would put sheet piles in the ground, and if we will get it out again in a nice way , we can give it back to the one we loaned it from, in this case the one who is sponsoring company. And it can be used again for a dam or another building and actually by picking all the construction elements, we really thought about it well, if we take them out can we use it again"* (Interviewee 7, personal communication, 4 March 2019); Use of cable for the cone structure, because the form is unique, therefore if it was designed with steel, it would be not reusable easily (Structural Package Content-Concept Design, Witteveen+Bos, 2019); Use of steel for the foundation instead of concrete, to have 100 percent recovery of structural materials (Interviewee 7, personal communication, 4 March 2019). *"So don't use any concrete for the foundation slabs, it is steel. During the whole project, we pushed the contractor not to use concrete. Because for the contractor it is easier to use concrete"* (Interviewee 8, personal communication, 21 June 2019).

- Use of common materials in other local structural projects. *"We wanted to use sheet piles for the big walls, because you can easily put them in and can take them out again, as we also usually use for building pits. Then they can be used for another project again"* (Interviewee 2, personal communication, 22 May 2019). *"for instance, the white pipes of the laboratory, they are water drains, and if we take them off, we can use them again as water pipes"* (Interviewee 7, personal communication, 4 March 2019).

- Consideration of solutions for the ownership of materials and components, by renting the main materials from the local suppliers; to facilitate the reuse of materials. *"For Dubai project, some components are rented, because the project lasts for six months and then will be dismantled"* (Interviewee 1, personal communication, 22 May 2019).

- Consideration of standard sizes and shapes for the design of the components and elements. *"When it comes to HVAC systems there were changes. You need to do it in a way to be able to take them apart and resell them. So go for standard products and sizes"* (Interviewee 8, personal communication, 21 June 2019).

- Consideration of the deconstructability of the building; and therefore, DfD (will be elaborated in the next section).

By comparing the mentioned points and the theories on circularity aspects (look at Table 2.1), the aspects of circularity that were considered in the project can be summarized as in Table 4.1.

Circularity aspect	**Design decision in the project**
Design out waste **&** Use less materials	use of the sand from excavation as heat insulation in the walls
Use secondary materials **&** Specify reclaimed and recycled materials	choice of local and common materials and facilitate reused material and reuse and recycle after deconstruction
Design for standardization	standardized design of MEP systems
Design for Deconstruction	consideration of deconstruction in design of connections
Take-back schemes	renting the main reusable materials (sheet piles) from the local suppliers

Table 4.1: Summary of the circularity aspects considered in the project

DfD in the Dutch Pavilion Project

The fact that the pavilion will be deconstructed after the Expo event, in addition to the circularity theme of the Expo, require considerations for the deconstruction phase of the building. In this sense, DfD is both implicitly and explicitly considered in the design phase. However, due to different reasons, such as contractual reasons and segmentation of design and construction, not all aspects of construction and deconstruction are considered properly in the design phase. This will be elaborated more in the next sections. The following are the design decisions and considerations related to DfD in the design phase of the project:

- Set up the structural connection principles by engineers in a way to ease the disassembly. *"we set up the principles, so we say there must be a bolted connection and it should be like this"* (Interviewee 2, personal communication, 22 May 2019).

- Consideration of connections in the last phases of design. *"Not in the beginning of the design, but when you go more to the construction part, you have to think of the connections of the structure and details of the structure. And it can be a good way to reuse structural elements. Because now we demolish them, and for the concrete parts, we break it and reuse it only for roads, but maybe for different elements we can use if we can easily take them out. So, I think it is a good approach but it is not common sense"* (Interviewee 2, personal communication, 22 May 2019).

- As a requirement of Expo, no toxic material is used.

By comparing the mentioned points and principles of DfD (look at Table 2.4), the principles of DfD that were considered in the project can be summarized as in Table 4.2.

Use and Role of BIM in the Dutch Pavilion Project

Although BIM has capabilities for achieving DfD goals, in practice, it might not be utilized. To identify trade-offs and issues for using BIM for DfD in practice, as one of the case study objectives, the use and role of BIM in the project was discussed by the practitioners. The results in this regard are as follows:

DfD principle	Design decision in the project
Use recycled and recyclable materials	*as mentioned in Table 4.1*
Avoid toxic materials	no use of toxic materials
Minimize the number of types of materials	few types of materials chosen for as the main materials of the building
Use durable materials	choice of materials that can be used for more than one time in the local construction industry
Use mechanical connections	set up principle on dry connections rather than wet connections

Table 4.2: Summary of the DfD principles considered in the project

- The requirements from the Expo authorities regarding BIM were to have *"3D BIM models"* in the native, IFC, and NWD file formats. (BIM Package Content – Final Design). *"the client did not ask anything for BIM, it was only from Expo, that in the end, have a BIM model of structure and then they started adding more and more that they wanted in there"* (Interviewee 7, personal communication, 20 June 2019).

- Lack of BIM planning in the beginning of the project between the design participants. *"I am not sure if we had really agreements with architects. Quite soon, it was clear, that they don't have enough time to make the transfer to use Revit or ArchiCAD"* (Interviewee 8, personal communication, 21 June 2019). Which leads to lack of consistency in the software use and therefore, issues in interoperability. *"their engineers work with STAAD.Pro, that engineers of the project did not have it did not know how to work in it, so there was constantly a discussion between software, so actually the power of BIM, that we can have one thing and we can combine it, here the software made communication even impossible. We have great engineers, but we cannot communicate, because one is working in one software, and the other does not"* (Interviewee 7, personal communication, 20 June 2019). *"it turned out that the structural engineer started working in a different version of Revit from MEP people"*; *" The fact that we even internally did not keep with the standards"* (Interviewee 8, personal communication, 21 June 2019).

- Design and 3D modeling are not developed within a same platform. Therefore, 3D modeling is done after the design is done (Interviewee 3, personal communication, 22 May 2019). *"But what is happening is not that. People still work towards 2D drawings. However, they should work in 3D"* (Interviewee 8, personal communication, 21 June 2019).

- Lack of a single model in the design phase of the project: The engineers had a mutual model, but architects did not have one (Interviewee 3, personal communication, 22 May 2019). However, the model in the engineering company was also not complete and therefore, not useful enough. *"we had our structure 3D model, that was only the structure, and in this case if you look at the structure of this building, it is only these big walls and floors, so the result of that was that it was a super empty BIM model. So there was no use to have it in the meetings"* (Interviewee 8, personal communication, 21 June 2019).

- Change management is done in a traditional way. *"Now each time architects change their plans, we adjust it in our model. There was no clash control regarding structure or installations. Each time we have to put it together"* (Interviewee 2, personal communication, 22 May 2019). Therefore, the BIM capabilities for this purpose was not utilized. For instance, Navisworks was used by MEP engineers for checking the HVAC systems, however, individually, and not in a multidisciplinary way.

3D modeling of the building in this project has been stopped at some point (due to different reasons). Deliverables to the client for design phase were mostly in 2D drawings and documentation. Therefore, these documents were produced as the final design of the building by 2D drawings in a CAD software. However, the existing model (modeled in Autodesk

Revit) and how it was approached and developed for the purpose of DfD can be described under the following categories:

- material and component design: not all the elements are modeled; for instance, MEP systems and architectural elements are not completely modeled; non-geometric information is not available.
- interface design: the model does not have explicit or implicit information on the interface design (look at Figure 4.1 and Figure 4.2).
- construction and deconstruction planning: there is no explicit information for construction planning/ phasing. This may contain considering the labour and equipment, or sequences of assembly and disassembly.
- information management: The model can be considered as an object-based 3D model, however, only representing the form of the building. The incomplete model cannot be updated in the construction phase and afterwards (maintenance, operation, and deconstruction).

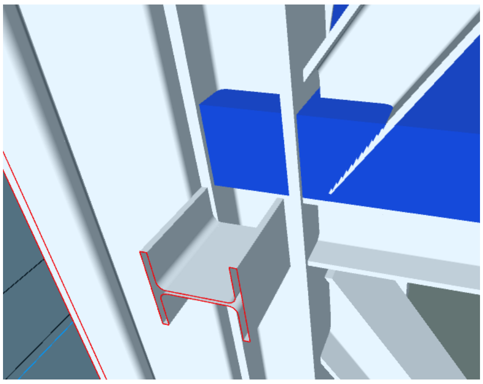

Figure 4.1: Modeling detail- wall section: interface of wall and floor structural elements are not modeled. (Retrieved from 3D model, Witteveen+Bos, 2019)

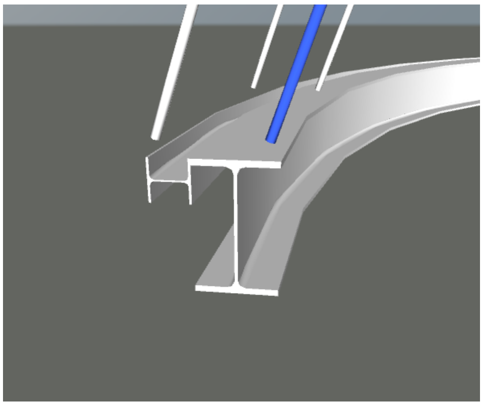

Figure 4.2: Modeling detail- cone section: connection of the cone's beam and cables are not modeled. (Retrieved from 3D model, Witteveen+Bos, 2019)

The model does not represent all the components and elements of the building. It also does not have adequate information on the components and their relations and interfacing. For assuring the construction, and therefore, deconstruction of the building based on its design, the symbolic representation of components is necessary. The interfacing of components is also vital, either explicitly or implicitly provided. However, the model in this case, is just representing the form, and has no analytical information. Therefore, it can be concluded that the model does not fulfill the requirements for construction and deconstruction. The communication between the design and realization is done in an old-fashioned way. For the purpose of deconstruction, the communication of design is mainly done verbally, and not via a mutual model. In other words, BIM model is not usable for this purpose, therefore, the risk of failure of construction and deconstruction (as designed) is high. Lack of design information can lead to need of double work, or failure in realization of design ideas and considerations. By taking all mentioned above, how BIM was used in this project is summarized in Table 4.3.

BIM uses in the project	**Description**
Structural Analysis	structural analysis not linked to the model, structural designed modeled in Revit
Energy Analysis	building energy analysis not linked to 3D model
3D coordination	not used for coordination, only done by the Revit modeler
Mechanical Analysis	not used properly, checking PDF's of the 3D model
Sustainability Evaluation	using outputs of the structural model for sustainability evaluation

Table 4.3: Summary of the BIM uses in the project

Design Process of the Dutch Pavilion Project

To improve the DfD practice and utilization of BIM for this purpose, identifying the design process of the project and the decisions are important. Based on the data gathered from the case study, the schematic time-line of the project is represented in Figure 4.3. The time-line shows the decisions made about DfD and BIM, which are the main objectives of the case study. In this regard, the following remarks can be identified:

- Segmentation of the design process; for instance the structural engineer was not involved in the architectural decisions made for the structure. *"It is a little bit difficult. Because the structural engineers are not at the most leading members of the team. Mostly we have to confirm the design of the architects and telling what is possible and what is not possible"* (Interviewee 2, personal communication, 22 May 2019).
- Segmentation of design and construction phases. *"We don't do a lot of construction planning. It is done by the contractor. We make the design and the contractor plans"* (Interviewee 1, personal communication, 22 May 2019); *"With architects (when working in the design team), it is not very important how it is planned to be constructed. Because the planning part is not important for the architects. More for the client"* (Interviewee 2, personal communication, 22 May 2019); *"Construction and deconstruction are really for the contractor. He might change the design. But it is part of his job"* (Interviewee 2, personal communication, 22 May 2019); *"We designed the principles of the connections. But the size of the bolts are contractor's job. So really the details of the details"*(Interviewee 2, personal communication, 22 May 2019).
- Not all information is explicitly transferred between the different participants; Implicit design information. *"You can do it (design for deconstruction) by your own thinking. So it is your wisdom, thinking, designing, planning, you have to think before, not an extra layer in model"* (Interviewee 3, personal communication, 22 May 2019).
- Coordination of design and construction, with constraints of the budget and time, were mostly discussed in design meetings of architects and engineers with the contractor. There were more regular meetings between architecture and engineering firms in the beginning of the design phase. Other parties were also included in the meetings afterwards. Communication with the contractor in the regular meetings and Whats app group, for the goal of coordination (Interviewee 6, personal communication, 4 June 2019).

The participants have faced different challenges during the design phase of the project. Although part of them are specific to this project and its unique aspects, such as specific

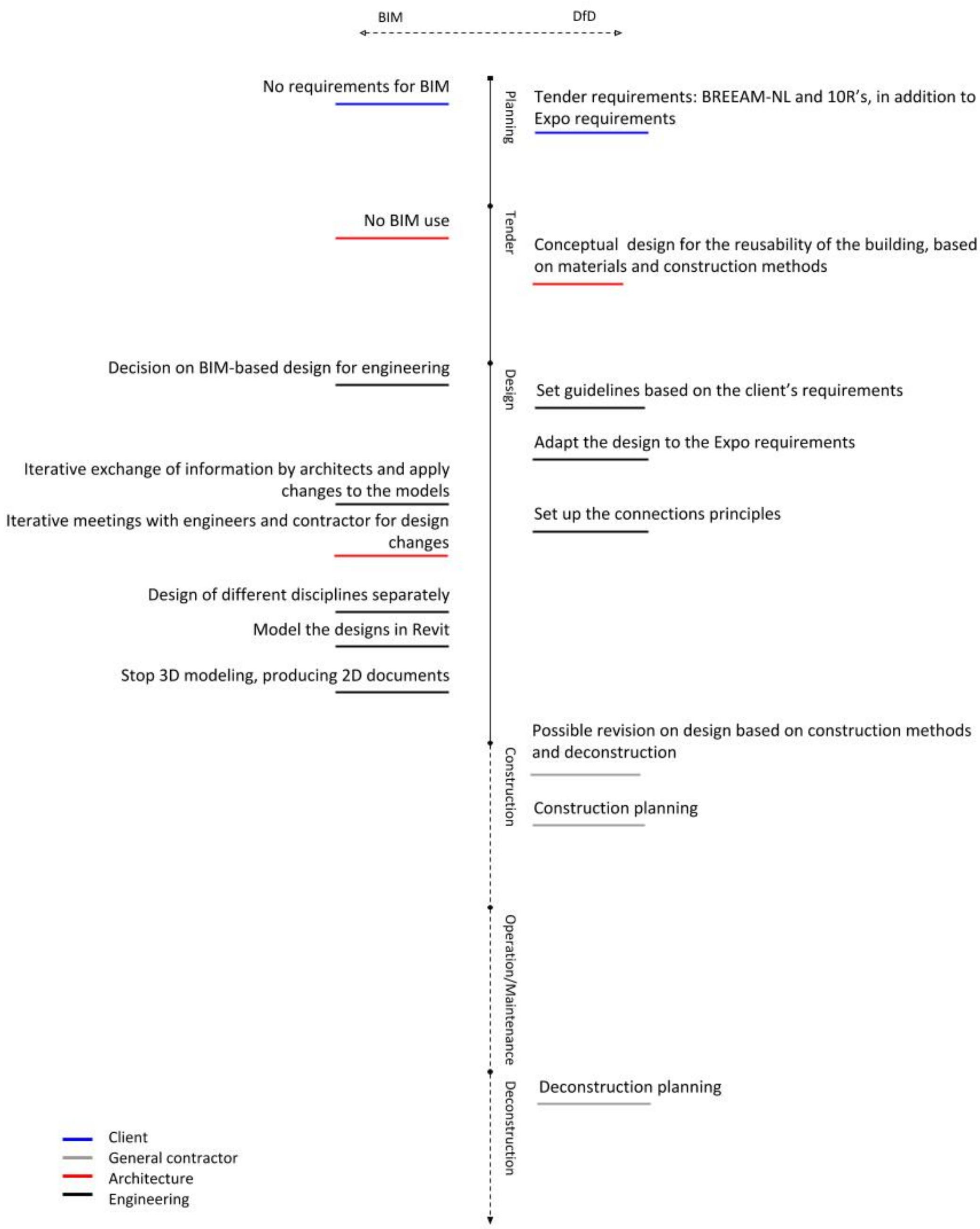

Figure 4.3: Schematic design process (own illustration)

issues of Expo, tight schedule, and restricted budget, to name but a few, part of them are more directly related to the design process and BIM planning. The importance of the challenges is due to the fact that they can be analyzed and the reasons can be detected. The project's specific issues would be identified, and the more general issues with other projects are detected. This procedure helps altering the roots of issues, and adjusting them in the improved design process. These challenges are categorized as follows:

Project specifications

- Client's requirements are enormous and changing. In addition, the requirements are not clear in some cases. *We thought that we worked and designed the details to a point that was enough, but they said no. That was the change"* (Interviewee 8, personal communication, 21 June 2019). However, part of the challenge is due to unfamiliarity with the requirements, since it is a foreign project. *"This was a very difficult project regarding time and the client was really difficult regarding changes. Europe codes approach in comparison to Dubai codes are different"* (Interviewee 2, personal communication, 22 May 2019). *"there are different layers of requirements, also the general requirements in Dubai...But there was a list of many codes. It takes few weeks to study all these codes"* (Interviewee 1, personal communication, 22 May 2019).

- The project has a tight schedule in comparison to its scope. It leads to a tendency to less complicated work processes. *"but at a certain moment there is much pressure from the contractor and the client that we want it to be done in time. And then you start in the traditional way. Make a sketch, and because at the end it should be also delivered in 2D, then why should it be in 3D?"* (Interviewee 7, personal communication, 20 June 2019).

- Cultural differences led to difficulties in communication and misunderstandings; *" There were a lot of challenges mainly related to Dubai way of designing and communication with the client. Expectations were very different. What we noticed was that they have quite a conservative way of designing, and we made steps they did not understand or were not used to. It resulted in some communication struggles. We learned that we need to put more effort in the way we communicate designs. So, design was not the problem, but the way that we presented it. So that was mainly an issue during the project"* (Interviewee 1, personal communication, 22 May 2019). *"in Dubai everything is done by law, so everything is defined by the rules and the books and thinking out of the box is really difficult for them. This whole project is thinking out of the box, who uses sheet piles to make a building. So sheet piles for cladding, prove it. If you have done everything tested"* (Interviewee 7, personal communication, 20 June 2019). *"The main challenge was the Dubai context. The Dubai rules, their standards, which are not written down anywhere. That is really the main challenge"* (Interviewee 8, personal communication, 21 June 2019).

- The tender requirements from the client were not completely consistent with the requirements of the Expo. Therefore, there were some overlaps and uncertainties (Interviewee 5, personal communication, 4 June 2019). In the tender phase BREEAM was supposed to be considered (required from the client), however, the Expo authorities required LEED certificate (Interviewee 4, personal communication, 24 May 2019 & Expo2020Dubai, 2016).

Communication, collaboration, and coordination

- Lack of consistency in the use of protocols and working processes by all participants; *"How it works here in the company, sometimes you have to hop on and hop off, so when you hop off someone has to take your job. So, it differs in skills and same work ethics"* (Interviewee 3, personal communication, 22 May 2019). However, there are protocols, for instance, for BIM (Interviewee 6, personal communication, 4 June 2019).

- Lack of mutual meetings and design sessions with all involved participants in the design team, is one of the issues that one of participants have mentioned in their interview. *"More creating a team. And connection with the project. Mutual meetings. Design sessions"* (Interviewee 3, personal communication, 22 May 2019). However, there were meetings held during the design phase between different companies. *"(we communicated in) meetings mostly. Not on the phone. more discussions between engineers, us (architects), and the contractor"* (Interviewee 7, personal communication, 20 June 2019). Therefore, it can be related to the communication or involvement of different participants' concerns in the decision making procedures and agreements.

- Segmentation of the project between different companies and rigid division of tasks, however, a more integrated collaboration was required. *"because it is fragmented between engineers, architects, and the contractor. They are more target-driven and they have to make profit and high scope"* (Interviewee 3, personal communication, 22 May 2019).
- Lack of efficient and adequate intraorganizational and interorganizational communication. *" We have all kinds of means but we don't communicate"* (Interviewee 3, personal communication, 22 May 2019). *"There was a moment, I was in Dubai, and I came back on Monday, and in one day I produced 16 drawing in single line to discuss. Sometimes you need to do it. It could take me 8 hours to communicate"* (Interviewee 8, personal communication, 21 June 2019). *"It was more to get everyone together, to get the right information from the beginning phase. That was a challenge"* (Interviewee 4, personal communication, 24 May 2019).
- In addition to the previous challenge, involvement of many different parties in the project led to difficulty of communication and information sharing (Interviewee 6, personal communication, 4 June 2019).
- Lack of personal connection of participants to the project (not in all levels); *"I am not a robot. It is the more the connection between the people, you can overcome problems. It is about working together. You don't have to be friends with them, but a good team"* (Interviewee 3, personal communication, 22 May 2019).

BIM

- Complexity of BIM platforms was a barrier for using them properly. *"BIM should be more simple and probably better regulated. I think it is more about the way we communicate, not just digital, but also besides that"* (Interviewee 3, personal communication, 22 May 2019). *"Basically because we want to be efficient and free to make anything we want. Rhinoceros 3D is a nice program for that. It is the most stable software for making geometries, and also in complex geometries, since it developed from shipping industry, so 3D shapes are good for it. So that is one thing that we can work in it easily. Second, is that people learn it really fast and easy, so almost everybody here can work in it, even one who does not know, after two weeks can make models in it. After three or four months they can do almost anything in it. But for a BIM guy, we need training and it takes time to get efficient in it and make profound models. The next thing about Rhinoceros 3D is that it has good capabilities of communicating with our 2D program, AutoCAD. And we have plug-ins (for Rhinoceros 3D) to communicate with Revit. So, that is efficiency, we never want to be blocked by software, it is not in the library so you cannot make it. That is mainly the reason"* (Interviewee 7, personal communication, 20 June 2019).
- No clear level of detailing, is one of the challenges regarding modeling of the building; *"Disadvantage of 3D is that you can detail a lot, you can go crazy and there is no end. But i don't work for free"* (Interviewee 3, personal communication, 22 May 2019). *"For me this LOD is more interesting, what level of detail are you going to put in your model?"* (Interviewee 7, personal communication, 20 June 2019).
- Use of BIM can be time-consuming, which was a challenge in this project; *" You can see much more (with Navisworks), but it also takes more time to go through"* (Interviewee 1, personal communication, 22 May 2019). *"things like that have a learning curve, and projects like this, you only have a few months. You should not take the risk. So that was an issue. And really in the beginning it was clear that 3D BIM part would collapse"* (Interviewee 8, personal communication, 21 June 2019).

- BIM is not used by all the project's parties, and it decreases its power. *"Suppliers and contractors are not used to BIM. Then, it is a little bit difficult. Because they are used to work traditionally. They want to sell their elements and that's it. There is no benefit for them to work with BIM"* (Interviewee 2, personal communication, 22 May 2019).
- Lack of agreements on the content of data in models. *"It is something we did for the last ten years. But apparently it can be a challenge but not necessarily to blame BIM. For instance, there was a misunderstanding of software package to use. There was a lack of architectural data. So, MEP needed that to put installations on walls for instance. I don't think you can say BIM is more work"* (Interviewee 8, personal communication, 21 June 2019).
- BIM was not used from the beginning of the project. *"from the start (we should work) in BIM and just from the beginning, start 3D"* (Interviewee 3, personal communication, 22 May 2019). *"There was no or very little architectural data in the model"* (Interviewee 8, personal communication, 21 June 2019).
- Unfamiliarity with software and tools could be a barrier. *"I started working with Relatics, to be the main source of logging. It is more like a log in my case. Logging the meetings, all the decisions. In the end, that really helped. Then, it (Relatics) started to be less used... I think that it is not necessarily complex, but because we are not used to, a little bit complex"* (Interviewee 8, personal communication, 21 June 2019).

4.2. Conclusion

The findings of the project are compared to the theoretical findings regarding DfD and BIM processes in the design phase from chapter 2, and the conclusions are as follows:

Design for Deconstruction

In the project, the construction and deconstruction planning are completely the responsibilities of the contractor. Some considerations for construction process have been done in the design phase. *"So let's say that we have used a very heavy pipe (in the design) that needs a special crane to come there, that would have been stupid. So we thought to that level"* (Interviewee 7, personal communication, 20 June 2019). However, design for deconstruction requires a more holistic life-time perspective in the design process. Clearly, the form of contract and division of a project's responsibilities have impact on this issue. This has influence on both the design strategies and the information modeling and management of the project. Therefore, it can be concluded that form of collaboration has influence on the design process of a project, and a multidisciplinary integrated collaboration approach can improve DfD. For instance, the decisions made regarding circularity of the project, were done in an iterative process from the conceptual design to technical design. *"So it was first, what do we need to make? What are the standards, and what are the alternatives from Dubai, what has the least impact, and what is the most circular? Always that thinking process. Still happening. We still need to change things"* (Interviewee 7, personal communication, 20 June 2019). By facilitating the communication processes and the integration of the design tasks, the quality of the design process increases. An example of this is the fact that local architect of record could have been involved in the design phase earlier, and some mistakes would have not occurred (Interviewee 8, personal communication, 21 June 2019).

On the other hand, in theory, DfD is identified as a strategy that maximizes the value recovery of the buildings, and it is asserted that designers can have the highest influence on the circularity of a building. However, in reality, the interests of the stakeholders regarding DfD are different and in some aspects might be in conflict or inconsistent. Designers should have an incentive to consider the DfD principles. Otherwise, it can be approached as an extra work to them, and the decisions for this purpose postpone to the realization, and finally deconstruction phase. This issue relates directly to contractual form of the project. To achieve DfD, it is vital to address it contractually as well.

In theory, the DfD principles include two groups of product-related and process-related categories (look at Table 2.4). The decisions made for the purpose of deconstruction in the design phase of the project, were mostly from the categories of material design, component design, and interface design. However, the construction planning, deconstruction planning, and information management categories were less or not considered; in other words, mostly product-related and less process-related. The main reasons for this is lack of awareness of DfD principles as an aspect of circularity. In addition, the segmentation of the design and construction has influence on this issue.

Information modeling and availability of information in the lifetime of the building, is asserted as an important aspect of DfD. However, in the project, some of the design decisions, are not explicitly shared with the next user of that information (the contractor, in this case). This can lead to repetition of some tasks, and decrease of impact of the DfD aspects in realization of the building (construction and deconstruction of the building).

BIM Use and Role

One of the important aspects of BIM is providing multipurpose communication means. For instance, it decreases the language barriers (Sanvido, 1990). In this project, although interorganizational and intraorganizational communication had a high level of importance, a big part of the challenges and problems were related to communication. *"Miscommunication and misunderstanding were the main issues in this project"* (Interviewee 8, personal communication, 21 June 2019). The participants have faced these challenges during different stages of the project, and mostly figured them out by personal communication at the end. Examples are as follows:

- Cultural differences; *"A representative went to Dubai and had conversations with the client (Expo authorities). They were very negative in the beginning with our design because it was something they were not used to see and in their opinion we did everything wrong, but it was not the design, the way we presented as what it is, take it or leave it, and they are not used to this approach. So the direct Dutch communication was not appreciated"* (Interviewee 1, personal communication, 22 May 2019).

- Information sharing; *"I communicated to all the different parties via one person in a meeting, and he communicated to everyone. And everyone got the ambitions"* (Interviewee 4, personal communication, 24 May 2019).

- Change management in the process of design; *"If we see changes we discuss it to the leader engineers of this discipline. So they have to agree"* (Interviewee 1, personal communication, 22 May 2019).

The challenges related to communication, however, might not be figured out easily, and lead to increase of work load. *"At the end, the design had to change a lot, because of new requirements, in our eyes new requirements. In their view (Expo authorities) it was logical"* (Interviewee 1, personal communication, 22 May 2019). *"I try to fix it. You never know what has happened (in the model designed by someone else) and there is no log"* (Interviewee 3, personal communication, 22 May 2019). *"We had to combine all information from all the suppliers, try to make all necessary changes, make compromises, iterative process"* (Interviewee 6, personal communication, 4 June 2019).

Communication between the participants was done in a traditional way. *"So we transferred everything via email. Lots of emails. A little bit unprofessional"* (Interviewee 8, personal communication, 21 June 2019). This can be seen from two perspectives. First, from the point of the traditional contractual form of collaboration in the project, therefore, segmentation of the tasks and lack of integration of design and construction. Second, from the point of information modeling and exchange, which is about lack of a mutual digital platform for collaboration. The later can mitigate the former to some extent. For instance, one of the issues was the low influence of participants in some parts due to the segmentation of the design; *"our influence is limited"* (Interviewee 2, personal communication, 22 May 2019). However, by having an integrated platform, and having instant feedback loops, it could be mitigated.

Although there was a BIM planning in the beginning of the project for the architects and engineers, it was not practiced in the end. Architects were not using it. mostly because of unfamiliarity (with BIM) (Interviewee 5, personal communication, 4 June 2019). Benefits of

BIM can be utilized if it is approached thoroughly and consistently by all participants of a project. This requires familiarity with BIM processes and more importantly, agreements on use of it in the beginning of the project. In addition, it can be concluded that to guarantee the use of BIM in a project, clients' requirements on BIM and contractual agreements should be considered. Otherwise, the companies have tendency to work in their own way, which might be different and not consistent. In addition, the complexity of BIM results to not following it completely. Therefore, following protocols and standardization of the processes can help the users to continue working in the agreed system. Agreements on content of information and LOD are also vital. This is due to the endless possibilities for building information modeling. Therefore, for having clear, consistent, and feasible working processes for BIM, a project-based BIM execution planning should be issued in the beginning of the project.

BIM processes might be time-consuming in the beginning for some practitioners. This has to do with the learning curves in the beginning of application of new methods of working. However, in many senses, its benefits has been proved theoretically and in practice. *"But we have other projects that proved really if you collaborate, you come up with beautiful models. Perfect"*; *"Yes, it (Relatics) started to be less used. Because it takes more time than we wanted. Then, it failed. But still, again and again I appreciated that I logged everything in that"*; *"basically, BIM could definitely helped. We have proof of that in many other projects"* (Interviewee 8, personal communication, 21 June 2019). *"I think regarding time, it can be better. If everyone is constantly doing it right, and then we can get rid of all the drawings, reports. Now we have to put a lot of effort in reports. But with a BIM, you can have all the calculations. All the input and specifications, and then it can save time"* (Interviewee 2, personal communication, 22 May 2019).

For some purposes, BIM functions might not be yet fully developed and convincing for practitioners. *"I am not completely convinced that it is moving forward if you start to use Revit, because I am not convinced that this software is much better or we will be much more efficient, cause I think at the end it is not going to be more efficient. Probably it takes more time, especially in the beginning. In the end maybe it will be more efficient, I don't know."*; *"Basically because we want to be efficient and free to make anything we want. Rhinoceros 3D is a nice program for that... we are trying to be on the front of design, make more disciplines and gain more knowledge to serve the client."* (Interviewee 7, personal communication, 20 June 2019).

On the other hand, the move of market and the increase of BIM demand, is an incentive and motivation for practitioners to get used to it more. In this sense, a road-map for BIM customization and utilization internally can be useful. *"But we are doing more it (BIM) because the market is moving there, and the government is demanding the knowledge to do in BIM, at least we need a BIM model"* (Interviewee 7, personal communication, 20 June 2019). At the same time, the learning processes and opportunities for internalizing and familiarizing BIM can help companies to achieve BIM capabilities. *"We are talking to two people who we want to hire, experienced in this, and they can be hired as Revit persons, and the idea is that this person works on the project, and at the same time train two people of ours to start working (in Revit)"* (Interviewee 7, personal communication, 20 June 2019).

The architecture firm in the consortium is a smaller firm than the engineering firm, and this can lead to differences in the firms' tendency to adapt new working cultures or tools. Generally, the smaller firms prefer more intuitive project environments, however, the larger firms prefer more flexible tools for customizing their own project environments (London, Vishal, Ning, Claudelle & Ljiljana, 2010). In a multidisciplinary project with different sizes of involved parties, these differences are inevitable, therefore, it is important to consider them from the beginning of the project, and settle down the possible issues they may cause. The important thing in such context of collaboration, regarding BIM coordination, is interoperability between participants. Therefore, it can be said that internal preferences of software use and processes are different, however, to have mutual interorganizational working capacities, the information inputs and outputs should follow standards. IFC files are an example solution to this issue. *"In the beginning, we discussed with the engineers, we don't work in Revit here. We work 3D in Rhinoceros 3D and 2D in AutoCAD. But we can work from Rhinoceros 3D in IFC. So, we can read Revit files, we can export IFC's. So we are used to work within BIM for projects, but via Rhinoceros 3D"*; *"We work more on the form and for communication with* *the engineers we send 3D models. So, in the beginning, we said there is a BIM package, that was part of the contract of the engineering firm, and we can work quite fast in Rhinoceros 3D, so we are keeping it for design and looking at it in Rhinoceros 3D, then at the certain moment, when the engineers figured out the structure, the idea was that the engineers make the BIM model then we would import it to our software and make the architecture work there and give it back to them and at the end have a nice model"* (Interviewee 7, personal communication, 20 June 2019).

It is important to see BIM in two perspectives; as a new design process, and as a new technology. *"In a small sense, it (BIM) is making sure you have object-based data, object-based 3D model. In a broad sense it is managing all the building information in a project which includes documents, databases, and geometrical data, and try to make sure the data stays to high quality standards"* (Interviewee 8, personal communication, 21 June 2019). In the former point of view, BIM is a broader and deeper change in the AEC industry. It can introduce new capabilities; for instance, tracking the design decisions through the design phase and storage of information on that, which can be useful in knowledge management or accountability in the future. Therefore, it should be approached as a new way, not as a new technology for the traditional way of working in AEC. To achieve this, it requires mutual understanding and holistic view on how it brings new perspective to design and construction processes and methods, collaboration, and information modeling. This is clear from the different definitions that practitioners have for BIM. *"Building information model. It is actually model, I am doubting actually now. For me, it is building information model. We have discussion about that in this office"* (Interviewee 7, personal communication, 20 June 2019). Although the differences in BIM definitions and uses from the point of view of practitioners are mainly due to their differences in roles they have in a project, BIM should have a mutual planning internally. Lack of BIM planning causes missing its capabilities. This leads to the latter perspective towards BIM. In this sense, it is vital not to let BIM block the practice. At the end, it is the means to have the final result (buildings, in this research). *"So, that is efficiency, we never want to be blocked by software, it is not in the library so you cannot make it. That is mainly the reason"* (Interviewee 7, personal communication, 20 June 2019). This also applies to communication and collaboration between parties. Software and tools should not block the communication or become barriers. *"There were so much uncertainties between the engineers and local advisors (of the contractor) that they could not agree, at a certain moment, the engineers decided that they are going to solve it in Dubai, because they are working in that software. At that moment the model of the engineers stood still and this one kept developing but we could not export again and give it back. So we were looking at PDF's and people were trying to draw here at best they could, but the engineers stopped engineering at some point and we did not get anymore input, then of course our plans started to float according to structure, so we had to keep it aligned as good as possible. But I think it went wrong when these two (models) started to split up. And then also the engineers since they are not working actively on the problems, they did not know what is going on and then the discussion became that they found the solutions and the engineers wanted to be convinced and then they would not send the calculations or they could not check it and it was hard to do, so because of software a lot of things happened. So you could almost say that how software can be a blocker instead of helping"*; *"It was an eye-opener, 3D-wise and software-wise; that if you don't work in the same package, if you don't have the mutual understanding, then the software is not helping, would have been better to have sketches at the end"* (Interviewee 7, personal communication, 20 June 2019). For all this, and in the shift towards BIM, changes in roles and responsibilities occur. In this sense, the role of BIM managers and coordinators can be identified. This is in addition to the learning and training processes for practitioners.

In the project, BIM was perceived and applied mostly as a separate layer to the design process. Its 3D modeling function is the most approached function. However, it is not necessarily integrated with non-geometric design information. BIM can be beneficial for design process as well. It can help improving the design, for instance, by providing different analysis capabilities. Another aspect is improvement of design integration and mutual design development rather than segmented design process and communication of the final results. However, the 3D modeling function was also not completely and properly utilized.

5

Process Map

In this chapter, it will be discussed how the design process could be improved by identifying how BIM should be used in the design process. To validate the results, an expert panel session will be held.

5.1. Design Process Improvement

In order to improve the product of the project, which is a circular building to be deconstructable, the design process was analyzed at chapter 4. In order to achieve this, the following is done:

1. comparing what is done as DfD, and adding the missing parts to the design process;
2. since BIM has capabilities for DfD, identifying how it can be used for it;
3. addressing the reasons of why not BIM was used properly, and identifying the aspects that are out of the scope of the study.

Based on the findings from chapter 4, the missing aspects of DfD are as follows:

- complete material and component information;
- design and information of interfaces (assembly and disassembly instructions);
- considerations for providing the sequences of construction and deconstruction.

At the same time, BIM capabilities have been explored in chapter 2. BIM in AEC industry, is a transition from graphical representation to symbolic representation. Properly constructed BIM can be defined as a representation of a building by symbols of its components and elements, and their relations. Modeling can be defined by creation of BIM objects, representing building components, containing geometric and non-geometric characteristics and relationships (Volk et al., 2014). This should contain all necessary information to produce any relevant views.This is done by transforming planning into constraints. In fact, this is why BIM has importance in terms of DfD; because symbols can be manipulated and this brings numerous advantages, deconstruction planning is one of which. This is ”fit-for-purpose” approach; in other words, expressing goals in terms of tools. Therefore, by having a complete object-based 3D model, linking the relevant non-geometric information to it, construction and deconstruction planning would be possible too. The following capabilities of BIM could be used in this project:

- Parametric design: This aspect of BIM enables manipulation of design in an integrated way. It introduces a new way of design instead of the traditional way, however, makes change management, and development of design easier. Code validation is also a developing capability of BIM, which helps to check the model parameters against project specific codes. This can be specially helpful in projects with different group of requirements and codes, such as the case study.

- Information storing: Different stakeholders and different time periods in the lifetime of a building, and the necessity of having information on the materials' future reuse options, or specific information provided by suppliers, make it logical to store all the information in one model, and keeping them updated by the growth of the building.
- Analysis: Different analyses (structural, energy, etc.) in the design phase occur. BIM helps for integrating the analysis of different disciplines, and using the results of analyses in the design process.
- Design review: The most important aspect of completeness of the model in multidisciplinary projects can be 3D coordination (clash detection) and inter-disciplinary design reviews. These functions decrease the possible errors in design and prevents further costs and time for the corrections. In addition, it decreases the risks of misunderstanding and errors which can occur with the traditional design reviews (such as reviewing 2D drawings). This also helps the procedures of change management, with higher accuracy and efficiency. Additional benefits are omission of drawing production from the process of design.
- 5D simulation: This can be done by Time-liner function in Navisworks. The input is project scheduling (can be from Microsoft Project or Primavera), and the output will be the simulation of construction. This enables time-based clash detection, which is highly important for deconstructability of the building. By doing so, the barriers in construction and deconstruction processes can be mitigated in the design phase. Implicit consideration of construction sequences and feasibility is done to some extent in the case study project. However, a simulation of construction brings the mutual understanding of the whole process.

BIM is defined by Gu, Vishal, Claudelle, Kerry & Ljiljana (2010) as the process of maintenance of all the relevant information to a building (or construction project) in its lifecycle. Design is defined as the process through which the client's needs are defined, quantified, qualified, and communicated to the constructor (Sanvido & Norton, 1994). Expediting the understanding and viability of deconstruction sequence for a building elements is a means to DfD. Deconstruction planning, simultaneous to constriction planning and labeling components will provide directions for deconstruction stage (Guy et al., 2006). Construction planning and deconstruction planning should be done as part of the design. It is possible that the contractor and the deconstruction contractor in the future alter details in them, however, this is vital to share the information on design; what are the sequences of construction, what is the hierarchy of building elements, and how the connections can be accessible and dismantled. Therefore, the design for deconstruction can be tested; whether or not it is possible to be deconstructed. The steps of the proposed design process is illustrated in Figure 5.1.

5.2. Process Map Design

Lack of integrated processes is the biggest obstacle to utilizing the benefits of BIM (Wu & Raja, 2013). By taking this issue into account, based on the case study findings on DfD and BIM in practice, and by comparing them with the theories on these topics, a process map is designed to fill in the gaps and improve the process, to achieve a better product (building). BIM protocols aim guiding at either industry, enterprise, or project level (Kassem et al., 2013). This process map is designed at the project level. For designing the process map, the following aspects should be considered:

- Stages: Defining stages and a phase-review process reduces the risks, and improves the focus on each phase. Stage-Gate process provides these benefits (Kagioglou, Cooper, Aouad, Sexton, Hinks & Sheath, Kagioglou et al.).
- Gates: The division of decision making processes to ”soft gates” and ”hard gates” can help the utilization of resources in a design process. The former refers to activities that are allowed to progress rather than overhauled, and the latter refers to decisions with

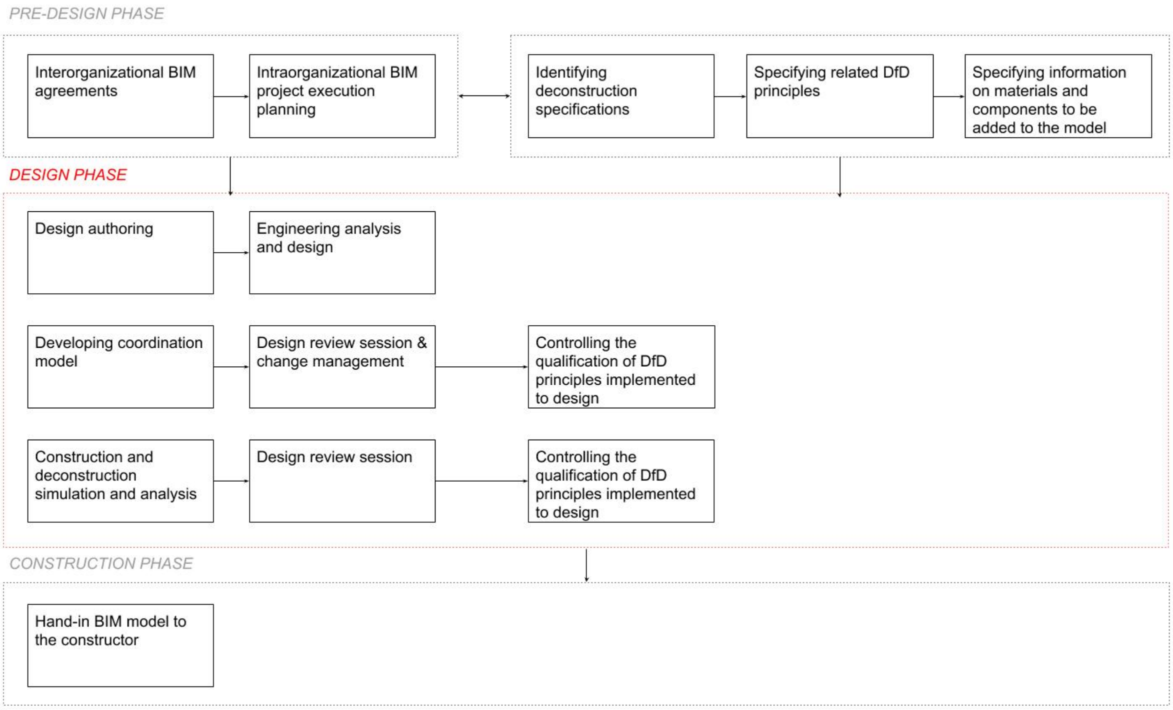

Figure 5.1: Steps of the proposed design process

high investment and impact on the project (Kagioglou, Ghassan, Rachel & John, 2019). It enables the cooperation and iteration in the process, as well as respecting the key decisions (Kagioglou, Cooper, Aouad, Sexton, Hinks & Sheath, Kagioglou et al.).

- Responsible actors: Contractual agreements have influence on the WBS of a project, and the distribution of the responsibilities to organizational roles. To avoid the differences made by contracts, the process map can change the responsible actor to activity zone (Kagioglou, Cooper, Aouad, Sexton, Hinks & Sheath, Kagioglou et al.).

The process map will be depicted by the means of Business Process Model and Notation (BPMN). BPMN is a process modeling standard enabling visual representation of business processes, which is mandated by National BIM Standard effort commissioned by the National Institute of Building Science (NIBS) (Wu & Raja, 2013). An integrated design process model (IDPM) represents the main activities and functions, in addition to the flow of information through design phase (Sanvido & Norton, 1994). The process map is designed to demonstrate the process of maintaining the relevant information of DfD in the project, which is illustrated in Figure 5.2. Samples of implementation of the process map to the case study were produced to be discussed in the expert panel session. An example of these samples is the deconstruction simulation of the building, which is illustrated in Figure 5.3.

5.3. BIM Process Map for DfD

The following remarks on the design of the process map are important to be mentioned:

- As was mentioned in the previous section, the process map is designed based on the related activity zones. Therefore, the first step of the process map was identifying the related activity zones in such projects.

- Some of the preparatory tasks should take place in the pre-design phase (look at Figure 5.1), which are illustrated in the process map from the start of the process until the start of the design phase.

- BIM coordination is an activity zone that should be considered in the process, who is responsible to plan for BIM in the project, and based on the contractual form of the project, in either levels of interorganizational and intraorganizational. In addition to the planning of the BIM agreements, it is required to control the proper approach to BIM by all the participants. The responsibility of such a role is related to the fact that a BIM model will be of which party's interest. For instance, in this project, the contractor, who is responsible for construction and deconstruction, can be the first beneficiary of a proper BIM in the project.
- Considering deconstruction as an activity zone has a high level of importance. Although in practice, demolition is mostly approached as the end-of-life of buildings, and the stakeholders related to this phase are demolishers, who might not have enough knowledge and capabilities of deconstruction projects. However, by the growth of circular economy in governments and market approaches, this issue might alter in the coming future.
- Circularity in the built environment requires time to be completely familiar for the practitioners. Therefore, an activity zone for this purpose is considered.
- By involving the end-users of the information, which are the constructors and deconstructors, from the beginning of the pre-design phase, the requirements of these stakeholders are considered in the design phase. DfD aims for facilitating the deconstruction process. Therefore, it is vital to consider their requirements from the very beginning of a project.

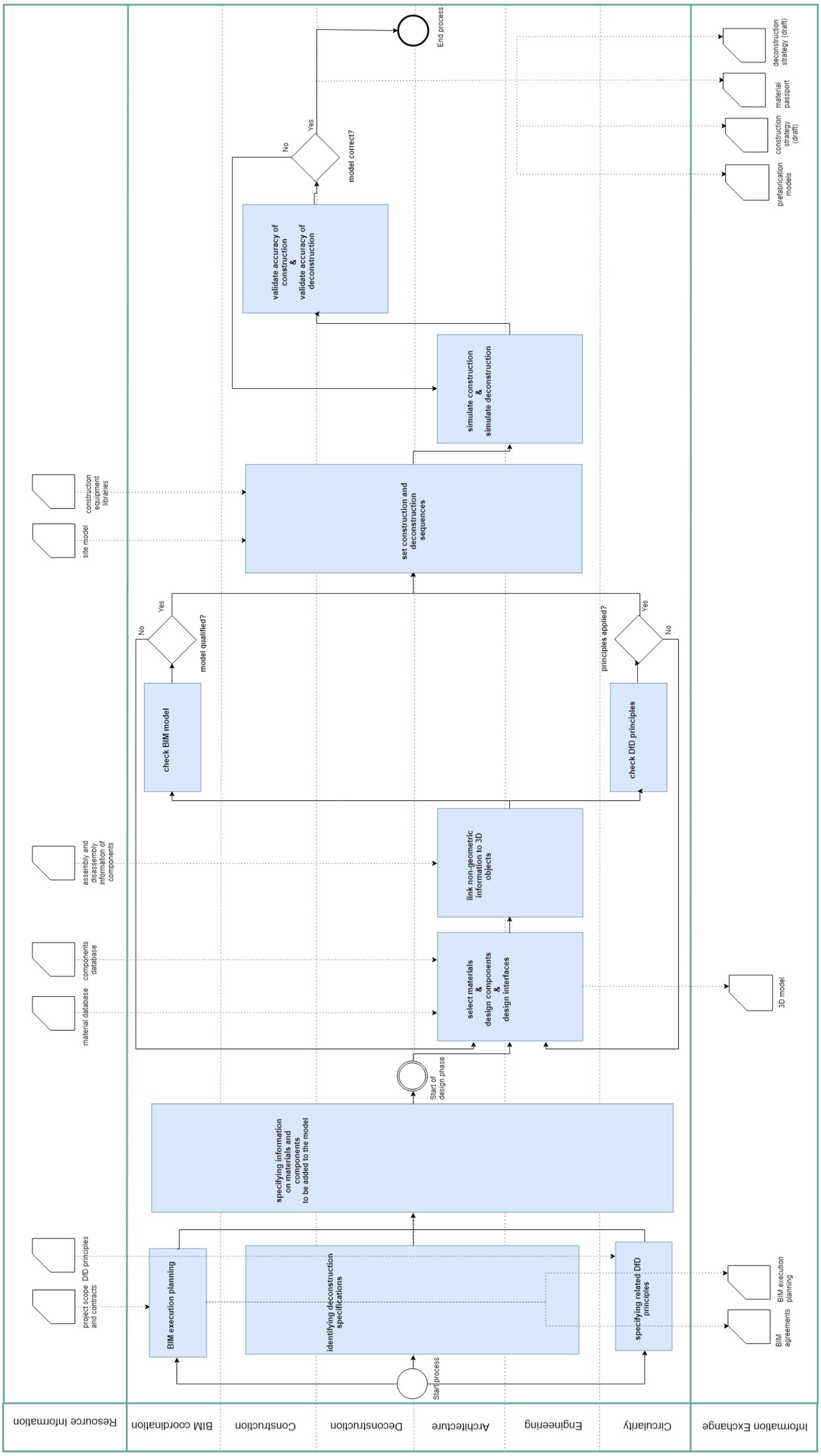

Figure 5.2: BIM for DfD process map, own illustration

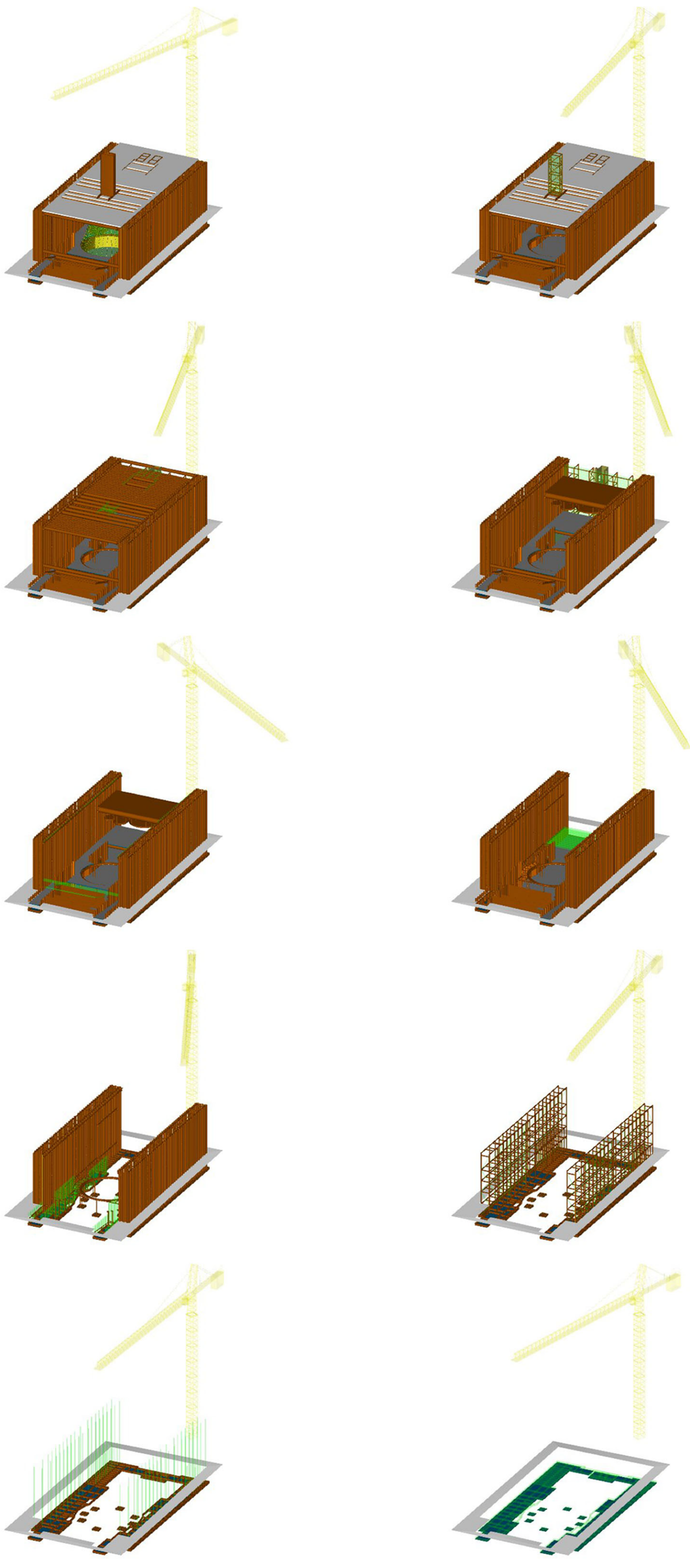

Figure 5.3: Deconstruction simulation of the case study project, exported from Autodesk Navisworks

5.4. Validation of Research Results

To validate the research results, an expert panel session was held to discuss the research findings and results.

5.4.1. Expert panel Session

By selecting experts in the main themes of the research, the panel was formed. The list of experts is provided in Appendix F. The research findings, the process map and its application of it, shown by samples from the case study project, were presented to the panel. The discussion and evaluation of the experts on the research results are as follows:

Discussion

From the point of view of the structural engineers, the main reason of not using BIM in the project, was lack of capabilities and complete interfaces of software packages. *"Structural analysis was not done in Revit. Revit was used for making drawings, not for analysis. Because in Revit you cannot calculate. Connection design was also done by hand. BIM was used for visualizing the project. Because it is not possible. The software used for structural analysis is not linked to Autodesk, for instance, therefore, the model in Revit could not be used (exported) for analysis."* (Expert 2, expert panel, 12 July 2019). To address this issue, having a complete software package use plan and consideration of interfaces is vital. *(In another project) in Autodesk, the main model could be in Revit, so also architects could change it, and then it was connected to Robot, to calculate the structural design. The collaboration between software packages is required"* (Expert 3, expert panel, 12 July 2019). The same issue was also happening for the sustainability analysis. For this purpose, Grasshopper was used, but it was not linked to a 3D model, and for energy analysis, Rhinoceros 3D was used. Having a holistic view, the project manager had this opinion that since it is possible to design the connections in Revit, it should have been done completely. On the other hand, from the point of view of the BIM coordinator the problem is lack of planning for BIM. *"The main goal of BIM is to add everything in the same environment, so there is no possibility to miss any information. The goal of BIM in a project, is that from the beginning, to have the end in mind, so we have to start what goal we want to reach. So if the goal is not clear from the beginning, the result would be like this. Therefore, the planning in the beginning is vital. You can do many different things in BIM. It should be specific to the project"* (Expert 5, expert panel, 12 July 2019).

Another aspect would be the benefits of BIM for different parties. *"Why and who gains to use BIM and coordinate? Why to care about it? For Witteveen+Bos, BIM is to a certain level necessary. That is an important question. what does the client gain by BIM?"* (Expert 1, expert panel, 12 July 2019). The consensus on BIM mutual working and responsibilities is vital from the management point of view. *"But if not all use it, and one party uses it, then they will lose their profit on using BIM. BIM can make profit, but if you don't see that and feel responsible for the profit, then it is not going to be required and people won't find it important enough. The idea of having BIM agreements between all parties, in the beginning of the project, is a good idea. However, they have to be equally responsible for BIM, which is never going to happen, since they have different interests. They have different ideas of profit. There should be requirements on that, so to make people responsible for that"* (Expert 1, expert panel, 12 July 2019). In addition to interorganizational perspective, this issue should also be addressed intraorganizationally. *"Engineers don't look at the model. they just want to export from the model to have the 2D drawings. They don't care. It is surprising that people don't look in 3D model, however, it is really easy. In the process everyone loses the interest in BIM, because there is no one or no organization that drives that need. To make all responsible for that and assures that everyone is using BIM and getting the information"*(Expert 1, expert panel, 12 July 2019). This is not necessarily due to lack of access to software or models. *"Navisworks freedom, for instance, makes it possible for all to have access to the 3D model"* (Expert 5, expert panel, 12 July 2019).

All parties can achieve advantages from BIM separately, additionally to the whole project. So there are two points of approach. First, as a holistic consistent process for the project, between all parties; and second, as a process for each organization. Even if other parties don't do it right, it can be beneficial for one then. *"clients sometimes demand for BIM, but at the end, they don't go back to it, they don't look at it. They don't care. Same happens when we deliver the design to the contractor. They don't use the model, they make their own models. They don't feel the responsibility"* (Expert 1, expert panel, 12 July 2019). *"If the client is the asset manager also, it would be different, because then they care for the BIM also. It is not something that ends with construction, therefore, in asset management, BIM makes everything easy for them, instead of the amount of papers to have the same information"* (Expert 5, expert panel, 12 July 2019). If you don't use BIM completely, it doesn't show its benefits. Therefore, there is a vicious loop. *"Success of BIM depends on each separate party, if they have adapted to BIM. that is easy to say to have all parties in the beginning to have agreements on BIM, but that is not enough, because they have different interests in BIM. What is needed, is from the beginning, to put somebody on a project to drive all to use BIM"* (Expert 1, expert panel, 12 July 2019). *"BIM is like a circle, if you stop the circle, it doesn't work anymore"* (Expert 5, expert panel, 12 July 2019). This is ideal to have all parties connected. But even in each part of the project, it can be used, with defining the boundaries and agree on them. Upper level and lower level should be seen separately. Two important points here are move of the market towards the increase of demand of BIM, and the fact that managers cannot expect from engineers to utilize BIM without defining the responsibility for them. If the processes are clear, it can be beneficial for everyone, and every minor task. Required is to know all the capabilities and all the connections in the BIM network, and make guidelines for participants, and make the drive for use of BIM (such as a coordinator). *"There are different processes for each company, to work with BIM and to have circularity"* (Expert 1, expert panel, 12 July 2019).

From the point of view of the structural engineer, using BIM can be time-consuming. *"For the modeler it would be double work"* (Expert 2, expert panel, 12 July 2019). On the other hand, from the point of view of the BIM coordinator, time can be saved by modeling building information in the correct way. *"because they don't understand BIM. If you have to create 3D model, but you make 2D drawings and then from that you make 3D model, then that is double work"* (Expert 5, expert panel, 12 July 2019). *"That is why you have to start with a clear goal in mind with BIM"* (Expert 5, expert panel, 12 July 2019). If the procedures are not clear, then the use of it is time-consuming and then it will be a tendency not to use it.

The role of contractual organization of the project, how the general contractor was in direct contract with the client, and the engineers and designers were the advisers of the contractor and are not contractually related to each other also had adverse impact on the project. Therefore, part of the issues regarding the integration of design can be attributed to that. *" The whole engineering part had only 10% of the project's cost, and 90% for the material and construction, therefore, it makes sense that the contractor is at the direct contract with the client. That is why I don't understand why they didn't push more for involving DfD in the design of the project, because it would be for their benefit at the end"* (Expert 1, expert panel, 12 July 2019). Circularity of buildings, and aspects of it such as deconstruction require governmental obligations to happen. *" I find it that there is no external pressure by government, law, codes, to build the building circular, the client has no pressure to do it. As far as I have understood, BIM is the tool, to make the deconstruction possible and doable in a smooth way"* (Expert 3, expert panel, 12 July 2019). *"DfD is a circle, and BIM also is a circle. And the client is the one who requires the building to be deconstructed. So why didn't the client make someone more responsible for that?"* (Expert 1, expert panel, 12 July 2019). Examples of other projects with BIM demands from the client can support this aspect. For instance, another project, in Witteveen+Bos, has a complete BIM coordination in all levels. *"All the BIM modelers have sessions for clash detection and designate responsibilities for each clash"* (Expert 5, expert panel, 12 July 2019).

There are other organizational aspects, which have also impact on these issues. *"Building sector started with BIM, but now infrastructure sector (in W+B) is completely going on with BIM, and not the building sector. Partly, because they have big projects for long period of time, everyone works on the same project"* (Expert 1, expert panel, 12 July 2019). *"The view of the teams is not aligned with the views of the company. we don't have enough resources for instance"* (Expert 5, expert panel, 12 July 2019).

Evaluation

For evaluating the process map, the experts were asked a set of questions. The questions and their opinions are as follows:

1. Do you think the process map will improve the design process?

   The design process will be more clear. The presence of the process map from the beginning of the project, for the specific goals, such as DfD, is asserted to be helpful. *"In general, having process maps add value and are helpful, both on company level and project level"* (Expert 5, expert panel, 12 July 2019).

2. Do you think the process map will improve the product (regarding DfD, Circularity of the building)?

   The design product, will be improved regarding the deconstruction aspect. This is mainly based on complete consideration of all necessary DfD principles in the process map. *"The product (the building) would be improved by involving the key findings of the literature review (DfD principles)"* (Expert 4, expert panel, 12 July 2019). However, since in this research the environmental aspects of circularity and DfD were not discussed, its impact is missing in the process map also. *"Environmental aspects are missing in this research"* (Expert 3, expert panel, 12 July 2019).

   In the design of the buildings, BIM can help to achieve deconstruction. Therefore, the process map will improve DfD. *"I don't agree that deconstruction cannot be applied to the whole building. By considering all the elements in the design process and put all the information in the model, it can be possible. Then you have to change products for instance"* (Expert 1, expert panel, 12 July 2019).

3. Do you think by following the process map, BIM would be utilized more?

   Capabilities such as 3D coordination or construction simulation were not well known by all experts in the panel. *"We also don't know the capabilities of the BIM. No one knows what BIM has to offer. There is no framework to work on"* (Expert 2, expert panel, 12 July 2019).

   In addition, the importance of manuals and guidelines for BIM is asserted by experts. *"There should be BIM manual, like quality manual, in the company"* (Expert 5, expert panel, 12 July 2019). Therefore, one of the main influences of the process map would be identification of BIM different capabilities, and assuring of their correct use between different participants. This reduces the individual errors and makes the process less dependent on each individual. *"If there are protocols and standards on working processes coming from the BIM coordination group, then it doesn't matter if you hire someone external for doing the task, or from another group. As long as they work based on the protocol, their work would be the same"* (Expert 1, expert panel, 12 July 2019).

4. How do you think it can affect the project in terms of time, cost and quality?

   The experts did not mutually agreed on the effect of the process map on the time and cost of the project. *"the time of the project and the cost would be increased. but the quality will be improved"* (Expert 4, expert panel, 12 July 2019). *"I don't agree. If everyone does it properly, the time spent would be decreased. If you don't start from 3D modeling, that would be less time. The impact of wrong design is also high. so, a proper 3D model, can decrease the time also, such as clash detection. It also has high levels of cost"* (Expert 5, expert panel, 12 July 2019). Partly, the perception for increase of time in BIM processes is due to lack of complete knowledge of them. *"The process of sketching in BIM is different. like in Revit.* (using libraries rather than drawing every detail) *BIM requires a different way of working"* (Expert 1, expert panel, 12 July 2019).

5. How much do you think such a process map can be generalized and applied to other similar projects?

   The importance and capabilities of BIM for deconstruction are not well-known in practice; as an expert asked *"How does BIM help deconstruction?"* The main and first thing is about information modeling, which is vital for DfD, because it means designing for the future of the building. Second is the capabilities it has for analysis, in other words, for planning and strategy finding for deconstruction.

   One of the aspects, agreed by all experts, is the importance of early involvement of all stakeholders, and beginning of BIM from the start of the tender phase. *"Connecting question 1 and 5, this process starts with the design phase, but I think it would be much better to start even from the tender phase. Then you have the links of the model from tender to next phases. The end product will be optimized, and everyone know what is the approach. Everyone can think aligned with the client. It will save lots of time, and revisions. If you start from the top, it also gives the chance to the client for agile thinking. So you will also give the client, many alternatives. So not just one design of the product, the client can choose between the products. Also, the contractor can be involved earlier. In this way everyone is involved, even the contractor is involved"* (Expert 2, expert panel, 12 July 2019).

   The process map aims for designing buildings to be deconstructed. Therefore, it has more of a framework characteristics. *"We already made some process maps for some BIM uses, like clash detection. I think that you don't have to generalize too much and be more specific for each project. The process map you have to adapt to each project. It is more like a general framework"* (Expert 5, expert panel, 12 July 2019). Therefore it should be considered that it should be adapted for each project. *"Risks of the projects are different, and they should be considered in the beginning. Otherwise, it is not possible to generalize"* (Expert 2, expert panel, 12 July 2019).

   A feedback from the experts on the process map was about the importance of short feedback loops rather than long ones. *"The last feedback loop in the process map, makes it vulnerable to use"* (Expert 1, expert panel, 12 July 2019). It does increase the process map's robustness, and also decreases the risk of huge changes in the project. *"We have to set up a baseline first, it can be time, cost, and in the process it is better to have some earlier checks, so an iterative process, an agile process. Sending the client the performance and products with shorter feedback loops"* (Expert 1, expert panel, 12 July 2019).

5.4.2. Conclusions of the Expert Panel Session

By taking all into account, it can be concluded that having a process map for applying BIM to DfD, is helpful for identifying capabilities of BIM and clarifying the working process. The process map would improve the building to be deconstructed. If everyone follows it correctly, it would help the project's time and quality, and since it can decrease the errors of design, it decreases the risks of additional costs in the execution stage.

For generalizing the research results and apply the process map to other projects, it is vital not to make it specific, and keep its general and flexible characteristics. It is important to decrease its vulnerability, by omitting long feedback loops and instead, having shorter ones. From the social point of view, identification of the interests of BIM for different stakeholders, and designation of its responsibility to specific roles is required to assure success of BIM. In addition, the early involvement of all parties and starting BIM from the early stages of the project, are asserted to be necessary.

6 Conclusion

In this chapter the conclusion of the research is provided. To address the main research question, a set of research sub-questions were formulated and introduced in chapter 1. Following the research design, the sub-questions were addressed. The final conclusion on these questions, and subsequently, the main research question is as follows:

| *What are the principles of DfD?* **|**

By doing a literature review on DfD, and gathering different principles on DfD, two main categories of principles related to product and process are introduced. The former contains principles on the level of materials, components, and interface design. These principles have a focus on the choice of the materials in alignment with circular economy principles, having a systemic view on design of components, and designing interfaces feasible for disassembly. The latter, contains principles focused on processes mostly. These principles include considerations for construction and deconstruction planning, and modeling and managing information from the beginning of the project and through its lifecycle. A complete list of DfD principles is provided in Table 2.4.

| *How is BIM used for the purpose of DfD in practice?* **|**

Although the enterprises in AEC industry are not unfamiliar with BIM, it can be asserted that building information modeling for DfD, is still at the level of documenting. It is mostly aimed for producing client's required documents from 3D models, and in the best case, to coordinate between different design teams and disciplines in the design phase. However, even the few mentioned uses might not completely and properly be accomplished too. This is due to different reasons, which are mentioned in the next sub-question.

From another perspective, BIM is mostly perceived as software packages for modeling the design, therefore, only as new tools for drawing. This limits the use of BIM to mainly 3D modeling. Lack of agreements on software packages to use although causes interoperability, multiplicity of models, and inconsistency of information exchange.

| *Why is BIM used or not used for the purpose of DfD in practice?* **|**

This study indicates that there are reasons for not using BIM in practice, which are related to three main aspects. First, the philosophy of BIM, and how it introduces a new way for the processes in AEC industry; Although BIM is not new, there is still lack of drive and belief in its benefits. Therefore, there is an inertia towards adapting to it completely. Lack of BIM requirements from clients in the projects is one of the reasons that BIM is not approached in projects. At the same time, DfD has goals for the future of the buildings, and its benefits are more towards the end of a building's lifetime. However, it requires extra work in the design phase. Therefore, inconsistency between stakeholders' interests is also an issue in this category.

Second, lack of clear goals and planning for BIM from the beginning of the project; If there are no clear goals, there would be no results. This requires early and mutual understanding of BIM and awareness of the need to plan for BIM interorganizationally and intraorganizationally.

Third, the operational aspects; Time is assumed as a barrier for BIM, since it is believed (by most of the practitioners) that BIM processes increase the time of the project (in design phase). However, it is known that BIM processes, if done properly, have positive influence on the cost and time of the projects. This is mainly due to lack of awareness of BIM capabilities, and lack of clear process maps and guidelines for BIM processes.

| *In which ways is it possible to utilize BIM for the DfD purposes?* **|**

BIM has foundations for DfD process. It can be defined as a symbolic representation of a building, by designating symbols for elements and their relations. By having all the geometric and non-geometric information in the model, producing any relevant view would be possible (such as construction simulation). This means that a properly constructed BIM is beyond documenting; it enables different analyses and testings. This is why BIM is advantageous for DfD and how it can help the design process.

Analyzing in BIM facilitates the integration of design disciplines. Therefore, for instance, the architectural design can benefit from the results of the engineering analyses and the iterative design process can be more integrated. This means that the design phase takes place in a more collaborative way between different disciplines. It introduces a new multidisciplinary design process, rather than the traditional segmented design process.

Finally, for the purpose of DfD, BIM enables testing the design of a building, to analyze whether it is possible to be deconstructed or not. This is necessary for circularity of the building to the extent of deconstructability. Furthermore, this enables to transfer the required information for the realization stage of the project, and the future users of the information, such as the stakeholders in the operation and maintenance phase, and at the end, for the end-of-life-time of the building. It makes the preparatory tasks of deconstruction phase possible; such as economic analysis, strategy finding, and planning of deconstruction. A complete model can even provide instructions of disassembly of elements.

This study indicates that identification of BIM uses for DfD is vital in the beginning of the project. By having the five categories of BIM functions from chapter 2, the BIM uses for DfD are demonstrated in Table 6.1.

Category	**purpose for DfD**	**BIM uses**
Gathering	information gathering on materials and components	linking information to model
Generating	parametric design and alternative generating	design authoring
Analyzing	energy, structural, MEP analysis	circularity analysis; engineering analysis,
Communicating	design coordination between disciplines and parties; information transfer to next stages	design review; 3D coordination
Realizing	construction and deconstruction planning	construction simulation; deconstruction simulation

Table 6.1: BIM uses for DfD

| *What are the essential sequences of the process of information modeling, that can clarify the application of BIM to DfD?* **|**

As mentioned in chapter 5, prior to the design phase, it is vital to have BIM mutual agreements between different involved parties. In this phase, BIM coordination plays an important role. In addition, a set of steps should be taken for each project itraorganizationally; [1] identifying BIM goals and uses; [2] designing BIM project execution process; [3] developing information exchanges; and [4] defining supporting infrastructure for BIM implementation.

At the same time, mutual understanding and approach towards DfD is vital; from establishing the principles related to the project, and connecting the requirements they make to the tasks and responsible roles. Circularity consultant plays an important role in this phase to establish the principles.

An important aspect of DfD process is the involvement of constructors and deconstructors in the early stages of the project. By starting the design with the specification of deconstruction requirements, the end of the building lifetime is really considered in its design. Facilitating deconstruction is the aim of DfD, and by doing so, the required specifications will be designed.

After the preparatory tasks, and in the design phase, considering the DfD principles is necessary, which can be divided to design considerations, such as minimizing types of connections in interfaces, and information modeling considerations, such as linking disassembly manuals to the 3D model. In addition, control of the process by BIM coordinator and circularity consultant is vital.

By having all the design information in one model, it is possible to test the deconstratability of the building. This can be done by simulating the construction and deconstruction of the building. At the end, documents, such as materials passport, and deconstruction strategy, can be produced from the model.

> **|** *What is the process map showing the sequences of activities of Building Information Modeling (BIM) for the process of Design for Deconstruction (DfD)?* **|**

Based on the identified essential aspects of DfD, and the essential process of BIM, the process map is illustrated in Figure 5.2.

7

Discussion and Recommendations

In the final chapter, the discussion is presented, discussing the findings, results, and limitations of the research. Then, the recommendations for practitioners, and further research are given. At the end, a personal reflection is presented.

7.1. Discussion

Looking at BIM planning, by the lens of systems thinking, it can be said that even if the BIM planning is designed for using it in the project for some aspects such as DfD, but the system is not working, then the system is not designed correctly. The purpose of a system, is different from the stated goals; it should rather be deduced from the system behavior (Meadows & Wright, 2008). Therefore, studying the way deconstruction of the building was designed in the project, how BIM was used for this purpose, and why it was used or not used properly, brought insight on the broadness of the issues related to the topic at hand. As stated in the literature, and as found out in the case study, lack of protocols and guidelines for applying BIM to design processes is a barrier. In this case, circularity aspects, also added to the complexity of the requirements of the project. Therefore, designing a process map for applying BIM to DfD process addresses part of the issues found in the study. The approach of the research study was from managerial perspective; therefore, to have a broad understanding of the system, identify the problems, and improve the system.

The goal of the process map is to ensure that essential aspects of DfD are considered in the design of a building, and it illustrates the sequence of essential activities that should take place in BIM process. By identifying the essential decisions and processes regarding DfD in the process map, the risks of ignorance of some aspects decrease. By having the activity zones related to the problem at hand, instead of specific roles, its generality has increased. Therefore, it can be used as a general framework that requires customization for other similar projects.

By applying the BIM processes to the model of the case study, and as the final result, the construction and deconstruction simulation were visualized. The improvement of the process by comparing the project deliverables and the results of the research, was approved in the expert panel session. The expert panel, consisting of related experts to such a project, could be an example of having different participants from different disciplines. The process map and the results were of clearer understanding for them.

The selected case study is a specific project, where the goal was to deconstruct the building and recover their value by entering them to new cycles. At the same time, it was not a typical building project. However, when looking at the purposes of the project, it was informative in specific ways. Some of the project's issues were related to its unique context, however, at the end, all projects struggle with different issues. No project is similar to another. Therefore, it was tried to grasp the opportunities it suggested to use for this study. Also, it was tried to separate the issues that were specific to the project's context, from the issues that can be more common in practice.

Partly, some of the issues regarding BIM, and consequently DfD, can be related to the organizational structure of the project. The form of collaboration of this project is traditional. The client is in contract with the contractor, and the consultancy firms are individual advisors of the contractor. This can be the cause of many difficulties in design phase. Segmentation of design disciplines and construction was the reason of some problems. However, a correct approach to BIM could mitigate these issues to some extent. By doing so, even a segmented design process could have been integrated more and resulted in better product, and smoother process.

It is also important to mention that in this research, the point was not criticizing the project and the parties' performance. As a single case study, it was tried to look at it vigilantly and analyze the way things work in practice, and by addressing the issues, trying to improve the processes and products.

Deconstruction is theoretically the cornerstone of circular economy in the built environment. To understand this, it is important to answer *why* about circularity; what is the goal of circularity? Circularity aims for elimination of waste from human made cycles. By projecting it to the built environment, one can say that it is about recovering the highest possible value from the end of a building. Therefore, it is crystal clear that deconstruction makes it possible to recover the highest possible value rather than demolition. Now, to know why DfD is vital, one should answer *how* to achieve deconstruction? DfD is the procedure of facilitating deconstruction. It takes the vital aspects required for deconstruction into account at the beginning of a building's lifetime. This leads to the final question of this research chain; *what* is required to implement DfD? Information is the answer. Producing the information of a building, and updating it through the passage of time is what DfD requires; this is how BIM is connected to DfD.

From the case study, it can be concluded that using BIM requires an obligation. It means that in practice, there is still a tendency to avoid doing BIM processes, which might be believed that take more time (since they have new aspects and require learning), and consequently increase the costs. Process maps for implementing BIM, play important roles along with other guides on BIM. By familiarizing the practitioners with the BIM benefits and capabilities and making the processes clear, implementation of BIM increases. However, obligation is required in the level of each project. This is because of the philosophy of BIM, which has short-term and long-term impacts. In short-term, BIM is beneficial in design phase itself. However, a proper building information model, founded in the beginning of the project, and updated through the phases of the project, is valuable in the long-term for the constructors, operators, owners, and deconstruction contractors. Therefore, since the interests of different stakeholders are not necessarily consistent, it is important to address this issue.

DfD, can also be looked at, with the same approach. Designing the building in a way to be deconstructed, and providing the required information should take place at the design phase, however, the main benefits of DfD are exploited in the end of a building's lifetime (deconstruction). Segmentation of project phases, and specially, segmentation of design and construction phases, can lead to decrease of the importance of DfD (as it should be properly) and ignorance of some aspects of it in the design phase. Therefore, it is vital to clearly ask for the required aspects of DfD in an obligatory way.

Benefits of BIM are broad, and in different levels. For having full benefits of it, having all stakeholders around one model, developing the design by that, and updating it through the building's lifetime, commitment of all parties is required. In this project, for instance, it can be said that BIM should have been approached contractually also. This means that if the project has BIM ambitions in the whole level of the project, agreements on BIM need a proof of execution by all parties. On the other hand, in each part of the project, BIM had smaller benefits also. Examples of this can be production of all required documents as outputs of a complete model.

Changes in the systems of thinking and working requires deliberate effort. BIM should be approached as a new technology, and as a new philosophy of working in AEC. DfD can be approached from these two perspectives also. First, as the level of a product that is aimed for deconstruction. Second, as a new design process. An important finding from the case study is that, in both cases, the former perspective is comprehended and implemented more easily in the project, and also in the culture of enterprises; BIM is mostly used as a 3D modeling software, and DfD is mostly approached as decisions for the choice of materials (product-based rather than process-based DfD principles). To utilize their complete benefits, it is required to approach them from the latter perspectives as well.

A vicious loop can be identified through the different involved parties in the design phase, regarding BIM. Almost everyone can blame some other participant for taking a wrong decision in this regard, or not taking a decision at the right moment, or not acting as agreed. This is understandable to some extent; BIM is a growing boundary object. Its processes and requirements can hold the practitioners to approach it. Simply because in many cases, its benefits are not clear and absolute. In addition, its benefits are distributed between different stages and parties, however, its responsibilities might be not explicitly paid for. For instance, in this project, BIM was not a requirement from any authorities. If the designers are not convinced by its benefits for themselves, simply they reject BIM (since it is mostly perceived as extra work). It can be assumed that the main beneficiary of a properly constructed model, in this project, would have been the contractor, who is responsible for construction and deconstruction of the building. Because in that way, the design was clear and deconstructability of the building was assured. However, there is no proof that deconstruction can take place in the same way designed by engineers; because there is no proof that the building is constructed as the way it was designed. Because there are unknown parts in the design of the building, which can be easily identified by checking the documents.

7.1.1. Research Limitations

For the design of the process map, it is assumed that the building end-of-lifetime scenario is deconstruction. Therefore, the findings of the research become less reliable if this is not the case. In the current condition, not many buildings might be planned for deconstruction. However, by growth of circular economy in the built environment, they will increase.

The involvement of stakeholders in specifying the project's needs is vital. One of the main aspects of the process map is the early involvement of the stakeholders related to deconstruction of the building. This might be not possible due to unknown future of the buildings. However, it can be said that having the consultancy from this expertise is important for such projects. Unfortunately, the experts from this field were absent in the expert panel session, otherwise, their point of view could have been useful to the discussion of the research.

7.2. Recommendations

Based on the research conclusions, recommendations are given for the practitioners and for further research.

Use of Process Map

The process map is designed to guide the BIM processes for the purpose of DfD in buildings' design phase. It has characteristics of a general framework. The detailed stages of design phase are not considered in the study. This is due to the focus on the holistic approach to DfD. Also, the related activity zones are simplified. Therefore, using it for building design projects, customization is required.

Having process maps does not guarantee that they are followed in the process. Therefore, it is vital [1] to have interorganizational and intraorganizational contractual agreements, which have proof of execution; [2] to plan based on the organization's capacities; [3] and to identify the responsibilities of participants, and control the tasks continuously during the project.

General Recommendation

Circular economy is a change in the perspective in all aspects of the AEC industry. Therefore, its implementation takes time and practice. The project of Dutch Pavilion at Expo 2020 Dubai was not a typical building project, however, the participants have asserted that they had learned from it in different ways. They asserted that they are more aware of circularity and DfD, they have considered requirements for circularity for the first time in their design processes, and they have considered the whole life cycle of the building in their design (personal communications, May and June 2019). Therefore, it can be recommended to have projects in small scales that have impact on the learning of the organizations for practicing it. This also applies to BIM. Again, the project was not typical regarding BIM, however, it revealed some BIM issues in the organization. Knowledge management can help organizations to learn from such experiences, and exploit knowledge from them. This helps to turn the vicious loop of BIM into a virtuous loop (look at Figure 1.2).

Early involvement of the stakeholders in the design phase is beneficial to all. By specifying the requirements of different stakeholders, such as deconstructors, design for deconstruction can be efficient and effective. This also relates to starting BIM processes from the beginning of the project. BIM's benefits increase by approaching them from the early points in the project.

DfD requires an integrated collaboration. It can be said that segmented forms of collaboration may cause barriers in this process. However, even in such a case, approaching BIM correctly can mitigate these issues to a great extent.

Recommendations for Future Research

As stated the discussion, there are limitations to the research. Therefore, to utilize BIM for implementation of circular economy in the built environment, there are recommendations for further research as follows:

- **Stakeholder analysis:** One of the barriers that was found in this research study was inconsistency of stakeholders' interests regarding BIM for DfD. To investigate this issue a more in-depth qualitative analysis of stakeholders' interests in BIM for DfD can be helpful. In addition a quantitative analysis of stakeholders' benefits for the same purpose would be a good complementary research topic.
- **Scenario-based process map**: As an assumption to this research study, the end-of-lifetime of the building was known to be deconstruction. This assumption brings limitations to the research. Therefore, exploring DfD process for buildings that deconstruction might be only an option of the end-of-lifetime require more investigation.

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A

Business Process Modeling Notations

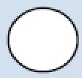
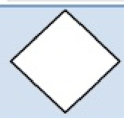
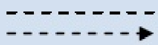
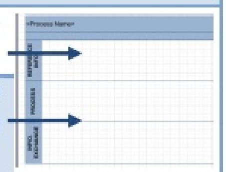
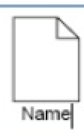
Element	Description	Notation
Event	An Event is an occurrence in the course of a business process. Three types of Events exist, based on when they affect the flow: Start, Intermediate, and End.	
Process	A Process is represented by a rectangle and is a generic term for work or activity that entity performs.	
Gateway	A Gateway is used to control the divergence and convergence of Sequence Flow. A Gateway can also be seen as equivalent to a decision in conventional flowcharting.	
Sequence Flow	A Sequence Flow is used to show the order (predecessors and successors) that activities will be performed in a Process.	
Association	An Association is used to tie information and processes with Data Objects. An arrowhead on the Association indicates a direction of flow, when appropriate.	
Pool	A Pool acts as a graphical container for partitioning a set of activities from other Pools.	
Lane	A Lane is a sub-partition within a Pool and will extend the entire length of the Pool - either vertically or horizontally. Lanes are used to organize and categorize activities.	
Data Object	A Data Object is a mechanism to show how data is required or produced by activities. They are connected to the activities through Associations.	
Group	A group represents a category of information. This type of grouping does not affect the Sequence Flow of the activities within the group. The category name appears on the diagram as the group label. Groups can be used for documentation or analysis purposes.	

Figure A.1: Business Process Modeling Notations (BPMN) description (Computer Integrated Construction Research Program, 2011)

B

Strengths and weaknesses of six sources of evidence

Source of Evidence	Strengths	Weaknesses
Documentation	Stable- can be reviewed repeatedly Unobtrusive- not created as a result of the case study Exact- contains exact details and references Broad coverage in terms of time, events and settings	Retrievability- can be low Biased selectivity, if collection is incomplete Reporting bias- recflects bias of author Access- may be deliberately blocked
Archival Records	(Same as above for documentation) Precise and quantitative	(Same as above for documentation) Accessibility due to privacy reasons
Interviews	Targeted- focuses directly on case study topic Insightful- provides perceived casual inferences	Bias due to poorly constructed questions Response bias Inaccuracies due to poor recall Reflexivity- interviewee gives what interviewer wants to hear
Direct Observations	Reality- covers events in real time Contextual- covers context events	Time consuming Selectivity- unless broad coverage Reflexivity- event may proceed differently because it is being observed Cost- hours needed by human observers
Participant Observation	(Same as above for direct observations) Insightful into interpersonal behaviour and motives	(Same as above for direct observations) Bias due to investigator's manipulation of events Possible ethical dilemmas and high levels of role conflict for the researcher (Saunders et al., 2000)
Physical Artefacts	Insightful into cultural features Insightful into technical operations	Selectivity Availability

Figure B.1: Strengths and weaknesses of six sources of evidence (Yin, 2018)

C

Framework for the development of a qualitative semi-structured interview guide

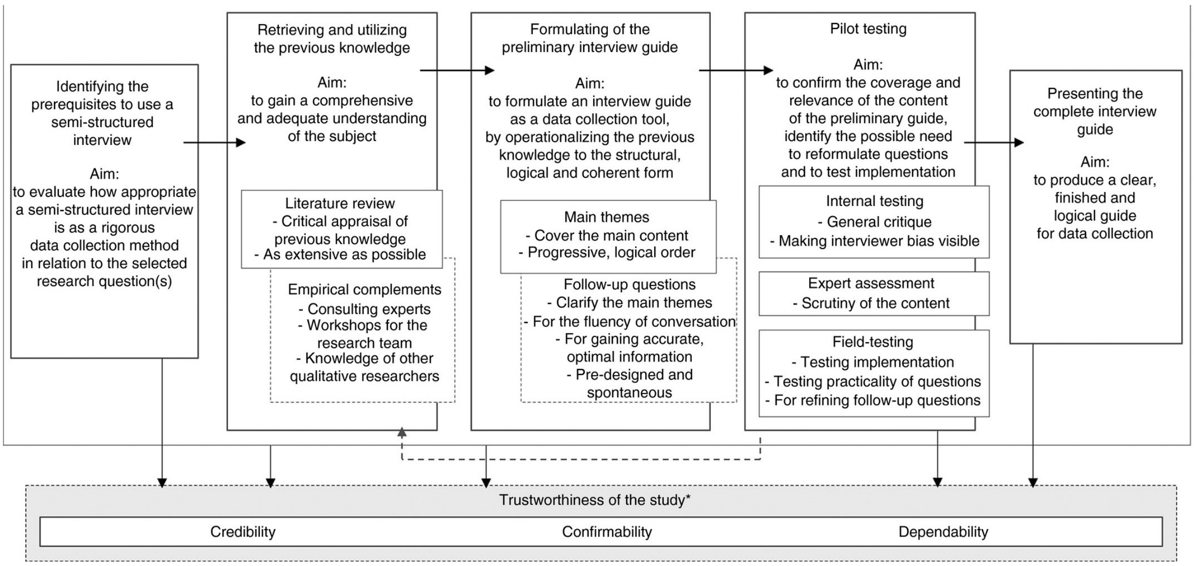


Table C.1: Framework for the development of a qualitative semi-structured interview guide (Kallio et al., 2016)

D

List of Interviewees

name	role	organization	date
Interviewee 1	MEP engineer	Witteveen + Bos	22-5-19
Interviewee 2	structural engineer	Witteveen + Bos	22-5-19
Interviewee 3	modeler	Witteveen + Bos	22-5-19
Interviewee 4	sustainability adviser	Witteveen + Bos	24-5-19
Interviewee 5	Project Director	Witteveen + Bos	4-6-19
Interviewee 6	MEP project manager	Witteveen + Bos	4-6-19
Interviewee 7	project architect	V8 Architects	20-6-19
Interviewee 8	project leader	Witteveen + Bos	21-6-19

Table D.1: Interview Schedule

E

Level of Development in BIM

Level of Development	Description
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.
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.
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.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
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.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Figure E.1: BIM Level of Development (LOD) definitions (Kreider & Messner, 2013)

F

List of the Expert Panel

name	role	organization
Expert 1	project manager	Witteveen + Bos
Expert 2	structural engineer	Witteveen + Bos
Expert 3	structural engineer	Witteveen + Bos
Expert 4	sustainability of buildings	Witteveen + Bos
Expert 5	BIM coordinator	Witteveen + Bos

Table F.1: Expert panel list