FACULTEIT ECONOMIE EN BEDRIJFSKUNDE

IMPLEMENTING BIM TO FACILITATE THE CIRCULAR TRANSITION IN THE CONSTRUCTION SECTOR

Word Count: 24.551

Jörgen Vanoverberghe
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Student number: 01502392, 01505984

Supervisor: Prof. Dr. Katrien Verleye

Master's Dissertation submitted to obtain the degree of:

Master of Science in Business Economics
Main subject: Business Economics

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Matthias Rabaey and Jörgen Vanoverberghe, January 2021

DUTCH SUMMARY

Deze masterproef is opgebouwd uit meerdere hoofdstukken met een nadruk op de literatuurstudie en een meervoudige casestudy met polaire karakteristieken. De literatuurstudie wordt aangevat met de toelichting van het bouw- en sloopafvalprobleem gegenereerd door huidige bouwpraktijken. Hiertoe wordt de overstap naar een circulaire economie voorgesteld als oplossing en wordt de specifieke toepassing voor de bouwindustrie besproken. Een belangrijke conclusie hieruit is dat de toepassing van dit model nog steeds veel barrières ondervindt. Het verdere verloop van de literatuurstudie bekijkt hiervoor de mogelijkheid van BIM als oplossing voor de belangrijkste barrières. Vooraleer de mogelijkheid van BIM als bevorderende benadering voor de circulaire transitie te kunnen bekijken, worden eerst de opportuniteiten, stimulansen en barrières van BIM zelf bekeken. Vervolgens stelt de literatuur 3 aanvullende benaderingen voor die in combinatie met BIM deze transitie op de voet zouden kunnen zetten. Deze 3 benaderingen zijn Design for Deconstruction (DfD), Material Passports (MP's) en Buildings as Material Banks (BAMB).

In het onderzoek van deze thesis wordt er kwalitatief onderzoek uitgevoerd. Verschillende partijen werden geïnterviewd om hun bevindingen te achterhalen betreffende hoe en waarom ze BIM gebruiken en hoe BIM deze transitie kan vereenvoudigen. Er werd gekozen om zowel Early Adopters als Laggards te interviewen. Early Adopters en Laggards worden opgedeeld naargelang ze BIM en Circulaire principes respectievelijk in verre mate of nog niet implementeerden in hun bedrijfsprocessen. Aangezien in de literatuur wordt besloten dat de fragmentatie van de sector een belangrijke barrière is, werd gekozen om verschillende types bedrijven te ondervragen. Deze bedrijven zijn studiebureaus, architectenbureaus en algemene aannemers. Naast deze interviews werden eveneens relevante artikels van deze bedrijven ten opzichte van het onderzoek geraadpleegd.

Voor de analyse van de data werd gekozen om gebruik te maken van NVIVO. Met behulp van deze software werden de argumenten uit de interviews gecodeerd en besproken. Het UTAUT framework toegelicht in de literatuurstudie werd vervolgens toegepast voor de analyse van de adoptie van BIM. Beide groepen erkenden dat de implementatie van BIM de efficiëntie kan verhogen en een groot potentieel bezit om de circulaire transitie te vereenvoudigen. Belangrijke barrières betreffende de toepassing van BIM zijn de hoge kostprijs en de steile leercurve, wat leidt tot een hoge verwachte inspanning. Daarnaast wordt geconcludeerd dat zowel de sociale impact van concurrenten en partners als de vereenvoudigende factoren zoals klanten en overheidsstimulatie een belangrijke rol spelen. Bedrijfsgrootte, complexiteit van de projecten en het type bedrijf hebben eveneens een invloed.

Zowel de Early Adopters als de Laggards vermeldden dat BIM de implementatie van DfD, MP's en BAMB kan ondersteunen. Merk echter op dat hierbij duidelijke definities en een uniform kader

noodzakelijk zijn. De geïnterviewde bedrijven benadrukten dat de overheid een belangrijke rol te vervullen heeft. Om deze reden werd besloten ook overheidsinstanties Vlaanderen Circulair en OVAM toe te voegen aan de casestudie. Hierdoor werd een inzicht te verkregen in het plan van de Vlaamse Overheid om deze Circulaire transitie van de Vlaamse bouwsector mogelijk te maken.

ACKNOWLEDGEMENTS

Writing this master dissertation was an interesting journey. As there were a lot of parties which participated in the research of this master dissertation, we would like to thank them for their participation. We would like to thank all the participants for their time and interesting interviews, making this master dissertation possible. We would like to thank Professor Katrien Verleye for the guidance through this dissertation, and for giving us the necessary insights and feedback resulting in this report as it stands. In addition, we would like to thank Professor Verleye for supporting the use of our background as Civil Engineers throughout this Economic master dissertation. Last but not least, we would like to thank our family and friends for their support.

Matthias Rabaey en Jörgen Vanoverberghe, January 2021

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
BAMB	Building as material bank
BIM	Building Information Model
BWPE	Whole-life Performance Estimator
CAD	Computer Aided Design
CDW	Construction and Demolition Waste
CEN	Committee for Standardisation
C&D	Construction and Demolition
DfD	Design for Deconstruction
E-BAMB	Existing Building as material bank
EPB	Energy performance and indoor climate
HVAC	Heating, Ventilation, and Air Conditioning
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LOD	Level of Detail
MEP	Mechanical, Electrical and Plumbing
MVD	Model View Definitions
RFID	Radio Frequency identification
RMM	Reused Material Marketplace

INTRODUCTION

One of the most important topics of today is the waste generation problem. The European waste generation is responsible for an environmental impact by causing pollution, climate change by greenhouse gas emissions and material losses. One of the major sectors contributing to the waste generation streams is the construction sector. Estimations by Eurostat rate the construction and demolition waste stream (CDW) at circa 46% of the total waste generation. To address this problem, the transition of the construction sector to a circular economy is crucial. The literature review of this master dissertation starts by addressing current traditional construction practices and the resulting CDW-problem. In the following part, the circular economy principles are explained in general and specific to the construction sector, concluding that there are still many barriers to the circular transition of this sector.

To overcome the barriers to the circular transition, the European Environment Agency proposes different possible actions which need to be taken throughout the building's life-cycle phases. This research focusses on the opportunities, enablers and barriers to the implementation of Building Information Modelling (BIM) as a facilitator to this transition, in combination with circular approaches such as Design for Deconstruction (DfD), Material Passports (MP's) and Buildings as Material Banks (BAMB). Currently, BIM-use is rising in the Architecture, Engineering and Construction sector (AEC), to enhance efficiency and collaboration of the different parties involved in the building life-cycle process. Although the application of BIM is rising, there are still a lot of AEC-companies lagging behind. Further development and refinement of the BIM processes are needed and are addressed in this research.

The research is conducted by a theoretical literature review combined with interviews and articles of different actors involved in the building life-cycle process. The selected actors range from AEC-companies to governmental institutions, active in Belgium and the Netherlands. The methodology is based on a multiple case-study, comparing findings of Early Adopters with Laggards.

CHAPTER 1: LITERATURE REVIEW

1 The construction and demolition waste (CDW) problem

One of the most important topics of today is the waste generation problem. The generation of waste is responsible for an environmental impact by causing pollution, climate change by greenhouse gas emissions and material losses. On top of that, even waste that is re-used, recycled, incinerated or landfilled still has a financial and environmental cost by the need for collection, sorting, transportation and treatment. (Groh & Dubik, 2018), (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018).

This master dissertation will focus on providing a possible solution to the problem of the material waste generated by all construction activities throughout the project's lifecycle, defined as construction and demolition waste (CDW). In 2018, Eurostat estimated that the European construction sector is responsible for a CDW stream of 820 tonnes every year, constituting to circa 46% of the total waste generation. Although the environmental impact of CDW can be considered relatively low compared to other waste streams, the European government places an important focus on the CDW-problem, because of its large volume and weight. The CDW concern lies mostly in the logistics and land occupation. The European Waste Catalogue categorizes CDW into 8 different categories according to materials:

- Concrete, bricks, tiles and ceramics;
- Wood, glass and plastic;
- Bituminous mixtures, coal tar and tarred products;
- Metals;
- Soil, stones and dredging spoil;
- Insulation materials and asbestos-containing construction materials;
- Gypsum based construction material;
- Other construction and demolition waste.

A misconception is that CDW is only generated in the construction phase, while it is produced throughout the whole lifecycle of the project, namely: design, construction, operation & maintenance and demolition. The current problem is that CDW is mostly landfilled without further treatment. To reduce the depletion of natural resources and landfilling, it is crucial to further enable recycling and reusing of construction materials. Therefore, the European Union has come up with the Landfill directive (1999), the Waste framework directive (2008), the Circular Economy package (2018) and the EU Circular Economy Action plan (part of the Green Deal) (2020), providing action plans addressing i.a. the waste generation problem. A possible solution for the CDW-problem is introducing the circular economy principle in the construction sector, which is discussed further on. (Groh & Dubik, 2018), (Adams, Osmani, Thorpe, & Thornback, 2016), (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018), (European Commission, 2019).

1.1 Stakeholder awareness and influence CDW analysis

Although the level of awareness of CDW is increasing, a lot of managers and contractors still see waste management as an increase in the project cost lowering the project's profit. Managers and contractors focus mainly on cost, quality and timely delivery of the project rather than implementing waste management to optimize the use of resources and protect the environment from the abundant CDW-flow. One of the main problems to the uptake of responsibilities by the different stakeholders involved in the projects lifecycle is caused by the fragmented character of the industry. This fragmentation causes an unclear agreement of which stakeholder is responsible for waste management. In this chapter, the different stakeholders involved and their impact and awareness of the CDW-problem are discussed. (Groh & Dubik, 2018).

Public and private clients

In most cases, the clients are eventually the ones ending up paying for the CDW generation. However, these costs are overlooked and not included in the total cost of the buildings, which leads to neglecting CDW management. Public and private clients have a great power to influence this CDW generation by including waste management into the construction requirements. Adams, Osmani, Thorpe and Thornback (2016) concluded that the clients are still not sufficiently aware of the CDW problematics. (Groh & Dubik, 2018), (Adams, Osmani, Thorpe, & Thornback, 2016).

Designers

Akinade et al. (2018) proposed that waste consideration should be a responsibility that is a priority for designers. These designers have a great influence on the level of waste being generated since their designs influence all other stakeholders. They also possess the power to influence the clients to take CDW into account. (Akinade, et al., 2018).

Client advisors

Client advisors play a similar role as designers when it comes to the minimisation of CDW generation. These stakeholders should take responsibility to inform the clients of the importance of waste management. (Groh & Dubik, 2018).

Main Contractors

As main contractors mainly focus on profit and execute budget-oriented according to the design made by Architects and Engineers, they tend to avoid making additional costs regarding waste management, as it is cheaper to generate waste instead of solving the issue. Their influence on the CDW generation is rather low, as they do not have control of the waste being generated by pour design etc. However, they do influence the amount of waste being generated on-site. (Groh & Dubik, 2018).

Subcontractors

As subcontractors are located very low in the hierarchy of the construction process, their influence is even lower than the main contractors. Since there is a lot of competition, there isn’t much room for waste management improvement. (Groh & Dubik, 2018).

Material suppliers

The power of the material suppliers to influence the CDW generation depends on the clients. If the clients are aware of the need of waste management, material suppliers can influence the CDW generation in a great way by better handling the materials, reducing the packaging volume, providing a take-back scheme for packaging, unused materials et cetera. (Groh & Dubik, 2018).

Construction and demolition waste recyclers

As construction and demolition contractors demolish the existing buildings, waste recyclers have little to no influence on the waste being generated. They receive waste and decide what they will recycle. They do have an influence on the recycled/stored waste ratio, depending on their recycling technologies. (Groh & Dubik, 2018).

Regulators

Through the introduction of laws and fiscal measurements, regulators are one of the most important enablers of waste minimisation. These regulations can influence the point of view of the clients on waste management. (Groh & Dubik, 2018).

Public

The influence of the public regarding waste management can be enormous. It is necessary to raise the awareness of the public about the necessity of a lower CDW generation. The awareness of the public will also heighten the awareness of the clients. (Groh & Dubik, 2018).

2 Circular Economy as a solution to the CDW problem

2.1 Circular Economy

Before being able to analyze the transition of the construction sector to a circular economy, it is important to get an understanding of what the circular economy principle represents. The current market setup consists of fulfilling the continuous need for product creation by applying a take-make-use-dispose model, causing the depletion of material resources and increase of landfilling. This linear business model doesn't deal with materials in a sustainable way, leading to an economy which has a low consideration for the conservation of materials. In addition, a rapid acceleration of consumption occurs. The focus of these companies is eco-efficiency instead of eco-effectivity. As illustrated in Figure 1, the difference between eco-efficiency and eco-effectiveness lies in the impact on the environment. In contrast to the eco-efficient approach that tries to reduce the negative impact, the eco-effective approach tries to optimise the positive impact. To make the transition from an efficient to an effective model, the whole business cycle needs to be redesigned. Although companies using the linear business model try to minimise the negative impact on the environment, the impact remains existent. In the circular economy model, however, the eco-effective approach focusses on reusing or upcycling used material. (Nederland Circulair!, 2020) According to the Ellen Macarthur Foundation (2015), there are several risks connected to the linear model. First, there is the price risk. Due to the more difficult circumstances in which resources are mined, the volatility of the price rose in recent years. Next, there is the supply risk, since most of the countries import non-renewable resources. A third risk is the degradation of natural systems, such as the oceans. (Ellen Macarthur Foundation, 2015), (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018).

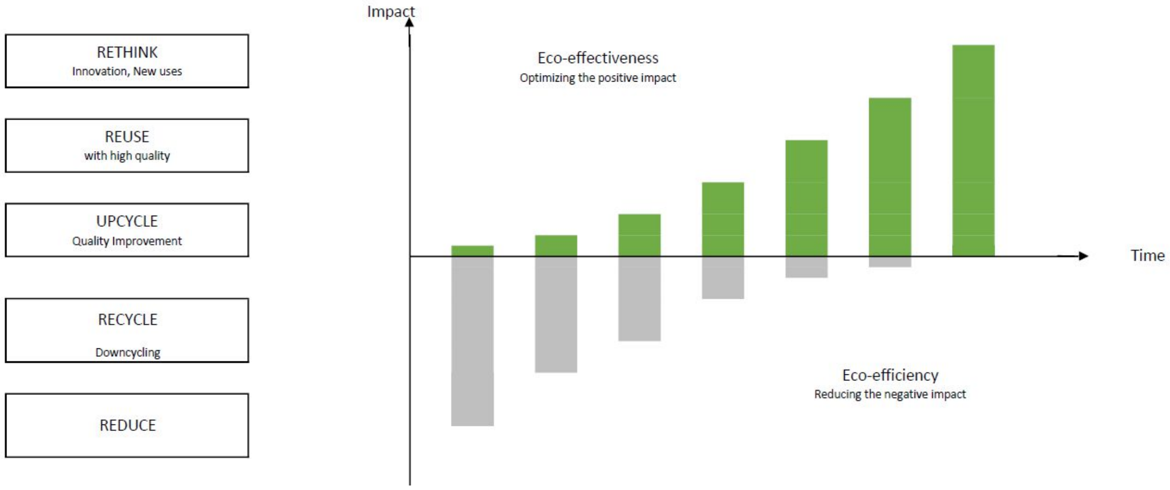


Figure 1: Difference eco-effectiveness and eco-efficiency (Adapted from Nederland Circulair! (2020))

'*Het Groene Brein'* defines the circular economy as: "*an economic system of closed loops in which raw materials, components and products lose their value as little as possible, renewable energy sources are used and system thinking is at the core*". The circular economy model is a business model that gained attention due to its point of view on the use and re-use of resources. The model itself promotes sustainable development and tries to solve environmental challenges. In addition to the positive impact on the environment, the circular model also aims to stimulate economic growth. (Korhonen, Nuur, Feldmann, & Eshetu Birkie, 2018).

One way to make the transition towards a circular economy is to rethink the value creation chain of companies. The Ellen Macarthur Foundation (2015) presents three main principles to rethink the value chain. The first principle is maintaining natural capital by checking the use of finite materials and the number of renewable resources. The second principle is to optimise the resource yield in both technical and biological cycles. It is important to note that the technical and biological cycles are separated from each other. While technical materials have limited availability, e.g. plastics and fossil fuels, biological materials can be regenerated, e.g. wood, food and water. The third and final principle is to try to minimize the negative externalities to improve the effectiveness of the system. (Ellen Macarthur Foundation, 2015), (Nederland Circulair!, 2020).

The European Union (2020) aims to achieve climate neutrality by the year 2050. To achieve this goal, the European Union needs to make a faster transition towards a circular model which gives back to the planet more than it takes, hereby considering the planetary limitations. To complete this transition, a framework for sustainable products must be developed. (European Commission, 2020) A study of the Cambridge Econometrics, Trinomics and ICF (2018) concluded that the transition towards a more sustainable business model would generate around 700.000 extra jobs net. According to the research, this could lead to an increase in the European Union’s gross domestic product by almost 0.5% by 2030. (Cambridge Econometrics, Trinomics, & ICF, 2018).

According to the Circle economy (2019), ± 62% of the global greenhouse gas emission can be assigned to the extraction, processing and manufacturing of goods, and 38% caused by the supply and use of the goods. The Swedish sustainability consultancy Material Economics concluded that the transition to a circular economy could lead to a reduction of 56% in greenhouse gas emission in the value chains of steel, plastic, aluminium and cement industry. Furthermore, the transition would eliminate the need for the importation of raw materials to the European Union, leading to an additional global reduction. The reduction in the mining of raw materials and waste dumping also results in the preservation of ecosystems and the protection of nature. (Circle Economy, 2019).

According to Vermunt, Negro, Verweij and Hekkert (2019) the transition towards a circular economy will benefit businesses and create opportunities for entrepreneurs. The study concludes that companies will be able to reduce material costs and new markets will arise. The report also states that companies will have a more stable flow of materials and hence a more constant material price. (Vermunt, Negro, Verweij, & Hekkert, 2019).

Regarding the circular transition, the demand is also growing for the product-as-a-service concept that allows customers to purchase the desired result rather than the equipment that delivers that result. For example, Philips now offers the option to buy an amount of Lumen instead of a lightbulb. In this case, Philips both installs, maintains and replaces lamps while reducing waste by recuperating and recycling broken equipment. (Syke, 2018), (Ellen Macarthur Foundation, 2015).

2.2 Circular economy in the construction industry

In the first chapter, the current CDW-problem was addressed. As a solution to this problem, the traditional conservative construction sector requires a circular transition, applying the principles explained in the previous chapter. This chapter starts by listing the barriers and enablers to the circular transition, continuing by going over the possible actions that need to be taken in the built environment. The chapter closes by selecting several relevant actions, which are explored in the following research.

2.2.1 Barriers and enablers to the implementation in the construction industry

Although the bibliometric analysis conducted by Benachio, Freitas and Tavares (2020) showed that the number of publications regarding the circular economy model in the construction industry is rising, there are still important barriers impeding this transition. (Benachio, Freitas, & Tavares, 2020)

Adams et al. (2016) performed a study surveying around 110 stakeholders in construction, ranging from manufacturers and clients to consultants and researchers. The results of the survey indicated that although there is a good level of awareness, there is a clear need to communicate the benefits of the circular model. The most significant barriers and enablers to the transition of the construction industry to a circular economy identified in this study are presented in Table 1.

Table 1:Most significant barriers and enablers of circular economy in construction (Adapted from Adams, Osmani, Thorpe, & Thornback(2016))

Barriers	Enablers
Complexity of buildings	Design tools and guidance
Fragmented supply chain	Measure the value of material/product
Low value of material/products at end of life	Financial incentives to use secondary Materials
Unclear financial case	Best practice case studies
Lack of market mechanisms for Recovery	Assurance schemes for reused/secondary materials
Lack of consideration for end-of-life issues (buildings)	Awareness raising campaign
Lack of incentive to design for end of life (products)	Development of enabling technologies to recover materials
Lack of circular economy knowledge	Development of higher value secondary markets
Limited awareness across supply Chain	Viable take-back schemes
Lack of interest	Clear business case

Adams et al. (2016) concluded that the lack of incentive to design for end-of-life issues, followed by the lack of market mechanisms to aid greater recovery and an unclear financial case were leading factors to the slow adoption of the circular business model in the construction industry. Together with the highly fragmented nature, which was also found to be a significant barrier, these challenges indicate the need for further incentives to enable the circular transition. (Adams, Osmani, Thorpe, & Thornback, 2016).

Another important conclusion of this research is that the stakeholders acknowledge the technical challenges, the complexity of building design and the lack of recovery routes as important barriers, but rate this as less important to the ones discussed above. This is explained by their believe that upcoming research and new technological innovations will help overcome these barriers.

The research of Adams et al. (2016) indicated that all stakeholders rated a clear business case as the most important enabler to this transition. Apart from that, the other opportunities which were rated as significantly important enablers are the greater recovery of materials through viable take-back schemes and higher value markets, assurance schemes for reused materials, best practice exemplar case studies and an awareness scheme. (Benachio, Freitas, & Tavares, 2020), (Adams, Osmani, Thorpe, & Thornback, 2016).

Finally, it is important to note that the research of Adams et al. (2016). indicated that demolition contractors have the perception that designers are not aware enough of the circularity in construction. However, this makes sense, since demolition contractors demolish buildings which have been designed in the past. Adams et al. (2016) state that one of the main challenges to the transition towards a circular economy is the uncertainty of material prices in the future, resulting in the need to estimate the potential value of the materials at the end of life. They concluded that the lack of incentives to design for end-of-life, the lack of market mechanisms and an unclear financial case are the main challenges to make the transition. (Adams, Osmani, Thorpe, & Thornback, 2016).

2.2.2 Circular economy possible actions in the built environment

As stated in the previous chapter, many bottlenecks hamper the transition to a circular economy in the built environment. The European Environment Agency (2020) states that often these bottlenecks are linked with past or current building practices. To enable a circular built environment, additional measures need to be taken with a focus on the whole lifecycle of construction products to preserve resources and close the loop. The European Topic Centre on Waste and Materials in a Green Economy has therefore presented a list of typical key actions to enable circular economy across a building's lifecycle, as presented in Table 2. (European Environment Agency, 2020).

Table 2: Possible actions to enable circular economy in the built environment (Adapted from European Environment Agency (2020))

Material production phase	Design phase	Construction phase	Use phase	End of life phase
the building materials are renewable;	modular and easy-to-disassemble buildings;	avoid material surpluses by using tailor-made construction materials;	update building information models and its material passport during use;	qualitative pre-demolition material auditing and waste management planning;
the production processes have low environmental impacts;	durable, flexible, upgradable, repairable and adaptable structures	create a material passport during construction;	performance-based contracts for the built environment;	decontamination of the built environment;
the materials have a high recycled content	reduce the amount of materials used by avoiding over specification and using higher-strength materials;	additive manufacturing (such as 3D printing of concrete);	extended producer responsibility, for example, for carpets (Hilton. 2018);	at source sorting of high-grade material fractions;
the materials are highly durability;	integrate nature-based infrastructure	selective sorting of construction waste;	increase use intensity of buildings through;	monitoring demolition and renovation work to assure material quality for recycling and reuse;
the building materials are not hazardous.		give away unwanted or surplus stock from the construction;	lifetime extension through repairing, strengthening, and retrofitting;	selective demolition;
		Create and maintain value through the entire lifecycle of a building and its parts by using BIM	maintenance of buildings and infrastructure.	preparing for reuse and recycling;
				increase traceability, quality assessment and certification of CDW;
				improved sorting systems for materials inseparable materials.

The conclusion drawn from this action list is that actions need to be taken at every stage of the built environment.

Another important note is that the design phase is key to enable recycling and aiding buildings and construction products to be easier to repair or more durable, resulting in resource savings. Circular design principles compare the use of resources against the needs and functionality of the building or infrastructure and take into account Design for Deconstruction, which is further elaborated in chapter 3.2 Design for Deconstruction. Since current material streams generated during renovation and demolition work are the inheritance of old linear economy practices, Design for Deconstruction were not yet applied. Therefore, a lot of the materials are often not easy to disassemble (e.g. glued materials, spray insulation, …) and are not reusable or high-grade recyclable. The EU Construction and Demolition Waste Management Protocol (EC, 2016) therefore describes the actions which need to be taken at the end-of-life stage to enable demolition practices, processing methods and logistics suitable for these material streams. (European Environment Agency, 2020)

2.2.3 Selection of actions for better construction and demolition waste management

This report will address a selection of relevant actions by focusing on the implementation of BIM as a facilitator to the circular transition. Apart from BIM, three sub-actions will be discussed, with the opportunities of BIM to the application of these sub-actions as a red wire throughout the different chapters. The selected actions will be further discussed in the following chapter.

3 Approaches to facilitate the implementation of Circular Economy in the AEC sector

The further development of this master thesis will focus on the opportunities, stimulators and barriers to the implementation of BIM and its use as a facilitator to the circular transition. First, the concept and possibilities of BIM will be discussed, together with the solutions BIM offers to the different barriers impeding the circular transition. Following the chapter covering BIM, 3 other sub-approaches, which focus on facilitating a circular economy in the built environment, were selected and will be discussed. These sub-actions are Design for Deconstruction (DfD), Material Passports (MP's) and Buildings as Material Banks (BAMB). As this research focusses on the implementation of BIM as a circular facilitator, BIM will be the red wire throughout all following chapters, linking the opportunities of BIM to enhance the application DfD, MP's and BAMB.

3.1 Building Information Modelling (BIM)

3.1.1 What is BIM

Building Information Modelling (BIM) is an intelligent model-based process that focusses on enhancing the collaboration between the different stakeholders involved during the entire lifecycle of a project (design, construction, operation & maintenance and demolition/renovation). BIM begins with the design of a digital 3D model which includes linked data with both physical and functional characteristics. The data linked to the intelligent 3D model enables document management, coordination and simulation through the entire lifecycle.
A common misconception is that BIM is a software focusing on the modelling aspect, while BIM is actually a set of software, 3D models, processes, and databases. Therefore, the focus of BIM lies in the "I", or the information management rather than the modelling aspect ("M"). BIM is a dynamic process, since the models and project information evolve throughout the development of a project. (Autodesk, n.d.), (Fernandez, 2013).

Today, an increasing number of architects, engineers and contractors are using BIM because of the growing complexity of architectural, engineering and construction (AEC) projects. Advances in technology like BIM help industry professionals work more efficiently and effectively. (Autodesk, n.d.).

The use of BIM stimulates a transparent information flow between stakeholders by offering a central information platform and thereby eliminating information loss. The enhanced collaboration between all the stakeholders, results in large efficiency gains, lower costs, fast project delivery, fewer miscommunications, inaccuracies and delays, growing business opportunities and lower emissions and waste.

A study performed by McKinsey (2016) concluded that large capital construction projects typically take up to 20% longer to finish and are up to 80% over budget. The use of BIM could reduce these delays and budgetary problems. The study also shows that 75% of companies adopting BIM reported positive returns on their investment with shorter project duration and savings on paperwork and material costs. The investment in BIM, therefore, can be of the most relevance for more complex and integrated infrastructure projects, with a wide range of activities and stakeholders involved. (McKinsey, 2016), (European Commission, 2019).

Apart from a technical decision, implementing BIM is therefore also a business decision that improves communication among business partners, provides more information for decision making, improves the delivered service quality, reduces the project duration, and reduces the cost throughout all the stages in the life-cycle of a building or infrastructure. (McKinsey, 2016).

3.1.2 BIM dimensions and maturity levels

With the BIM technology, there is no limit to the types of data (dimensions) or information added to the 3D model. Depending on the used source, the definition of the dimensions can be slightly different. For this report 7 dimensions, as defined in the report of Cherkaoui (2016), will be used, defined as:

- 3D: visualization of the building in 3D;
- 4D: scheduling, facilitating time programming and following the project evolution;
- 5D: cost estimating to help calculate and adjust the budget;
- 6D: sustainability, providing environmental and energy-efficient solutions;
- 7D: facility management;

(Josseaux, 2018), (Cherkaoui, 2016).

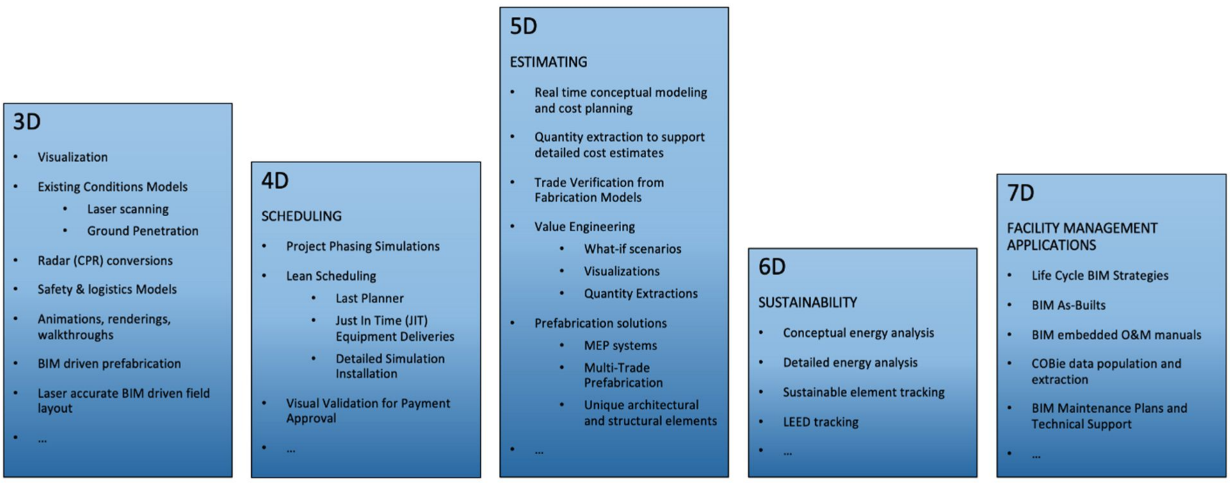


Figure 2: BIM dimensions (Adapted from Cherkaoui (2016))

The transition from a traditional modelling approach to an Open BIM approach is not instantly possible but is a gradual process with different maturity levels. As shown in Figure 3, 4 maturity levels are commonly used to describe the maturity of BIM implementation. (Z. Dakhli, 2015), (European Commission, 2017).

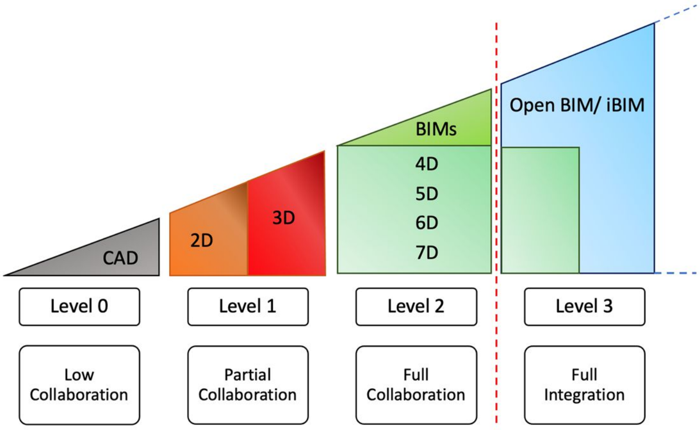


Figure 3: BIM maturity levels (Own creation)

- Level 0 starts with the absence of collaboration, where all parties work separately using 2D CAD. On this level, every party works with their tools and standards, exchanging the 2D CAD via paper-based or digital prints. Furthermore, the projects do not contain geo-referenced and do not have the same units and models. Therefore, this level does not apply BIM.
- On Level 1, a 3D model is added with a structured database for conceptual work. However, on this level 2D CAD is still the most used work-form, and collaboration is still at a low point as the different parties work on separate models. Data is shared using mediums like email.
- Level 2 is the level on which all parties use separate 3D CAD models. Although the parties work on separate models, on this level the focus lies on a higher level of data sharing. This is enabled by using a common file format such as IFC, which is explained in Chapter 3.1.6, to exchange the design information between the different stakeholders. At this level, both time management (4D) and calculation of the budget (5D) are added to enable project management through the BIM. Although some literature reports suggest that sustainability (6D) and life cycle management of the building (7D) through the use of BIM is only enabled on Level 3, this report will offer solutions which can already be implemented at Level 2.
- Finally, Level 3 is the ultimate goal where the construction industry is aiming for. Level 3 implies using an "Open BIM model", which is a central 3D CAD shared model accessible by every party facilitating the collaboration in a single model. All stakeholders work directly in a single model stored on a centralized server, accessible throughout the whole lifecycle. Hereby the model evolves throughout the different phases of the project. (Z. Dakhli, 2015), (European Commission, 2017), (Josseaux, 2018).

Study shows that in 2017, the majority of leading international construction firms were aiming to reach Level 2. (Alreshidi, 2017) Only a minority was already implementing some aspects of Level 3, such as shared model-based delivery of information throughout the supply chain and lifecycle of the building or infrastructure. However, as the red dotted line in Figure 3 suggests, no firm has yet been able to fully reach Level 3, where full collaboration is facilitated by a single shared model. (Alreshidi, 2017), (Josseaux, 2018).

3.1.3 BIM throughout the project lifecycle

Throughout the whole lifecycle of the building or infrastructure, BIM can be used for different goals, as presented in Figure 4.

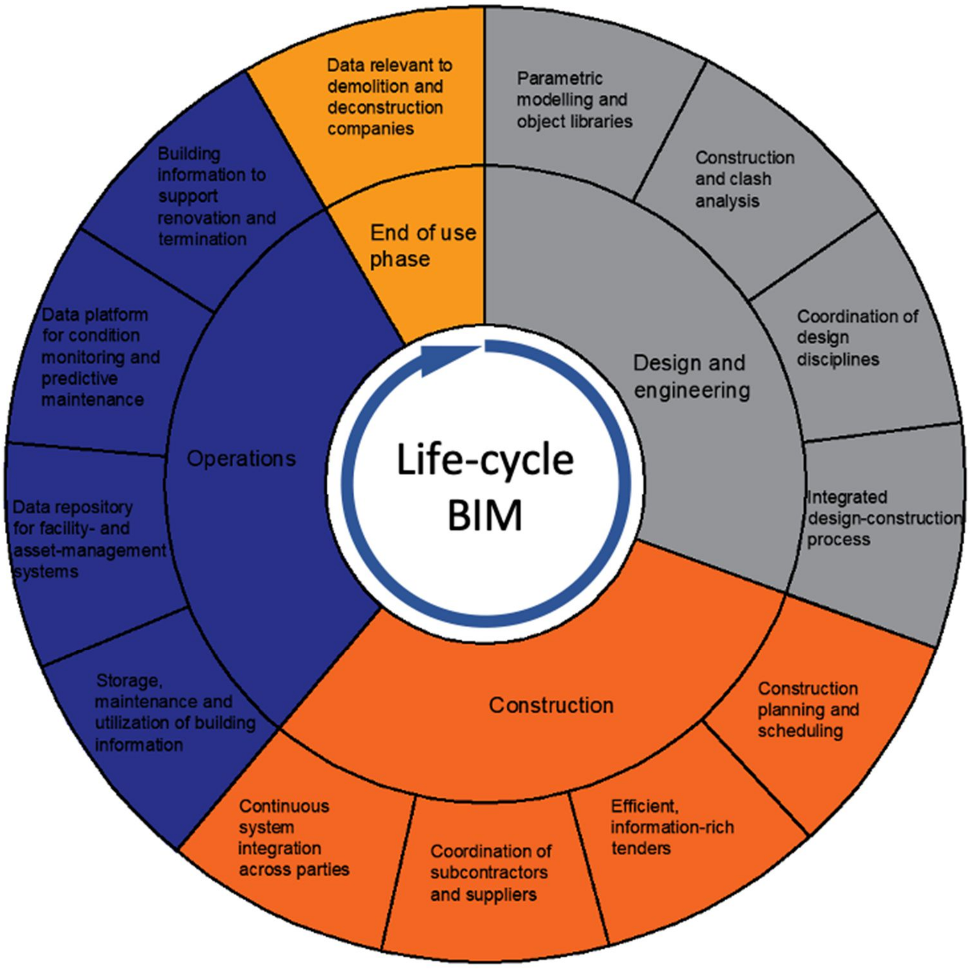


Figure 4: BIM throughout the construction lifecycle (Own creation)

Design and Engineering

The study performed by Moreno, Olbina, and Issa (2019) shows that BIM offers a lot of benefits during the designing phase. During this phase, architects and engineers perform conceptual design and analysis while detailing and documenting. Since BIM auto-adjusts its 2D plans, based on the 3D drawing, it is easier to evaluate multiple designs of the construction. BIM allows faster information sharing between

design disciplines while being less prone to mistakes and omissions. This enhances collaboration and decreases rework. Depending on the dimensions of BIM used, it can also be used to perform more accurate cost estimates and sustainability analysis in a much earlier stage than traditional construction processes. It can allow designers to assess performance, sustainable design and environmental impact on a much more detailed level. Another useful advantage for architects is to use the 3D model as a visualization towards owners and other stakeholders.
The main advantage to engineers in this phase is the opportunity to use BIM to perform structural analysis and the ability to automate the extraction of manufacturing information.
BIM data can also allow project managers to perform scheduling and look into the logistics. (Autodesk, n.d.), (Moreno, Olbina, & Issa, 2019).

Construction phase

As stated in the work of Fernandez (2013), only a few construction firms use BIM throughout the entire course of a project. Most construction firms either stop using BIM in the preconstruction phase or use only fragments of the BIM process. There is still a misconception that BIM does not work in the field. Although there are still some difficulties and barriers to the implementation of BIM in the field, different case studies, such as presented in the work of Fernandez (2013), show the contrary. (Fernandez, 2013), (Autodesk, n.d.).

Some of the main advantages to enhance the productivity of BIM for contractors and construction managers in the field is using BIM to:

- Facilitate trade coordination and run clash detection;
- Perform construction analyses and planning;
- Quantity take-off and cost estimating;
- Material and equipment tracking on-site using RFID;
- Document management using the software library.

(Fernandez, 2013), (Moreno, Olbina, & Issa, 2019).

Operation and maintenance phase

When a BIM model is composed during the previous stages of the construction process, it contains information and data about the whole infrastructure and the different building service installations. Therefore, an updated as-built BIM model can be a very useful tool during the operation and maintenance phase, enabling efficient facility management. It can allow facility managers and owners to locate elements and enable document management of e.g. warranties, tech sheets, operation and maintenance manuals and schedules, servicing logs, … BIM could thereby also be used to perform cost-effective and efficient renovation or deconstruction. (Autodesk, n.d.), (Total BIM consulting, n.d.).

End of use phase

As the report of Olugbenga and AKinade (2017) mentions, until this point, the use of BIM for end-of-use practices such as demolition, deconstruction and recycling is often neglected. As previously mentioned, the focus still lies in the earlier phases while BIM could offer many benefits to reduce the CDW-stream generated during traditional demolition practices. As the reduction of the CDW-stream and the transition to a circular economy using BIM is the subject of this master thesis, the benefits of BIM during this phase will be mentioned further on. (Olugbenga O. Akinade, 2017).

3.1.4 Enablers and barriers of the European BIM Market

The growth of the European BIM market is driven by a set of factors including integrated urban development trends and government policies and initiatives. In the last years, there has been an increase in public infrastructure and other renovation projects in Europe. These projects are often large and complex and require the involvement of a wide range of stakeholders, driving the need for BIM in the European market. The second major driving factor for the growth of the European BIM market is the increasing number of EU Member States that are implementing (binding and non-binding) policies and initiatives, increasing the adoption of BIM in public procurement. (European Commission, 2019).

In 2016, an EU BIM Task Group was founded to align the use of Building Information Modelling in public works with a common European network. Although different countries are moving at a different pace, the foundation of the Task Group was a big step for the digitization of the construction sector. (Paul, 2018).

One of the factors impeding the potential benefits of the adoption of BIM is the limited implementation by large European industry players. In a report of the European Commission (2019), a study is implanted showing that in 2016 only 29% of the construction companies in Europe used BIM 3D, and only 6% used BIM 4D. In this report, it was shown that the industry players recognized the reduction of errors, greater cost predictability and better understanding of the project as the main benefits of BIM. Although BIM adoption has had significant growth since 2016, the current use is still far from its full potential and is still fragmented along the value chain. BIM is mostly used in the design and construction phases, with the operations and maintenance phase lagging far behind. (European Commission, 2019).

Therefore, BIM is mainly used by architects and general contractors, and less by engineers and trade contractors. In the report by the European Commission (2019) it is stated that: "*Looking forward, 68% of European architecture firms agree that architects failing to provide BIM-compatible information will already fall behind in three years with the percentage dropping to 30% when it comes to construction firms. This suggests that BIM value and benefits are harder to achieve when it comes to the operation and maintenance phase than during the design and construction phases.*" (European Commission, 2019). The report also points out that the lack of demand for BIM by project owners is not driven by a lack of acceptance, but by the lack of awareness of the benefits BIM can bring to the construction, operations and maintenance stages of the life cycle. Government policies and requirements for the use of BIM in public procurement can thereby be the awakening enabler for BIM awareness during those phases. (European Commission, 2019).

3.1.5 BIM to address the barriers to the circular transition

In this chapter, the focus will lie on the areas of BIM that provide a solution to the main barriers to the circular transition of the construction industry, identified in chapter 2.2.1, as fully covering BIM is out of the scope of this thesis. As mentioned in chapter 2.2.1, 2 of the most significant barriers to the circular transition are the fragmented nature of the industry and the low consideration for the entire life-cycle of the building.

BIM as a potential solution to the fragmented nature of the construction industry

As mentioned in the previous chapters, one of the main goals of the creation of BIM is to enable collaboration. Traditional communication using 2D plans is prone to errors resulting in additional costs, delays and often lawsuits. As BIM is based on a 3D model and changes to the project are automatically updated in all drawings, this tackles the majority of design errors and reduces time consumption and delays. As the level of BIM-use increases, the collaboration between the stakeholders involved increases. This enhanced collaboration offers a solution to tackle the fragmentation barrier.

BIM as a potential solution to the low consideration for the entire life-cycle of buildings and infrastructure

One of the major problems in the construction industry is the inefficient information flow between different stakeholder throughout different phases of the building lifecycle, resulting in information losses. Information is lost in the transition to succeeding project phases (design, construction, operations, end-of-use), as it is common practice for different companies to be responsible per construction phase. During these different phases, analyses require unique information specific to the application. As this leads to the inability to re-use data from previous phases, this information is non-transferred or not used. This in contrast to the collaborative BIM-based delivery process. Here, all information from previous phases remains present in the model. For specific applications, the necessary existing information can then be filtered out of this model and new information can be added. By adding information directly to the same model, the BIM model's information-richness increases throughout the life-cycle. The eliminated need for re-entering information for specific applications, as information can be re-used from the existing model, results in a reduction of errors and time consumption.

As BIM could support the management of building information throughout the whole life-cycle, it can be seen as a tool for product life-cycle management resulting in higher product quality, lower risks and a reduction of waste.

One major problem with this workflow is the lack of interoperability between the specific applications used by different disciplines. To be able to apply this collaborative workflow all information should be interoperable and stored on a platform accessible to all stakeholders. This ensures that every discipline can contribute to the model regardless of the software they use. In traditional 2D CAD methods the difference in the level of detail necessary for the discipline, and the responsibilities connected to the drawings was not an obstacle. In comparison to the separate workflow with 2D CAD, working on one central BIM model creates new problems. The first is the need for a way to extract only the necessary information and level of detail needed for the discipline. Second, it also creates a problem of responsibilities as every discipline works on the same model: 'which discipline is responsible for which aspect?'.

A possible solution for the first problem is to work with the level of detail (LOD) defined by the US-American BIMforum (2019). The full explanation of this system is out of the scope of this literature review, therefore Figure 5 gives a brief visualization of this system.

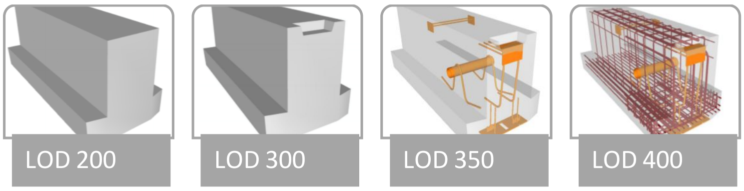


Figure 5: Level of detail (LOD) (adapted from BIMforum (2019))

A possible solution to the interoperability problem is to work with Industry Foundation Classes (IFC's) and filtering out the necessary information using Model View Definitions (MVD's). These concepts are a crucial step to pave the way to the third level of BIM and thereby exploiting the full potential of BIM. These concepts will therefore be further explained in the next chapter. (buildingSMART, 2020)

Finally, it is important to note that after the design and construction phase, an as-built BIM model should be delivered to facility managers and should be passed on to, and modified by, the relevant actors from there on. This is of most importance to extend BIM throughout the whole life-cycle as the operation phase is the longest phase where most of the costs in the whole life-cycle occur. As the as-built contains much data irrelevant to facility managers, this data can be filtered. The Construction Operations Building Information Exchange MVD (COBie) is the most commonly used standard to enable the transfer of relevant data from the as-built BIM model to facility management systems. (BIMForum, 2019), (Groh & Dubik, 2018), (European Environment Agency, 2020).

3.1.6 BIM standardization and interoperability

As stated in the report of the European Construction Sector Observatory (2019), most of the stakeholders in the construction sector acknowledge the importance and relevance of BIM, but adoption is often limited. One of the main barriers to BIM adoption is interoperability. (European Commission, 2019) The design and construction of a building is a team activity. Because of the increasing complexity of construction projects, it is an increasingly fragmented process. More and more activities need to be outsourced to specialized subcontractors, supported by their computer application. Standardization and interoperability are therefore essential to facilitate collaboration between multiple types of experts. Therefore, the ability to exchange data between applications is key. (Fernandez, 2013), (European Commission, 2019).

BuildingSMART is the leading organization on the development and adoption of open, international standards and solutions for infrastructure and buildings. The organization promotes international consensus among stakeholders on specific standards and has created a wide range of standardization work including:

- The Industry Foundation Classes (IFC);
- Model View Definitions (MVD);
- Information Delivery Manual (IDM);
- BuildingSMART Data Dictionary (bSDD);

BuildingSMART has a liaison with the International Organization for Standardization (ISO). On a European level, the Vienna Agreement (VA) regulates the relationship between ISO and the European Committee for Standardisation (CEN). This way BuildingSMART has an indirect liaison with the technical committee for building information modelling of CEN (CEN/TC 442) to ensure the acceptance of adopted standards. (European Commission, 2017), (buildingSMART, 2020).

Industry Foundation Classes (IFC)

BuildingSMART (2020) defines the Industry Foundation Classes (IFC) as: "*a standardized, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard (ISO 16739-1:2018), meant to be vendor-neutral, or agnostic, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases.*" (buildingSMART, 2020) IFC specifies a conceptual data schema and exchange file format for BIM data to be exchanged between software applications. With the IFC schema specification, BuildingSMART International aims to promote OpenBIM. (buildingSMART, 2020), (European Commission, 2017).

As stated by BuildingSMART (2020), the IFC codifies:

- the **identity** and **semantics** (name, machine-readable unique identifier, object type or function);
- the **characteristics** or **attributes** (such as material, colour, and thermal properties);
- the **relationships** (including locations, connections, and ownership);

of:

- **objects** (like columns or slabs);
- **abstract concepts** (performance, costing);
- **processes** (installation, operations);
- **people** (owners, designers, contractors, suppliers, etc.).

The IFC schema specification can construe the use, construction, and operations of a facility or installation. IFC can define both physical components of buildings, manufactured products, mechanical/electrical systems, as more abstract structural and energy analysis models, breakdown of costs, schedules, etc. (buildingSMART, 2020).

The use of IFC today is typically focused on the exchange of information between different parties involved in a specific business transaction. It is important to mention that the IFC exchange does not mean that the model made in one software can be exchanged with an IFC export to another application to continue modelling. BuildingSMART (2020) often states that IFC is like the PDF of BIM. It makes a frozen copy of the original content and can be used in other applications to view, measure, used for clash detection, cost estimation etc., but it cannot be edited. For example, when an architect sends an IFC model to the HVAC engineer for energy analyses. The IFC reference model contains all the information needed to perform the energy analyses, but the HVAC engineer can't change the model. To make changes the HVAC engineer has to request the changes to the architect, who can then send a modified IFC model back. Although modification of IFC reference models could technically be possible, it is not the intended workflow. (buildingSMART, 2020).

Information Delivery Manual (IDM)

The IDM is a manual that defines when, which and by whom the information has to be exchanged during the building process. By using this manual, the different partners get an insight into the subset of IFC (MVD) that they need to use when exchanging information on a certain point within the building process. This manual aims to clarify the way to collaborate using IFC. In Figure 6 the IDM-principle is presented, with the blue circle being the whole IFC-model, the green circles being the subsets or MVD's as explained hereafter, and the arrows indicating the point within the Building Construction Processes that a certain MVD has to be exchanged. (buildingSMART, 2020), (buildingSMART, 2010).

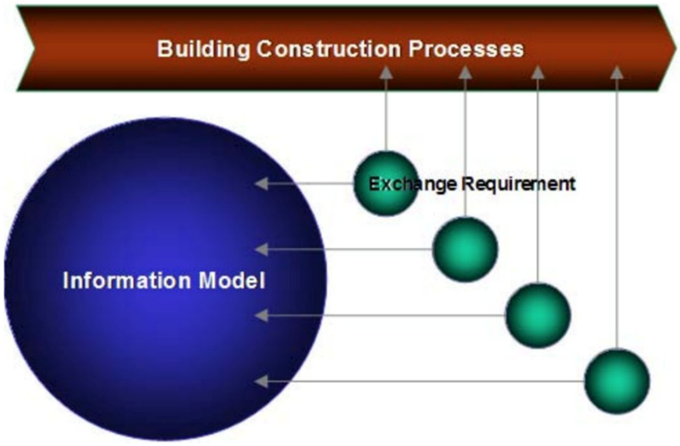


Figure 6: Concept of Information Delivery Manual (IDM)(Adapted from BuildingSMART (2010) Copyright: GNU Free Documentation License)

Model View Definitions (MVD)

BuildingSMART (2020) defines a Model View Definition (MVD) as: "*a subset of the overall IFC schema to describe data exchange for a specific use or workflow, narrowing the scope depending on the need of the receiver.*" (buildingSMART, 2020) IDM makes it possible to predefine what, when and by whom information needs to be transferred. In its essence, MVD is a filtered view of the IFC-model allowing users to export specific packages of model information, or thus subsets of the IFC schema, to meet a particular use in the AEC industry. (buildingSMART, 2020).

Data Dictionaries

In construction, different parties often use different terminology or language for the same thing. To be able to work together in a digital environment, different terminology can be a bottleneck for collaboration. A Data Dictionary connects all terminology with internationally standardized and machine-readable concepts to remove this obstacle. (buildingSMART, 2020).

3.2 Design for Deconstruction

In chapter 2.2.2, various actions to enable the transition of the construction sector to a circular economy were addressed per phase in the construction life-cycle. In this chapter, a solution is presented which takes place in the design phase but has an influence on the CDW generated throughout all the following phases of the construction project, namely Design for Deconstruction (DfD). Currently, it is common practice to demolish buildings before they reach their technological end of life. As buildings are demolished, a significant amount of CDW is generated. Therefore, the possibility of recycling and reuse of building components should be significantly increased. Besides developing new recycling methods, the possibility of recycling and reuse of components is inextricably linked with the way the building was designed. One of the main problems impeding high grades of recycling and reuse of building products is the lack of DfD of existing infrastructures. As recycling and reuse of future buildings are crucial to make the transition to a circular economy, Design for Deconstruction is key.

The main idea of DfD lies in providing easy disassembly of buildings into their components to enable the possibility of reuse, reassembly, reconfiguration and recycling of those components, extending their useful lifetime. However, design for deconstruction is a concept that doesn't have fixed boundaries. Many actions can be applied to contribute to DfD. In the following part, the most relevant actions are listed.

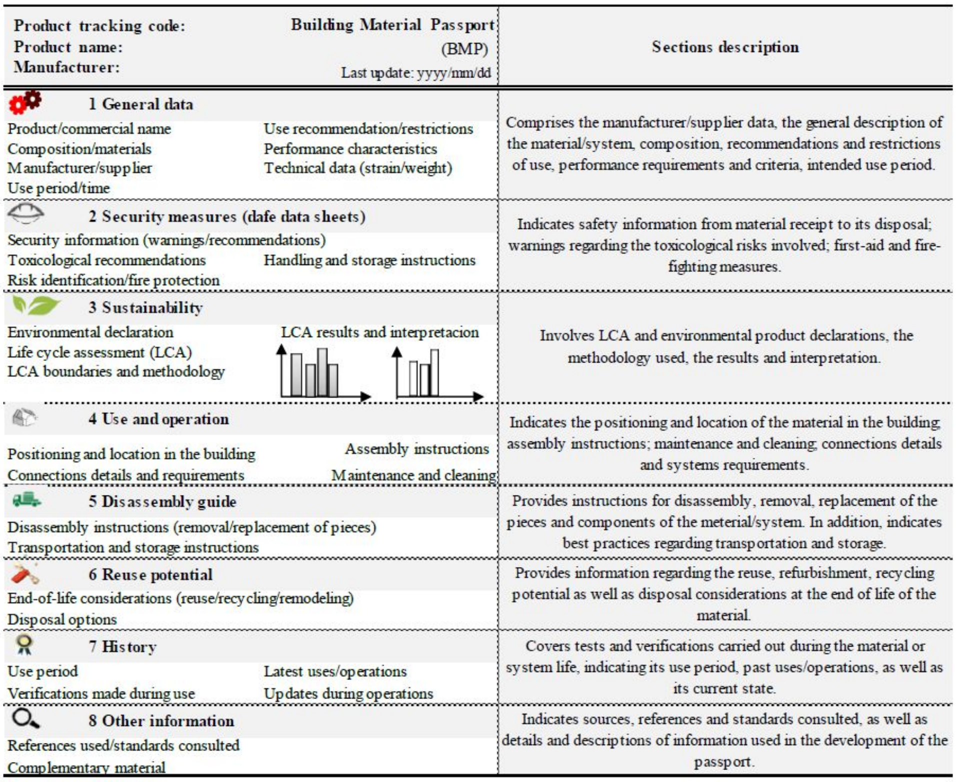
- The first action takes place on the level of the design of the whole building. One of the major reasons for the premature demolition is the lack of the adaptability of existing buildings to various socio-economic trends. Therefore, DfD should support the flexibility and adaptability of the building to make shifts in functionality possible. This would extend the building's lifecycle.
- The second idea lies on a component level. As a building is composed of a lot of different components each with their characteristics and technological life-time. Therefore, choices should be made in the design phase to enable repair, recycling, disassembly and remanufacturing/replacement of building components. This results in extending the existing buildings life-cycle and preserving the quality/value of the building and the components of which it is composed.
- The above-mentioned ideas are both methods to extend existing buildings life-cycles. However, when the building has eventually reached the end-of-life, the design should facilitate the recycling- or reuse-potential of components to be reused in new projects. Applying these concepts would take buildings into the direction of functioning as material banks, which is explained in chapter 3.4.

DfD requires providing Deconstruction companies with the necessary documentation and deconstruction plans. The documentation should contain information on the reuse, recycling or reclaiming methods. This is where Material Passports comes in the picture, which will be discussed in chapter 3.3. In the research about Circular Economy in the Built Environment, Arup (2016) foresees the use of a cloud-based BIM system supporting DfD by recording and tracking materials and components through their life-cycle. (Arup, 2016), (Rios, Chong, & Grau, 2015), (Groh & Dubik, 2018).

3.3 Material Passport

As concluded in the report of Heinrich and Lang (2019), the AEC sector is lagging behind regarding digitisation in comparison to other industry sectors. This creates a huge opportunity for the implementation of new technologies to fasten the transition towards a circular economy. To make this transition, large amounts of data need to be collected, processed, stored and utilised. (Heinrich & Lang, 2019). As the BAMB report (2020) states, a currently occurring information gap of material- and product-data in the building's lifecycle result in a great need for standardised methods of data. Currently, the composition and properties of materials and products are still missing or not communicated to the relevant actors in the buildings value chain. Material Passports offer a solution to close this information gap. (BAMB, 2020). Copeland and Bilec (2020) define Material Passports as: "*datasets aimed to define and describe material characteristics focusing on value for recovery and reuse. With the evaluation of material flows, these passports can be useful to determine the market value of used building materials of different qualities*" (Copeland & Bilec, 2020).

According to BAMB (2020), these material passports should keep or increase the value of materials and products over their lifetime, which should stimulate suppliers to produce more sustainable and circular materials. Material Passports should also support reversible building design, facilitate reversed logistics and the take-back on products/materials. Figure 7 gives an example of the material passport principle. (BAMB, 2020).



Product tracking code: / Product name: / Manufacturer: — Building Material Passport (BMP) Last update: yyyy/mm/dd	Sections description
1 General data Product/commercial name; Composition/materials; Manufacturer/supplier; Use period/time; Use recommendation/restrictions; Performance characteristics; Technical data (strain/weight)	Comprises the manufacturer/supplier data, the general description of the material/system, composition, recommendations and restrictions of use, performance requirements and criteria, intended use period.
2 Security measures (dafe data sheets) Security information (warnings/recommendations); Toxicological recommendations; Risk identification/fire protection; Handling and storage instructions	Indicates safety information from material receipt to its disposal; warnings regarding the toxicological risks involved; first-aid and fire-fighting measures.
3 Sustainability Environmental declaration; Life cycle assessment (LCA); LCA boundaries and methodology; LCA results and interpretacion	Involves LCA and environmental product declarations, the methodology used, the results and interpretation.
4 Use and operation Positioning and location in the building; Connections details and requirements; Assembly instructions; Maintenance and cleaning	Indicates the positioning and location of the material in the building, assembly instructions; maintenance and cleaning, connections details and systems requirements.
5 Disassembly guide Disassembly instructions (removal/replacement of pieces); Transportation and storage instructions	Provides instructions for disassembly, removal, replacement of the pieces and components of the meterial/system. In addition, indicates best practices regarding transportation and storage.
6 Reuse potential End-of-life considerations (reuse/recycling/remodeling); Disposal options	Provides information regarding the reuse, refurbishment, recycling potential as well as disposal considerations at the end of life of the material.
7 History Use period; Verifications made during use; Latest uses/operations; Updates during operations	Covers tests and verifications carried out during the material or system life, indicating its use period, past uses/operations, as well as its current state.
8 Other information References used/standards consulted; Complementary material	Indicates sources, references and standards consulted, as well as details and descriptions of information used in the development of the passport.

Figure 7: Example of Material passport (Munaro, Fischer , Azevedo, & Tavares (2019) Copyright Creative Commons Attribution 3.0 licence)

According to Heinrich and Lang (2019), material passports and BIM should be integrated to generate data for assessing the reversible design. They conclude that the material flow analysis of the stock is critical to support the supply and demand of the materials. It is important to note that the material passport is merely a tool to support measures taken to enable the circular transition. Material Passports contain the data relevant to recovery and reuse of materials, but do not assess or evaluate it. It creates an opportunity for other stakeholders to correctly evaluate the condition of materials/products. BAMB 2020 is currently developing a viable material passport system and has already launched a material passport platform prototype. (Heinrich & Lang, 2019).

Material passports should exist on different levels, depending on the complexity of the product. This would mean that there are multiple "layers" of passports. These different layers would represent the building as a whole, the system, the product, the component and the material itself. Every different layer would have its typical passport containing the necessary information. E.g. a closet is a combination of different components. The first layer (material level) of the passport would describe the properties of the different materials being used in the closet, being wood, glue, metal (from the screws) and plastic. The second layer (part level) would describe the properties of the different parts in the closet, being the panels, the screws, the hinges, etc. Finally, the third layer (product level) describes the properties of the product itself. (Groh & Dubik, 2018), (BAMB, 2020).

As the report of Groh and Dubik (2018) suggests. The system of material passports can be paper-based, digital with local or web-based storage or integrated into the BIM-model. In the research of this thesis, the opportunities, advantages and disadvantages of incorporation of the material passports in the BIM-model will be addressed. (Groh & Dubik, 2018).

3.4 BAMB

Due to the linear business model used in the construction industry, the Architecture, Engineering and Construction (AEC) sector is responsible for 40% of all carbon emission worldwide. According to Copeland and Bilec (2020), by 2050, it could take up to 2 piles of earth to handle the current rate of annual resource use. When applying the circular business model in construction, the AEC industry could reduce virgin material use, landfill waste and the environmental impact of construction. (Copeland & Bilec, 2020) One strategy to tackle the take-waste-dispose model is the use of buildings as material banks (BAMB). The idea behind BAMB is to consider buildings as a temporary storage of the building materials, waiting to be used in another building. E.g. a standardized prefabricated concrete beam can be used in another project when the original building isn't used anymore, the same goes for the panels used between the columns to form the wall of a building. The ultimate idea of BAMB is to deconstruct buildings and rebuild the buildings somewhere else, or at least re-use the components in another building. This application should be used locally, regionally and on a national scale. The European Union started the BAMB program, which is a collaboration between 15 partners that try to implement the circular economy in construction while aiming to increase the value of building components. Currently, the BAMB program is a framework designed by the European Union that still needs a lot of research before it can be adopted. In addition, the implementation of material passports and BIM is necessary to initiate the BAMB program. (BAMB, 2020)

Copeland and Bile (2020) developed a framework consisting of four major phases, using new technologies like blockchain, RFID and BIM to overcome the barriers and facilitate the transition towards a circular economy with the use of BAMB. This framework is shown in Figure 8, the four major stages are precursors, popularizing the project, assessing and optimizing, and primary usage. (Copeland & Bilec, 2020)

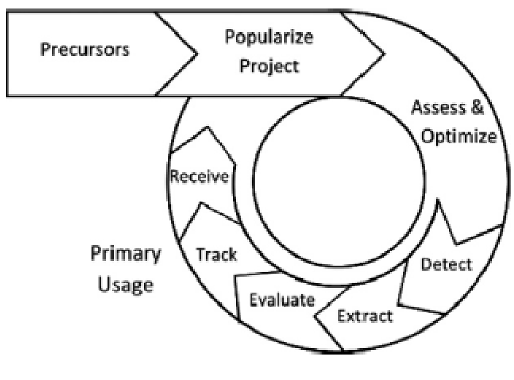


Figure 8: Framework BAMB (Copeland & Bilec (2020) copyright CC BY-NC-ND license)

3.4.1 Methods to gather the required information about the existing buildings

According to Rose and Stegermann (2019), several methods can be applied to gather the required information from existing buildings. This information is necessary to estimate the amount of materials available in buildings.

1. First, the As-built information (how a building is exactly built) about buildings can be consulted, which contains drawings, specifications and other documents about the building. This information can be useful to determine the availability of materials and to determine the possibility of re-use. However, these documents tend to be outdated, unavailable or incomplete.
2. A second way to acquire the needed information is the use of existing BIM models or the use of automated scan-to-BIM when no existing BIM model is available.
3. A third way to get the required information to achieve BAMB of existing buildings is In-use stocks research. This method describes the stocks and material flows and estimates the number of materials in existing buildings based on assumptions, like the homogeneity of material composition. E.g. Huuhka et al. created an inventory of prefabricated panels, this study contained data regarding the condition of the panels, information to re-use the panels etc.
4. Another way is to pre-plan the demolition and generate detailed information about the different components. This would make a connection between demolition contractors and architects possible, leading to the reuse of specific components. (Copeland & Bilec, 2020) (Rose & Stegermann, 2019)

3.4.2 Implementation in practice

A good example of the implementation of BAMB in practice is realised by Dutch architecture company Superuse studios. Superuse Studios has come up with an innovative way to preserve materials by developing the harvest mapping system. With harvest mapping, the company scans a perimeter with a radius of 25km from the construction site to find potential resources. They highlighted those hotspots on a map and added a material catalogue. Since there is currently a lack of E-BAMB (existing buildings as material banks), this process is time-consuming. (Rose & Stegermann, 2019)

An important factor in the use of BAMB is the material flow between the suppliers and demanders. The website of the company Superuse Studios connects both parties, making it a reused material marketplace (RMM). These RMMs are a virtual platform, where the supplier can put his unused materials for sale.
Figure 9 represents a flowchart of the E-BAMB information system according to Rose and Stegermann (2019), which suggest that the description of components for reuse properties should be based on a classification system rather than categories. When the auditor reviews the materials, they should include documents like photographs, location, quantities and potential savings of greenhouse gas emissions. (Rose & Stegermann, 2019)

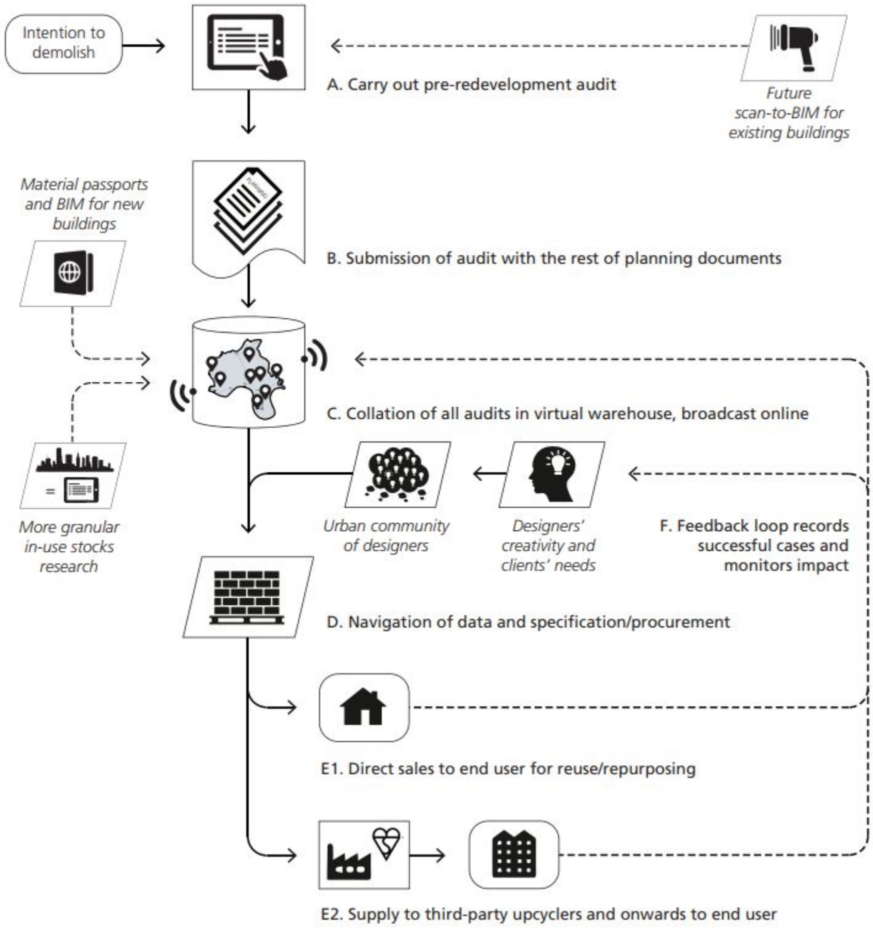


Figure 9: Coordinated approach to E-BAMB knowledge generation (Rose & Stegermann (2019) copyright CC-BY 4.0 license)

3.4.3 <u>Barriers</u>

One of the main problems with BAMB is the deconstruction of buildings. In the past, buildings weren't designed to be deconstructed, leading to a high cost of deconstruction labour. The difference between deconstruction (selective demolition) and conventional demolition lies in the fact that selective demolition consists of disassembling building components, resulting in a higher operational and labour cost. Traditional or conventional demolition consists of just destroying the building as a whole. Because of the currently low prices of raw material compared to the high cost of secondary raw materials (= materials coming from the deconstruction of buildings), the use of secondary raw materials is financially less interesting to construction companies. Since the demand and supply of these materials are low, additional storage of these materials is necessary, leading to an extra cost. For BAMB to work effectively, the market for reused building materials needs to increase. (Copeland & Bilec, 2020)

3.4.4 Werflink

Werflink is an online platform, used mainly in Belgium and the Netherlands, on which companies can sell, swap and share construction equipment, materials etc. On this platform, you can both place a supply and a demand for materials. The difference with BAMB is that this platform is based on sharing equipment during construction, compared to BAMB where a building is seen as a temporary stock of building materials that will be used in the future. (Werflink, 2020)

3.5 Other technologies and its potential

3.5.1 IoT

IoT or the Internet of Things refers to everyday items being connected to the internet. According to 50 five (2020), over 26 billion devices are connected to the internet, thinking of laptops, gsm's, fridges, lights etc. The Internet of Things devices can send data to the cloud and communicate with each other. IoT elevates the level of efficiency of everyday devices by adding sensors to collect data (e.g. temperature, humidity, wear and tear). These devices are connected via Wi-Fi, Bluetooth, ethernet or mobile data. The main principle of IoT is sharing and analyzing data. (FIVE, 2020)

Tang, Shelden, Eastman, Pishad-Bozorgi and Gao (2019) define IoT as "*Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications*". They also state that both BIM and IoT are still in their initial phases. IoT could enhance the data from BIM by providing real-time and recordable data from sensors and products in construction. The adoption of IoT in BIM can facilitate energy management, construction monitoring, health and safety management and building management. However, a unified framework is necessary to accomplish the full integration and use of IoT in BIM. (Tang, Shelden, Eastman, Pishdad-bozorgi, & Gao, 2019).

The following list gives an overview of the different domains and applications of IoT in construction. (Tang, Shelden, Eastman, Pishdad-bozorgi, & Gao, 2019).

- Construction operation and monitoring

  The integration of IoT in BIM gives the possibility to add real-time data to the building information model. This way, resources can be monitored and the on-site environment can be monitored, e.g. moving paths of resources can be visualized using these IoT sensors. Thanks to these sensors, communication and collaboration can be enhanced. Finally, construction performance and progress can be monitored using IoT devices, like quality control. RFID tags and GPS sensors can also be used to gather positional data of the different components

- Health and safety management
  Thanks to the real-time data, safety can be increased by visualizing malfunctioning components. When these sensors are combined with a portable warning system, hazards can be limited by warning the users of the existing danger.
- Construction logistic and management
  Prefabrication of construction elements can be facilitated using advanced sensors in combination with BIM. These sensors, like RFID tags, are effective tools to automate prefabrication. In addition, lean management in construction will be facilitated and IoT in combination with BIM

can track work progress, constraints and productivity. The danger, however, is an information overload due to all the data being generated. A standard is necessary to prevent this overload of information.

- Facility management

  Thanks to IoT sensors, maintenance can be checked, using the BIM model, instead of the need to check this locally. Problems can also be visualized using Augmented reality. Energy usage and building performance can also be checked using smart sensors. Finally, IoT can be used for disaster and emergency response: e.g. when a person is trapped in a burning building, the victim can be located using the BIM model.

Tang et al. (2019) concluded that a framework is necessary to fully integrate IoT in BIM. They suggested 5 different frameworks. (Tang, Shelden, Eastman, Pishdad-bozorgi, & Gao, 2019).

3.5.2 Blockchain

According to Murray (2018), blockchain is a database, being shared across a network of computers. As it has cryptographic features, it stores information in a secure way, while making sure every user can simultaneously view and verify the information. When a change is being made, the participants confirm these changes to one another directly, allowing them to do this without a third party. (Murray, 2018). Copeland and Bilec (2020) state "*Blockchain is a distributed and decentralized ledger that efficiently and irrefutably records transactions through secure and encrypted logs.*" They state that at this moment, blockchain is being used to highlight which parties made changes to the original BIM model. When applying BAMB, blockchain can ensure a reliable smart contract between supplier and demander. In addition, the location of the materials can be stored within this blockchain using RFID tags. (Copeland & Bilec, 2020).

4 Utaut framework

As this master dissertation examines the adoption of BIM, a framework is necessary to understand the acceptance of the technology. Therefore, the TAM and UTAUT framework were selected and examined. The TAM (technology acceptance model) and UTAUT (unified theory of acceptance and use of technology) theories describe the reasons why the acceptance of new technologies occurs at a fast or slow pace. Figure 10 gives an overview of the UTAUT framework. This model states that 2 different behavioural aspects influence the use of a new system, being behavioural intention and behavioural expectation. According to Warshaw and Davis (1985), behavioural intention is defined as "*The degree to which a person has formulated conscious plans to perform or not perform some specified future behaviour*". This in comparison to behavioural expectancy, which tries to predict actions based on the probability, using information about the external environment. According to Venkatesh et al. (2017), there are 3 predictors for behavioural intention, being performance expectancy (the degree to which the technology will help gain the performance), effort expectancy (the degree of ease to adopt the new system) and social influence (the degree to which others say you need to use the new system). Social influence and facilitating conditions (the degree to which there is organisational and technical support for the system) are the predictors for behavioural expectation. All predictors are influenced by gender, age, voluntariness and experience. (Venkatesh & Bala, 2008) (Warshaw & Davis, 1985) (M. Maruping, Bala, Venkatesh, & Brown, 2017)

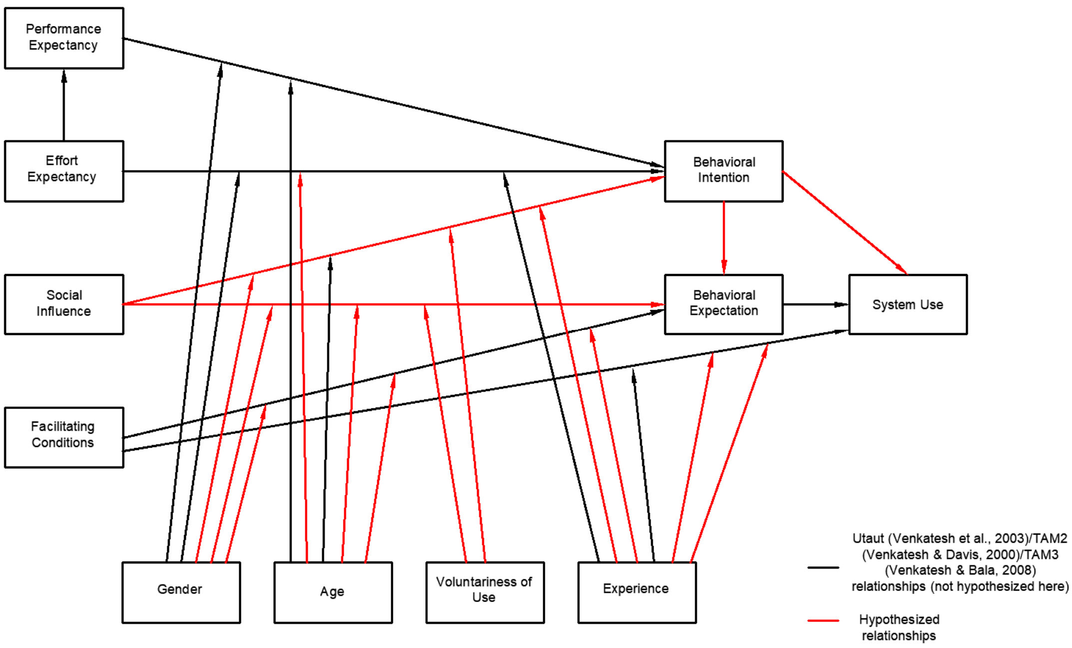


Figure 10: UTAUT model (Adapted from M. Maruping, Bala, Venkatesh, & Brown (2017))

5 Theoretical conclusion

As the first part of the literature review concludes, current traditional construction practices generate a large amount of CDW, resulting in an environmental impact mainly by logistics and landfilling. To address this problem, the implementation of the Circular Economy principles in the construction sector is a potential solution. However, the literature study shows that there are still many barriers impeding this transition in the construction sector, and actions need to be taken. In this master dissertation, BIM is proposed as a solution to some of the main barriers discussed, mainly being the fragmentation and the lack of consideration of the entire life-cycle. Literature review shows that BIM has significant potential to address these barriers by enhancing collaboration and information management. However, BIM is a relatively new concept and there are still some barriers that could prevent companies from implementing BIM in their business processes. In addition, 3 complimentary approaches are discussed, being Design for Deconstruction (DfD), Material Passports (MP's) and Buildings as Material Banks (BAMB). The main idea of DfD lies in providing easy disassembly of buildings into their components to enable the possibility of reuse, reassembly, reconfiguration and recycling of those components, extending their useful lifetime. Literature study shows that DfD requires providing deconstruction companies with the necessary documentation and deconstruction plans, introducing Material Passports as a possible approach. Material Passports are datasets containing material characteristics related to the value for recovery and reuse. Finally, when the possibility of deconstruction is there and components are made available for reuse, the BAMB concept is presented as a necessary step to close the loop. In the BAMB approach, buildings are looked upon as a temporary storage of components and components are reused in new buildings after deconstruction. Finally, UTAUT was introduced as a framework to allocate the enablers and barriers of new technologies. The main conclusion is that the literature review shows that the combination of BIM with the 3 proposed approaches shows great potential to facilitate the circular transition in the construction sector.

CHAPTER 2: METHODOLOGY

1 Research aim

As the literature review of this master dissertation concludes, the implementation of Circular Economy principles offers a solution to the current CDW-problem. However, there are still many barriers to the Circular Transition of the construction sector. The literature review of this master dissertation indicates the implementation of BIM in combination with Design for Deconstruction, Material Passports and BAMB as a potential facilitator to this Circular transition. The aim of the research is to determine whether the theoretical approaches have practical viability. This is done by conducting a multiple case study with the relevant actors in the field. Before being able to analyse the potential of BIM as a circular facilitator, it is important to create insight in how and why both BIM and Circular Economy are (or are not yet) implemented from a practical point of view. Only then the potential of BIM together with DfD, Material Passports and BAMB can be analysed.

The research aim can therefore be defined as:
Determining the enablers and barriers of BIM and Circular Economy principles and analysing the potential of BIM as a facilitator to the circular transition.

Related to the aim of this research, the set of research questions were defined as:

- Why are companies (not yet) implementing BIM? (Enablers and Barriers)
- How is BIM being used?
- What are the main enablers and barriers to implementing Circular Economy principles?
- Can BIM facilitate the transition towards a Circular Economy?
    - Why?
    - How? (Design for Deconstruction, Material Passports and BAMB)

2 Research design and case selection

2.1 Research approach

Based on the findings of the literature review, the research aim with a set of proposed research questions was defined. To provide an answer to the proposed research questions, a multiple case study was executed. As the literature review mentions, the construction industry is a highly fragmented industry where many different actors are involved throughout the construction process. Therefore, this multiple case study exists of interviews with different actors involved in the construction industry. The actors are split up in three groups, being the Laggards, Early Adopters and Governmental Institutions. The first two groups consist of Architectural companies, Engineering companies and General Contractors. The companies are divided into Laggards and Early Adopters based on whether they have already implemented BIM and Circular Economy principles into their business process. In the findings of the literature review and the interviews of the first two groups, it was concluded that the Government has a significant role relative to the research aim. Therefore, it was decided to add Governmental Institutions as a third group to the case study, to create insight into the aims of the Flemish Government related to the circular transition of the construction sector. Based on the results of the multiple case studies, a discussion section looks into the link between the findings of the case study and these of the literature review, followed by the managerial implications, limitations of this research and the proposed further research needed.

2.2 Case selection

The selection of the appropriate companies is necessary to obtain the right amount of data to provide insight into the current situation of BIM implementation. As stated in chapter 1.1, the construction sector is a very fragmented sector, where all actors have a different impact on the CDW-generation and the implementation of BIM and Circular Economy principles. The selected companies for this research range from AEC-companies to Governmental institutions mainly active in the Belgian and Dutch construction industry. The first category consists of architectural companies. As architectural companies are responsible for the design of buildings, these companies have a huge influence on material choices. In most cases, architects have the closest connection to the client. The second group consist of Engineering companies, responsible for the structural analysis and determination of the structural systems of the building. The third category consists of main contractors and construction groups responsible for the construction of the building or infrastructure. Finally, a selection of governmental institutions were interviewed, as the literature study concludes that they have one of the largest impacts on CDW-management practices. Table 3 gives an overview of the different cases.

Table 3: List of cases

Architectural companies			
Case 1	A-Architects	A-Architects is a private company situated in Belgium. The company was founded in 2013 by an architect. A-Architects designs both new construction projects and renovation projects. (Company website)	
Case 2	B Architects & Engineers	B Architects & engineers is a designing an engineering firm that was founded in 1952, meaning it has over 65 years of experience and know-how. The company is active in healthcare design and building engineering. The company has about 400 experts divided over different engineering and architectural disciplines. (Company website)	
Engineering companies			
Case 2	B Architects & Engineers	B Architects & Engineers is a designing and engineering firm that was founded in 1952, meaning it has over 65 years of experience and know-how. The company is active in healthcare design and building engineering. The company has about 400 experts divided over different engineering and architectural disciplines. (Company website)	
Case 3	C-Engineers	C-Engineers is an engineering company founded in 1972, located in Izegem. The company performs stability studies, drafts implementation plans for both structure and techniques, and coordinates ongoing projects. Over the years they've gained experience in houses, apartments, industrial projects, offices and the food industry. (Company website)	

Building group/main contractor			
Case 4	D-Contractor	D-Contractor is a company located in the Netherlands, this building contractor was founded in 1902. The focus of the building contractor lies in building futureproof. They state: “We are going to build to break down much faster: disassembly and reassembly of buildings and reuse of materials.”. D-Contractor contains a subsidiary that focusses on the circular building concept, using its building passport. (Company websites)	
Case 5	E-Contractor	E-Contractor is a multidisciplinary company active in construction, real estate development and concessions. Most of E-Contractors activities are located in Europe, with the headquarters based in Brussels. E-Contractor is also active on an international level with activities in the Middle East, Oceania, Africa, North America and Asia. E-Contractor is a full-service enterprise with contracting as core business. This means that the E-Contractor group can handle every aspect of a project, from financing over designing and building to operating and maintaining, thus managing the full life cycle of an asset.	
Consultants/government			
Case 6	OVAM	OVAM is a Flemish public service that ensures that waste, materials and soil in Flanders are handled in an environmentally conscious way. OVAM gives direction to the policy on waste, materials and soil and thus influences the implementation of the legislation. (OVAM, n.d.)	SAMEN MAKEN WE MORGEN MOOIER OVAM

Case 6	'Vlaanderen Circulair'	'Vlaanderen Circulair' is a multidisciplinary team embedded in OVAM, as a result of the merger of Plan C, the Flemish Materials Programme and SuMMa. 'Vlaanderen Circulair' has been appointed by the Flemish Government to realize the Vision 2050, with the circular economy as transition priority. It is a partnership of governments, businesses, civil society and researchers, which connects and guides citizens, entrepreneurs, civil society organizations, local authorities, etc. who want to set up initiatives in the circular economy. (Vlaanderen Circulair, n.d.)	

3 Data gathering

To answer the research question, a certain amount of data needs to be gathered. This data was gathered from different sources, such as interviews, company websites and non-company websites. The main data is gathered by conducting semi-structured interviews, based on the theoretical conclusions made in the literature review. The course of the interview starts with the main questions about the enablers, barriers and findings concerning the implementation of BIM, continued by investigating the use of BIM as a facilitator to the circular transition. Here, additional questions were posed concerning Circular Economy, Design for Deconstruction, Material Passports and BAMB, depending on the course of the interview. The interviews were executed in Dutch since this was the mother tongue of the parties involved. The data collected from non-company websites consists of articles and interviews found online, relevant to the research question, concerning the companies and governmental institutions involved in the case studies. The data gathered from the interviews were processed using the NVivo software. Table 4 gives an overview of the data that was gathered during this research.

Table 4: Overview of gathered data

Case	Company	Type of company	Data	
			Participants	**Secondary data**
			Function	
1	A-Architects	Architect	Manager	Company website
2	B-Architects & Engineers	Architect and engineering company	Project engineer sustainable design BIM/CAD manager	Company website Non-company websites: 3
3	C-Engineers	Engineering company	Manager	Company website
4	D-Contractor	Building group	Engineer Sustainability BIM/Revit-designer	Company website Non-company websites: 2
5	E-Contractor	Building group	Head of BIM, Digital & sustainable solutions	Company website Non-company websites: 3
6	‘Vlaanderen Circulair’/OVAM	Government	Facilitator Circular Economy, ‘Vlaanderen Circulair’; Team-bouwen, OVAM	Company website

4 Data Analysis

For this master dissertation, an abductive analysis was applied. As previously mentioned, data was gathered by conducting interviews and adding complementary articles. Here, all interviews were recorded and typed out. First, a preliminary analysis was made by going over the data sentence per sentence and grouping information by colour-indication. Based on the preliminary analysis, NVivo was used to code the obtained data according to the predefined groups and the necessary adjustments were made when needed. An example of the groups as used in NVivo is presented in Figure 11. The first group codes statements that are related to Why and How BIM is used when already implemented and Why and How it could be used when asked to Laggards. Here, Why is split up in two subcategories, Enablers and Barriers, stating what drives companies to use BIM and what hinders companies to use BIM. The second group contains all the statements made in relation to Circular Economy. The first child group then describes Why companies do (Enablers) or do not (Barriers) implement Circular Economy principles on their construction projects. The second child group contains all the statements made in relation to the proposed approaches from the literature review, being BIM, DfD, Material Passports and BAMB. It is important to note that while the parent group BIM contains all statements solely related to the implementation of BIM, BIM as a child group of Circular Economy Approaches solely contains statements made discussing the potential use of BIM as a facilitator to the Circular Transition.

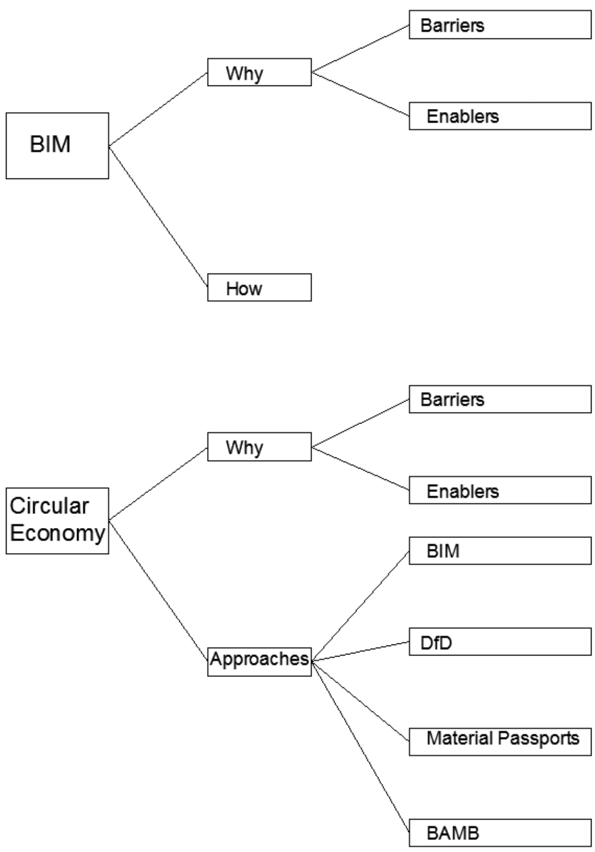


Figure 11: Nodes NVivo

CHAPTER 3: MULTIPLE CASE STUDY

1 Group 1: Laggards

The first group of the cases with polar types are the so-called Laggards. These are smaller companies which have not yet, or only to a certain extent, implemented BIM and the Circular Economy-principles in their business processes.

1.1 Selected companies

Case 1: A-Architects

A-Architects is an architectural company, mainly designing residential buildings. The architect of the company uses Google Sketch-up to make the designs and utilizes Autodesk AutoCAD to draw the building requests and the execution plans. Later, Microsoft Excel is used to generate different sheets to predict volumes and prices. The company has not adopted BIM to its working method and does not intend to use BIM in the future.

Case 3: C-Engineers

C-Engineers is an engineering company with an emphasis on large, complex projects. It is a multifunctional company that adopted a BIM-software package in September 2020. The company implemented this software-package since it was contractually required by the client. The BIM-model is needed to design the customers equipment and to check the possibilities to access the facility with the equipment. At the moment, this pilot project was launched to learn how to implement BIM into their working methods. In other cases, the stability of the project is calculated using FEM (Finite Element Method) software and calculated by hand. Later, the design of the projects will be drafted in AutoCAD and will be exported to PDF. Excel is used to generate the concrete and steel volume.

1.2 BIM

Since A-Architects hasn't yet implemented BIM into its working method, they are convinced that the deficits of BIM outweigh the benefits. The benefits for A-Architects lies in the fact that when a change is made to the design of a building, every detail automatically adjusts. This leading to less modification, leading to less loss of time and hence a **higher efficiency**. This auto-adjusting also leads to a lower chance of mistakes in the final model. The company indicates that clients and engineering companies would be an enabler to start using BIM. At the moment, **clients and engineering companies** do not yet oblige the use of BIM. As a lot of other architectural companies haven't implemented BIM either, the incentive to adopt the software is not yet in place. The last enabler, according to A-Architects, would be to participate in public tenders, since the use of BIM is often necessary due to the **complexity and size** of the projects. The company is used to drawing in AutoCAD and admits it has **insufficient knowledge** of the subject to start implementing it. Adopting this working method would take a lot of time and every employee and partner must be motivated to take part in this story. The **fragmentation** of the construction industry further complicates the adoption. Since BIM has a **steep learning curve** and there is insufficient demand in the residential housing market, A-Architects has decided not to start using BIM as long as it is not mandatory. This indicates the **conservatism** in the construction industry. They think that the **government** does not play an important role and that the implementation of BIM should start from the construction sector itself.

C-Engineers has adopted BIM since September 2020 due to a **contractual agreement** with a client. They tried to adopt the software in their working method about 10 years ago, but this turned out to be a bigger challenge than originally thought, indicating a steep learning curve. They eventually stopped the implementation until they started it again in September 2020. As the company is multifunctional, it is a major challenge to get the various parties enthusiastic about this change, indicating the problem with the **fragmentation**. These parties also need to take a lot of courses to learn how to work with this new software packages due to the current **lack of knowledge** on the subject. The company also highlights that this implementation will increase the project price. This **increase in project prices** will have to be paid by the customer. They also point out that small, residential clients can't use these complicated models. As the last barrier, the company points out that the **government** is not yet stimulating the use of this specific software. However, adoption leads to several advantages. These advantages could help fasten the adoption of BIM. Since there will be a 3D -model of the building or infrastructure, a lot of conflicts and mistakes can be prevented, using clash detection. In **large, complex projects**, it is almost a necessity to use BIM to keep track of everything in a more **efficient** way than using 2D CAD. The company states it will fasten the adoption if the customer is willing to pay extra and values the 3D model. Finally, C-Engineers also states that the government could accelerate the adoption of BIM throughout the construction sector by economic stimulation e.g. by allocating grants. The company aims to adopt full BIM in the future.

Table 5 and Table 6 give an overview of the enablers and barriers of the Laggards regarding BIM, with a green colour-indication when mentioned. The main enablers and barriers, as defined based on the preliminary analysis, are based on the grouping of several statements. A detailed overview of this project map for both Early Adopters as Laggards is added in Appendix 1.

Table 5: Main enablers BIM recognized by the Laggards

Main Enablers	A-Architects	C-Engineers
Follow new trends		
Higher efficiency	[green]	[green]
Customer request	[green]	[green]
Increasing project scale and complexity	[green]	[green]
Other	[green]	

Table 6: Main barriers BIM recognized by the Laggards

Main Barriers	A-Architects	C-Engineers
Fragmentation of the construction industry	[green]	[green]
Conservatism of the construction industry	[green]	
Lack of knowledge with a steep learning curve	[green]	[green]
Unclear financial case		[green]
Company and Project size	[green]	[green]
Government		[green]

1.3 Circular Economy

A-Architects has not yet adopted the circular principles into its key business. However, the architect already tries to focus on obtaining flexibility within the building, due to the demand of customers. He points out that certain customers like ancient castle-style materials, leading to the deconstruction of these castles. Note that this is due to aesthetic considerations rather than a circular point of view. The company states that the **customer** plays an important role in the implementation of Circular Economy into their business. A-Architects states that they will start implementing Circular Economy principles when the demand increases and **more specific information** regarding the subject is available. They state that the **government** has an important role in obliging these methods by adding penalties when the building doesn't meet a certain grade of circularity. However, according to A-Architects, this obligation will result in an **increase in building prices** and will complicate the feasibility. A-Architects states that the **conservatism** in construction is an important barrier of the Circular Economy-model. Since building are built to last several decades, the future value is difficult to predict. The architect points out that there is **not enough stimulation** to try to adopt the Circular Economy principles and that these methods itself are too vague. According to A-Architects, **the use of BIM could facilitate this transition**, clarifying the uses and locations of the different materials being used.
They say that they haven't yet thought of Design for Deconstruction. A-Architects also states never having heard of Material Passport and Building as Material Banks before the interview.

C-Engineers hasn't implemented the Circular economy model yet. C-Engineers mainly implements sustainable building by trying to minimize energy consumption, e.g. by installing heat exchangers to recover residual heat that would otherwise be lost. The company thinks that it would stimulate the circular transition by including Circular Economy measures in the calculation of the EPB by EPB-software. C-Engineers states that the **government** has a very important role in the stimulation of circular economy in construction. According to C-Engineers, there currently is a lack of a specific framework to help companies adopt circularity. Just like A-Architects, C-Engineers states that the conservatism and the long lifecycle of buildings hinders circular construction. They point out that their **customers are not yet aware** of the footprint of materials and that they are not yet willing to **pay extra**. The last barrier is the **fragmentation** in construction leading to slow adoption of new technologies as every stakeholder needs to keep up. Like A-Architects, C-Engineers states that BIM could facilitate this transition. The company states to be fond of using concrete due to its fire resistance and recycling possibilities. C-Engineers admits to not yet applying Design for Deconstruction. Although the company has heard of both Material Passports and Buildings as Material Banks, it does not yet apply these circular methods.

Table 7 and Table 8 give an overview of the enablers and barriers of the Laggards regarding the Circular Economy, with a green colour-indication when mentioned. The main enablers and barriers, as defined based on the preliminary analysis, are based on the grouping of several statements. A detailed overview of this project map for both Early Adopters as Laggards is added in Appendix 2.

Table 7: Main enablers CE recognized by the Laggards

Main Enablers	A-Architects	C-Engineers
Mission and vision		
Customer request		
Business opportunity		
Size company and projects		
Government		

Table 8: Main barriers CE recognized by the Laggards

Main Barriers	A-Architects	C-Engineers
Lack of knowledge and information		
Fragmentation		
Cost		
Lack of governmental stimulants		
Lack of information off existing patrimonial		
Lack of customer request and awareness		

2 Group 2: Early adopters

The second group of companies which are discussed are the early adopters. These companies are chosen because of their early adoption of both BIM and Circular Economy principles.

2.1 Selected companies

Case 2: B-Architects & Engineers

B-Architects & Engineers offer a broad range of services within the designing process. Those services include building engineering (master planning, programming, structural studies, special techniques, infrastructure and environmental construction) but also highly specialised expertise as fire safety engineering, acoustical engineering, sustainable design and facade engineering. As a part of sustainable design, B-Architects & Engineers offers support-services to companies to integrate circular thinking into the entire building process. B-Architects & Engineers use BIM for 100% of their architectural and structural designing, and 75% for MEP (Mechanical, Electrical and Plumbing systems). Although B-Architects & Engineers use BIM for nearly every project, the level of BIM depends on the customer request.

Case 4: D-Contractor

D-Contractor was selected as Early Adopter as it tries to be a forerunner to implement the circular economy in their construction projects with their Material Passport circular initiative. With this initiative, D-Contractor tries to make the transition by Circular Building and Circular Area Development through intensive cooperation with banks, tax authorities, governments and the practical experience of their partners in construction. As mentioned on the company site, D-Contractor has already started with the use of BIM.

Case 5: E-Contractor

As previously mentioned, E-Contractor is a multidisciplinary company active in construction, real estate development and concessions. As E-Contractor is the first Belgian construction company to obtain a level 2 BIM-certificate, based on the criteria of the PAS 1192-2 standard (design and construction), E-Contractor is a forerunner in the BIM market. As mentioned in the literature review of this master dissertation, level 2 is the highest maturity level possible today. E-Contractor is one of the companies which have signed the Green Deal for circular construction. Hereby, E-Contractor committed to working together with the other participants to pool experience and help the research to enable the circular transition of the construction sector in practice.

2.2 BIM

As mentioned in the literature review, the implementation of BIM in the business processes of construction companies is rising. To exploit the full potential of BIM as a facilitator to the circular transition, it is key that companies can overcome current barriers impeding the implementation of BIM. Therefore, it is important to understand what current enablers and barriers to the implementation of BIM are. In this chapter, the Early Adapters were asked How and Why they use BIM.

2.2.1 Use of BIM

Case 2: B-Architects & Engineers

As previously mentioned, B-Architects & Engineers uses BIM on all their projects with a variating level of maturity depending on the project and the customer request. When not asked by the customer or partners, B-Architects & Engineers uses Closed BIM internally. In Closed BIM the same software is used for the different applications of BIM. Here, the different trades conducted by B-Architects & Engineers use BIM compatible applications from the same vendor, in this case Autodesk. When B-Architects & Engineers are fully involved from A to Z on a project, B-Architects will use Revit Architecture to model architectural elements, B-Engineering will use Revit Structure to further develop the architectural BIM model on a structural base, followed by the MEP designer of B-Architects & Engineers who will use Revit MEP to model the building services.

B-Architects & Engineers has the advantage that Architecture, Structural Engineering and MEP fall under the same roof, and the use of Closed BIM can be guaranteed. This offers advantages as no file conversion is required in the Closed BIM method and approach, and interoperability problems are thereby eliminated. However, Closed BIM also restricts to the applications offered by the specific vendor, in this case Autodesk. This means that for the other specific expertise offered by B-Architects & Engineers, often a specific software is required that is not offered by Autodesk. Although the existing BIM-model can be used as a basis for the needed data, geometry and quantities, rebuilding the model is often required as current software does not allow for, or cannot import or read current BIM-models.

On the other hand, when a BIM model is requested by the customer or partner, which often will use different software, Closed BIM is not applicable. Here collaboration and the exchange of project information is realized by using IFC and COBie. Although it was mentioned in the interview that collaboration using IFC is not yet ideal.

Case 4: D-Contractor

D-Contractor stated that they mainly use BIM as 3D-visualisation and start-up for productions. When requested by the customer, D-Contractor uses the BIM-model as input to create Material Passports using Madaster. Madaster is explained in the section covering the use of BIM to create Material Passports.

D-Contractor also confirms that BIM is mainly used during the design and engineering phase, and the construction phase stating that after the delivery of the project, not much is done with the model.

Case 5: E-Contractor
As the Head of BIM, Digital & sustainable solutions of E-Contractor mentions in the interview, the last numbers show the use of BIM on 25% of the projects, which will now be even higher. E-Contractor aims to achieve 100%, except for small and simple projects. For E-Contractor, the main goal of the use of BIM lies in the management of information rather than the 3D model. Momentarily they are adjusting their infrastructure to implement the BIM-process into their business model. Therefore, E-Contractor has invested in a partner which has a platform for storing, managing and sharing data, using BIM-models.
Although E-Contractor mainly uses BIM during the designing and construction phase, it has recently started up a new service department specialized in operation management. In current practice, E-Contractor works together with clients to determine the needs for operation management and delivers a BIM-model which is filtered according to their needs. COBie is the most used standard for this filtering. The goal of the new operation management service is to go a step further and offer a platform for operation management to the client.

2.2.2 Acknowledged Enablers and Barriers

During the interviews, the companies were asked their findings on what the enablers and barriers are to the implementation of BIM. It can be concluded that although the companies have a completely different business model, a pattern is noticed in the answers given. In Table 9 and Table 10, the main enablers and barriers indicated by the Early Adopters are listed with a green colour-indication when mentioned. These main enablers and barriers, as defined based on the preliminary analysis, are based on the grouping of several statements. A detailed overview of this project map for both Early Adopters as Laggards is added in Appendix 1.

Enablers

The first internal enabler is the ambition of the company to follow or be a forerunner in **new emerging trends**. In all three cases, the companies indicated that following trends is necessary to avoid being left behind in the future. E-Contractor states that parties who are not yet using BIM are lagging behind and are less able to collaborate. According to E-Contractor, this would not only result in a competitive disadvantage for those companies, but their possibility to have an impact on the project would also be less significant. In addition, many of those companies do not comprehend the BIM-processes and need extra processes other than the existing ones, to make the collaboration possible.
The second internal enabler is the recognition of the advantages BIM offers to the **efficiency** of the company. All three companies initiated by experimenting with the new digital technologies on pilot projects. For E-Contractor, the start of BIM originates from the use of BIM for the construction of the a

project in Cairo. This was the first project where E-Contractor used BIM internally, where previous projects with BIM were realized by working together with an external BIM-responsible partner. Based on the experiences of this project E-Contractor concluded that BIM had significant advantages to increase efficiency and avoiding problems, launching the implementation of BIM in their business process.
A similar story was stated by B-Architects & Engineers. Through a pilot project where a 3D model was requested by the customer, they saw the potential advantages that the step to BIM could bring compared to the traditional 2D fumbling. The main advantage originating in this step was the possibility to auto-update all the plans through adaptation of the model. As also concluded in the literature, adjusting the plans was and still is a problem in the traditional 2D collaboration. As B-Architects & Engineers states: "After the first change, the possibility that your plans will still coincide correctly after two weeks is very small". In the case of B-Architects & Engineers, the employees responsible for experimenting and learning BIM became advocates for the implementation of BIM, encouraging the direction to reform their infrastructure and implement BIM in B's business process. B-Architects & Engineers group recognized that because of the collaboration of their architecture, structural engineering and MEP-department in the same model, many mistakes could be avoided by eliminating rework.

As stated in the literature, the scale and complexity of construction projects are increasing. As BIM offers the most benefits for large and complex projects, this is an important enabler to the BIM-market. E-Contractor states that although BIM was contractually mandated for the project in Cairo, it would have been impossible without BIM because of the complexity of the project. Respectively, the third and fourth enablers are therefore the **customer request** as well as the **increasing scale and complexity** of construction projects. This is also recognized by D-Contractor and B-Architects & Engineers, with B-Architects & Engineers stating that the request of BIM by the client is rising.

Apart from these main enablers, D-Contractor also recognizes the **government** as an indirect enabler. In the Netherlands, the government stimulates the circular transition by giving grants to projects where a Material Passport is delivered. D-Contractor states that currently, the best way to produce Material Passports that meet the requirements for this grant is by using Madaster. Currently, Madaster is the biggest initiative to produce Material Passports in the Netherlands and requires an IFC-file as input. Madaster will be further discussed in the section covering Material Passports of this Chapter. Besides D-Contractor, E-Contractor and B-Architects & Engineers both recognized that although the government could be an enabler, this is not yet the case in Belgium. B-Architects & Engineers, therefore, references to the UK, where BIM is mandatory for certain projects and a task force was created to develop the rules and methods covering the use of BIM.

The enablers are listed in Table 9, presenting a coloured overview of whether the company mentioned the enabler during the interview.

Table 9: Main enablers BIM recognized by the Early Adopters

Main Enablers	E-Contractor	D-Contractor	B-Architects & Engineers
Follow new trends			
Higher efficiency			
Customer request			
Increasing project scale and complexity			
Government			

Barriers

In the interviews, a lot of barriers to the implementation were listed. As this group of Early Adapters already uses BIM to a certain extent, these barriers are not only barriers that they faced, but also the barriers other companies could face to hinder the use of BIM. Here, the barriers mentioned in the literature resurface together with some additional barriers.

One of the main barriers concluded in the literature study was the **fragmentation of the construction industry**. Apart from E-Contractor, stating that the fragmented nature of the industry is a difficulty for BIM as well as for the circular transition, many statements were made throughout all three interviews, indicating the fragmentation as an important hindrance or difficulty. One of the problems with the fragmentation and thus the need to work together with a lot of different stakeholders is the lack of trust. When collaborating using BIM, not only the interoperability is a problem, but also the transparency required. As E-Contractor states, this need for transparency between the different partners often lies out of the comfort zone of companies. This statement also indicates the conservatism of the construction sector, which will be discussed as a second barrier further on. Here, it can also be concluded that construction groups like E-Contractor and B-Architects & Engineers, containing multiple trades under one roof, have an advantage on other smaller companies, which will have a greater need to outsource trades. Also, it is mentioned that IFC is not yet on point, creating difficulties when collaborating using software of different providers.

Another problem with the fragmentation of the construction is the lack of BIM knowledge of suppliers and sub-contractors. As D-Contractor states, a lot of suppliers and sub-contractors do not use BIM, as it does not offer that many advantages to their particular trade. Therefore, contractors cannot be selective based on the use of BIM by suppliers and sub-contractors.

The last problem with this fragmented character of the construction industry are the changing responsibilities during the project life-cycle. When one company does not use BIM, the chain will be broken and information, time and effort will be lost during the process.

The second barrier is the **conservative character of the actors active in the construction industry**. B-Architects & Engineers states that change management is a big difficulty because a mental change needs to be made. All three companies indicate that the construction sector is a conservative sector, with E-Contractor stating "people want to do their work the way they always did" and D-Contractor stating that the mindset of people is often "as it always worked, as it always will". According to E-Contractor, it requires a good and clear atmosphere to convince people otherwise. People will be hard to convince because of the fear for the unknown, the fear to create problems and the fear to make mistakes. As E-Contractor states, problems will occur in the beginning, but it is important to create an atmosphere where it is acknowledged that those problems are coherent to the learning process, and not the result of someone's mistakes.

The third barrier is the **lack of knowledge** and misconceptions about BIM and the **steep learning curve**. According to E-Contractor the main barrier, subsequent to the conservatism of the sector, lies with people and their need for coaching and training. As mentioned in the literature study, implementing BIM should be a gradual process. In the case of B, the implementation of BIM took 1 to 2 years for the Architecture department and 3 to 5 years for the Engineering department. B-Architects & Engineers indicates that BIM has a steep learning curve, requiring a lot of time and effort before reaping the benefits. In addition, D-Contractor mentions the steep learning curve, saying that the main barrier to the implementation of BIM is the unknown and chance of flaws in the software of the BIM-applications.

Another barrier is related to the **return on investment (ROI)** of BIM. B-Architects & Engineers states that the cost of software, training of employees, acquiring libraries, etc. can be an important barrier for companies. As D-Contractor adds to this barrier, companies cannot charge a higher price to the client for the use of BIM, as a result of which the return on investment (ROI) can be unclear to certain companies. This leading to a slower uptake of BIM.

This is especially the case for smaller companies. As D-Contractor acknowledges, larger companies will have more resources and knowledge to overcome financial barriers. This leads to the fifth barrier, being the **company and project size**.

All companies indicate that the **Government** can have a significant influence through legislation, financial incentives and other supporting services. Throughout the interviews, the companies indicated that the further development of uniform frameworks and legislation supporting the BIM-processes, responsibilities and contractual forms is necessary. Nevertheless, E-Contractor indicates that this is not an easy-to-develop uniform process as all companies have different approaches and methods, and all have to agree on these processes.

The barriers are listed in Table 10, presenting a coloured overview of whether the company mentioned the barrier during the interview.

Table 10: Main barriers BIM recognized by the Early Adopters

Main Barriers	E-Contractor	D-Contractor	B-Architects & Engineers
Fragmentation of the construction industry			
Conservatism of the construction industry			
lack of knowledge with a steep learning curve			
Unclear financial case			
Company and Project size			
Government			

2.3 Circular Economy

2.3.1 Enablers and Barriers

In the literature study, the different enablers and barriers to the Circular transition by Adams et al. (2016) were discussed. As a confirmation to the literature study, the enablers and barriers mentioned by the participating companies are listed in this section. In Table 11 and Table 12, the main enablers and barriers indicated by the Early Adopters are listed with a green colour-indication when mentioned. These main enablers and barriers, as defined based on the preliminary analysis, are based on the grouping of several statements. A detailed overview of this project map for both Early Adopters as Laggards is added in Appendix 2.

Enablers

Based on the interviews, it can be concluded that the main enabler behind the implementation of Circular Economy principles in the company's business processes is their **mission and vision**. Although this is the main enabler, the client is still the one paying for any additional costs. As seen in Table 11 and Table 12, this can be either an advantage or a disadvantage. When the client is engaged by sustainability and incorporates sustainability in the criteria, this can drive construction companies to go the extra mile. However, when the client is unwilling to pay extra for sustainability and is purely cost-oriented, the construction companies can only do as much as the budget allows, as they have to preserve a profit-margin.

Another enabler linked to the mission and vision of the company is that companies see a **business opportunity**. As E-Contractor states, this can not only be a business opportunity to increase the image of the company but can also benefit the company in the future because of the increasing scarcity and prices of raw materials.

Finally, the **size of the company and the projects** was also mentioned to be a possible enabler as well as a barrier. Large companies will have an advantage as they have more resources and knowledge, but also because they mostly focus on larger projects. Because larger projects come together with a larger budget, implementing sustainability and Circular Economy principles will require a relatively lower percentage of the total budget. Furthermore, these projects are mostly commissioned by companies (B2B) or governmental institutions instead of private individuals (B2C). These companies and governmental institutions have more knowledge about Circular Economy and are more likely to implement sustainability in the project criteria. According to E-Contractor, the companies that implement Circular Economy principles are larger companies because of the larger budget, but also smaller companies with great motivation. It is important to mention that although these smaller companies have a lower budget, they usually have greater flexibility for changes in infrastructure than large companies.

The enablers are listed in Table 11, presenting a coloured overview of whether the company mentioned the enablers during the interview.

Table 11: Main enablers CE recognized by the Early Adopters

Main enablers	E-Contractor	D-Contractor	B-Architects & Engineers
Mission and vision			
Customer request			
Business opportunity			
Size company and projects			
Government			

Barriers

The main barrier recognized in the interviews is the **lack of knowledge and available information**. As E-Contractor states it is still a groping in the dark. All companies recognize that there is a need for standardization and availability of information concerning the way of implementing Circular Economy principles in practice. As D-Contractor states, the currently available information is still very theoretical and hard to convert in practice. As E-Contractor says, Circular Economy is still a relatively new concept, certainly in the construction sector, and governmental institutions are still developing manuals, regulations and other information forms to support this transition.

The second barrier is the recurring **fragmentation** of the construction sector, where the barriers coincide with those of BIM.

As mentioned in the previous discussion concerning the enablers, the **cost** is a very important barrier. In addition to the client's willingness to pay for additional costs, the companies also mention that the current valuation of projects needs adjustments. Currently, only the short-term costs attributable to the construction of the project are taken into account. However, the residual value of buildings at end-of-use is still neglected, and buildings are fully depreciated. In a circular economy, however, materials and components that can be recovered still retain part of their value and should be taken into account in the calculation. This is not only the case in the valuation towards the client but also is neglected in the calculations done by banks, which neglect the residual value when financing the building.

The fourth barrier is the current **lack of governmental stimulation**. Currently, the market is still in search of the right methods and frameworks. Although governmental stimulation is rising, there is still a great need for previously mentioned information and possible circular certifications. B-Architects &

Engineers suggests that instead of making a budget available for grants, a tax reduction for circular projects could be a possible solution. However, as E-Contractor has stated, it is still hard to define a benchmark for circular building.

Other barriers already mentioned in the previous chapters are the **lack of information on existing buildings** and the **lack of customer request and awareness**.

The barriers are listed in Table 12, presenting a coloured overview of whether the company mentioned the barrier during the interview.

Table 12: Barriers CE recognized by the Early Adopters

Main barriers	E-Contractor	D-Contractor	B-Architects & Engineers
Lack of knowledge and information			
Fragmentation			
Cost			
Lack of governmental stimulants			
Lack of information on patrimonial			
Lack of customer request and awareness			

2.3.2 BIM as a solution to circular economy barriers

As concluded in the previous section, the research confirms that the **fragmentation** is an important barrier to the transition. The literature review states that BIM offers a solution to this problem by enhancing collaboration. As can be concluded from the section covering the enablers and barriers of BIM, the companies recognize that BIM has the potential to enhance collaboration, but still has some deficits. As B-Architects & Engineers states the collaboration is facilitated when using Closed BIM, but collaboration with different stakeholders, using different software providers through IFC is still very difficult. Further development of BIM is needed to make the step to Open BIM. In addition, collaborating with BIM asks for transparency and trust between the partners, what lies out of the comfort zone of many companies and is a barrier to BIM-collaboration.

Secondly, in the literature study, it was concluded that BIM could offer a solution to the **low consideration of the building or infrastructure's whole life-cycle**. Based on this research, it was confirmed that using BIM throughout the whole life-cycle could have significant benefits to eliminate losses of information and communication mistakes. Furthermore, the companies stated that the use of BIM could be very useful during the operation phase and at the end-of-use. However, currently, BIM is still mainly used solely during Design and Construction. Only in a few cases, the BIM-model was filtered to be useful for Facility Management. The use of BIM for demolition and deconstruction purposes is seldom used, although it could have many advantages, discussed in the next section.

2.3.3 Design for Deconstruction and BIM

The Design for Deconstruction principle listed in the literature review is an important step towards Circular Construction practices. In the interviews, the companies were asked their view on the usefulness of BIM to implement DfD principles.

Here, it is important to mention that unlike B- Architects & Engineers, which always participates from the design phase on, E-Contractor and D-Contractor are contractors. As D-Contractor mentioned, the impact of a contractor during the design phase depends to a large extent on the applied contract-form. In traditional contract-forms, the architect works out a design according to the requirements of the client. It is only when the designing process is completed, a contractor is selected by a tender procedure. Contractors will then make up their bid based on the detailed specifications and list of requirements of the tender. Currently, tenders are still often granted purely based on the price. As D-Contractor states, the late involvement in this process hinders the contractor to have an impact on the design. However, because traditional contract forms often resulted in problems between the different parties, new integrated contract forms are emerging, e.g. Design & Build (D&B). In those integrated contract forms the different parties, mainly being the architect, contractor and engineering firm, all work together from the beginning of the project. Because of the early involvement, all stakeholders can have an impact through all of the project phases, including the design phase.

Besides sustainable designing, B-Architects & Engineers also offers advice and expertise for Circular Designing. An expert in Circular Designing from B-Architects & Engineers, states that BIM has an interesting interface with Circular Design, amongst others because the demand is rising. Currently, B-Architects & Engineers realize its ambitions for Circular Design by focusing on 2 principles mentioned earlier in the chapter on DfD in the literature review. These principles are flexible or adaptable designing, to enable repurposing the building to various functionalities, in combination with dismantlable designing. Nevertheless, the expert states that the application of Design for Deconstruction is still in an early stage and the advice is often insufficiently followed.

Another way of implementing Design for Deconstruction is by assembling a Demolition-Inventory, Deconstruction-manual and Demolition-plan. Although these are very useful documents, D-Contractor points out that if the client doesn't have ambitions to use these documents, these documents will get lost over time. E-Contractor on the other hand, says that when a BIM-model is available, the model can be used as an information management centre to these documents.

All three parties agreed on the potential of BIM for Design for Deconstruction, as the BIM-models are a digital twin of the existing building. Currently, existing buildings are difficult to deconstruct because of the lack of information about the structure and its properties. The expert of B-Architects & Engineers states that as-built BIM models would be very useful to get an insight into the composition of existing buildings, as this is important to examine the possibilities for (selective) Deconstruction instead of Demolition.

Finally, it can be concluded from the interviews, that although BIM is not a necessity to implement Design for Deconstruction, all the companies recognize the potential of BIM to make this an easier process.

2.3.4 Material Passports and BIM

As discussed in the literature review, the companies recognize the collection of data to define and describe material characteristics as necessary to determine the value for recovery and reuse. Although this group of Early Adopters are forerunners in the field of Circular Economy in the construction sector, the use of Material Passports is limited but recently gaining popularity.

One of the main reasons for the limited application is the **unclear definition of material passports**. All three companies stated that to be able to boost the use of Material Passports, there has to be a **clear and uniform legislation or framework**. As E-Contractor states, a specific definition is needed to determine what information should be included in those Material Passports. According to B-Architects & Engineers, another barrier is the **long lifetime of the project**. The first problem of this long life is the need to store

data in a way that it is accessible at the end of the lifetime. B-Architects & Engineers suggests that the best way would be by storing Material Passports in a central database. When data is stored, not only the way of storage should be able to withstand time, but also the data itself. For example, information about the method of recycling certain materials can be included, but recycling technology is changing rapidly, making such information irrelevant over time.
Another factor impeding the use of Material Passports lies with the earlier mentioned **fragmentation** of the construction industry. As stated by B-Architects & Engineers: "To be able to produce Material Passports, there is a need for information about the supply chain containing data about the origin of materials in terms of material ingredients and dismantling methods".

One of the questions posed relating to the research question is whether Material Passports should exist separately from, linked to or incorporated in BIM. Here, all three companies stated that although Material Passports can be seen separately from BIM, the link to BIM or incorporation of Material Passports in BIM would have significant advantages. According to E-Contractor, the BIM processes are necessary for the production of Material Passports rather than the 3D visualisation in BIM. As E-Contractor and B-Architects & Engineers mentioned that, as the use of BIM is currently rising fast, it would be very useful to develop a uniform framework that provides a way to connect the data concerning Material Passports to the BIM-model. One proposed way is by developing a database where manufacturers can upload data, and clients can extract it to the BIM-model and Material Passports.

Another possibility is the use of the previously mentioned **Madaster-platform**. Madaster is the brand name of the Madaster Foundation. This foundation aims to preserve material value in all economic cycles by registering the material in an online database. The platform uses the IFC-file that can be exported from the BIM model to generate material passports. The platform itself doesn't calculate volumes, but it uses the geometrical information stored in the IFC-file. The materials are then divided into 6 different categories: stone, glass, wood, plastic, organic and metal. Additional information like total volume and weight of the different materials is added. There is a possibility to further specify the different materials into subcategories. Next, the software addresses the different materials to is location/use in the building, being construction, interior, technical installations etc. The circularity indicator was developed to indicate the level of circularity. This indicator is based on the materials, the lifecycle and the level of recycling at the end of life. However, this indicator is still in its development phase. The software can be used by project developer by submitting the 3D models of their portfolio, a material passport can be generated of every project in their portfolio. (Madaster foundation, 2017).

2.3.5 BAMB and BIM

To enable the circular transition, the literature suggests that the construction sector should take the step to Building as Material Banks (BAMB). In the interviews, questions were posed in order to determine the extent to which BAMB is already used, is possible in the future and what the current problems are.
Although E-Contractor indicated that for them BAMB is not yet of order, but will come soon, D-Contractor and B-Architects & Engineers stated that BAMB is already possible to a certain extent. In this segment, the statements of D-Contractor respectively B-Architects & Engineers will be discussed separately.

D-Contractor predicts that BAMB or Urban Mining will become mandatory in the future. Therefore, D-Contractor is currently adopting its internal infrastructure to be able to make the step to BAMB. D-Contractor points out that in the Netherlands, one of the biggest initiatives is Excess Materials Exchange (EME). EME is a digital matching platform for materials and waste products. EME develops a resource passport for the product containing information regarding the source, toxicity and detachability. They add a track and trace code using RFID or a QR-code to be able to track the materials. Later, they try to match the materials to the potential buyer, lowering the waste generation.

When B-Architects & Engineers are involved in a project, the aim is to realize a carbon-neutral/climate-neutral building. The expert states that the story of BAMB fits right in this goal and says that B-Architects & Engineers is currently working on it.

From the different interviews, the main barriers according to D-Contractor and B-Architects & Engineers are:

- The need to find an urban miner who wants to extract the material out of the building and sees potential sales of it on the second-hand market;
- Encouraging the architect to use second-hand products;
- Higher cost of second-hand materials compared to new materials;
- Matching demand and supply. A recycler will only retract the material if it is worth it, not only in terms of the state and properties of the material but also the quantity. Often the recycler needs a larger amount then can be extracted from one project.
- Change of regulations and requirement concerning materials or components over time*

*Because regulation is getting stricter, some recoverable materials or component will no longer meet these requirements. For example, when a door can be recovered, but the regulations concerning fire-resistance are increased, the door will not be able to meet those fire-safety regulations, and re-use without further action will be impeded. In addition, when materials or components need to be upgraded to meet stricter requirements, the cost will increase, making recuperation less economically viable.

D-Contractor says that BIM can be an important opportunity to obtain a database of construction products in the country. If BIM models can be stored in an e.g. municipal database, the switch to a circular economy can be made. For example, when a project design is made for a project with construction beginning 2 years later, the municipal database could create an insight to which materials will be available in that municipality within 2 years. In addition, the availability of the BIM models gives a good insight into what is inside the buildings being demolished/deconstructed.

3 Government Institutions

Different stakeholders were investigated during this master dissertation. These different parties clarified that they strongly believe the government has an important role in the stimulation of both BIM and Circular economy. For this reason, an interview was executed with 'Vlaanderen Circulair' and OVAM.

3.1 'Vlaanderen Circulair'

OVAM (Openbare Vlaamse Afvalstoffenmaatschappij) is a Flemish agency in charge of waste processing and is responsible for the entire waste policy. Their mission states: "*OVAM is a Flemish government department that ensures the handling of waste, materials and soil in a well-considered and environmentally conscious way. We give direction to the policy on waste, materials and soil and thus influencing the implementation of the legislation.".* 'Vlaanderen Circulair' is an operational part within OVAM that focusses on the circular economy in construction. OVAM was founded in 1981 and has evolved over the year, they opened landfill sites, incinerators and so on. Over the years, they realized the need for selective collecting waste. Later on, they initiated the soil decree and in 2011, the material decree was launched. In 2017, the group 'Vlaanderen Circulair' was founded to perform research and develop standards regarding the circular economy in the construction sector. Today, 'Vlaanderen Circulair' tries to motivate/stimulate companies to rethink their material usage chain by decreasing the amount of waste generated. 'Vlaanderen Circulair' wants to be among the first to reduce the material footprint and consumption. They aim to have established a significant reduction by 2030. They try to achieve this goal by motivating and stimulating all stakeholders from top to bottom. This is necessary in order to initiate a major circular transition in the entire construction sector. 'Vlaanderen Circulair' tries to stimulate the awareness of this transition by organizing their Open Calls, workshops and network events. These Open Calls are a way to analyze the current barriers for construction companies to make the circular transition. These barriers do not have to be specific to one theme. 'Vlaanderen Circulair' is supported by a team of researchers, these researchers investigate different aspects of the transition. They investigate what is necessary in terms of the needs of government regulations and means to stimulate the transition.

'Vlaanderen Circulair' has adopted methods from the Europe Commission and these methods fit within the framework of the European Green Deal. The European Green Deal is a set of agreements, written by the European Commission, of which its main goal is to achieve climate neutrality in Europe by 2050. This deal is a response to the various challenges, caused by environmental change, such as ocean and forest pollution, extinction of numerous species etc. The European Commission states: "*It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use."* In order to achieve this climate neutrality, the European Commission has come up with a roadmap, containing key actions and an indicative timetable. The policy areas of the European green deal are:

- Clean Energy
- Sustainable Industry
- Building and Renovation
- Farm to Fork
- Eliminating pollution
- Sustainable mobility
- Biodiversity

'Vlaanderen Circulair' addresses various problems by creating work agendas. These work agendas are concrete matters that need attention, circular construction is one of 6 agendas. In order to translate these agendas into practice, leverages are set up. These leverages make sure that the process is accelerated and thresholds are overcome. Examples of these leverages are financing, communicating, research etc. It can be noted that these actions are quite vague, while the industry requests some concrete measures. This is because the current system doesn't provide answers to the various challenges to make the circular transition. 'Vlaanderen Circulair' foresees to raise awareness by July 2021 through ministerial announcements and campaigns. By then, they want to have a practical interpretation of the work agendas and they want to have finished the roadmap Circular economy 2030. (Departement Omgeving, sd) (European Commission, 2019)

'Vlaanderen Circulair', OVAM, Vlaamse Confederatie Bouw and the minister of environment, nature and agriculture initiated the "Green Deal Circulair Bouwen" on 22 February 2019 at Batibouw. The event is a networking tool created to raise awareness regarding Circular construction. At the moment, the group had about 330 participants ranging from architects to building contractors. The participants are mainly Early Adopters, wanting to take the lead. The purpose is to connect people with the same sustainable mindset in order to come up with new ideas. They meet 4 times a year on action days and inspiration days. These days consist of interplanar sessions in the morning and workshops in the afternoon. In these workshops, solutions are explored for specific cases and issues. (OVAM, n.d.)

3.2 TOTEM

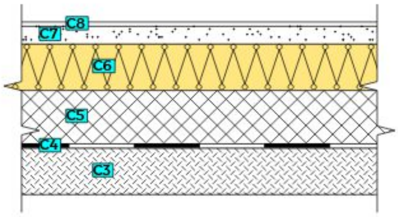
TOTEM is the abbreviation of Tool to Optimise the Total Environmental Impact of Materials. This tool is developed to help architects chose materials with a low environmental impact. It is an online, server-based program that is free. The tool is usable for about 2 years now and has already over 3400 registered users. TOTEM is developed in collaboration with the 3 regions in Belgium, meaning it could be used in all the parts of Belgium. The tool is also in line with the European framework, it is based on the standards EN15804 and EN15978. Transparency is extremely important in this tool as it has been released by the government. The tool helps to analyze the environmental impact of a building.

One way to calculate the environmental impact of a building is to perform a life cycle assessment on the building. A life cycle assessment is a methodology to calculate the impact of a product on the environment, considering all stages of the product. Life cycle assessment is also known as life cycle analysis, eco-balance and cradle-to-grave analysis. A life cycle assessment consists of 4 different stages, being: goal and scope definition, inventory analysis, impact assessment and finally the interpretation. (Krishna & Manickam, 2017)

TOTEM is based on the LCA method and utilises these results to calculate the environmental impact of the materials. In addition to LCA of the materials, TOTEM also uses heat losses to include the energy impact of the building. When the results of TOTEM are taken into account, a second model of the building can be developed trying to achieve a lower environmental impact with little effort. The programs itself is not 3D-based so lines must be added containing materials and their properties. TOTEM contains a list of pre-defined materials and structures containing data regarding the insulation and material impact. All components are derived from 2 sources, the EcoInventDatabank and the EPD's. The data from the EcoInventDatabank is generic data derived from the European averages and adapted to the Belgian context. The EPD's (Environmental Product Declaration) are specific environmental report regarding the impact of the product or group written by the producer.

Figure 12 gives an example of a pre-defined element in TOTEM, containing info regarding the thickness and lambda value (the amount of resistance to heat/cold). This example is a floor on grade. Note that the final column indicates the lifespan of a component, being 60 years for buildings, this is aligned with the European standard. At the top, the environmental cost is shown, this value is expressed in €/functional unit (being m² in this case). Note that this cost is an environmental impact expressed in Euro and not an actual cost. At the moment, there is a possibility to indicate that the material used is a new, a reused or an existing component of the building. This influences the total environmental cost of the project

Environmental cost:	37.56 €/FU
Materials:	32.61 €/FU
Energy:	4.95 €/FU
Category:	Floor on grade
Reference:	(13)+
Lifetime element:	≥ 60 years
Functional Unit (FU):	Surface area (m²)
U-value:	0.2 W/m²K
Origin of element:	Predefined element
ID:	ETI



Component(s)				
INT C8	Cladding | Rigid tiles | Glazed ceramic (300x300x10 mm) | Glued New	0.01 m	λ 0.81 W/mK	≥ 60 years
C7	Screed | Thick coating | Reinforced cement (50 mm) New	0.05 m	λ 0.85 W/mK	≥ 60 years
C6	Thermal insulation | Foam | PUR | Upon floor slab New	0.13 m	λ 0.028 W/mK	≥ 60 years
C5	Slab | Cast in situ | Reinforced concrete (150 mm) New	0.15 m	λ 2.3 W/mK	≥ 60 years
C4	Water barrier | Proofing sheet | PE (0.2 mm) | Loose laid with overlap New	0.0002 m		≥ 60 years
C3	Leveling layer | Loose filling | Compacted sand New	0.13 m		≥ 60 years
C2	Leveling (per m³) New			≥ 60 years
EXT C1	Excavation New	0.3 m		≥ 60 years
Total		0.4702 m	U 0.2 W/m²K	

Figure 12: Example of pre-defined structure in TOTEM (14/12/2020)

In total, 17 indicators are taken into account while calculating the environmental cost of a specific element. The 17 indicators are expressed in their unit, this created the problem of comparability. A few examples of these indicators are climate change, ozone layer depletion, acidification, ionising radiation, water deficit etc. However, the different indicators can be combined by multiplying a cost with the unit of each indicator. This results in an environmental cost expressed in €.

At the moment, there is a possibility to import IFC, CSV and xls files. This results in a connection to BIM which facilitates the analysis of a building. However, there is a limitation to the size of the project, resulting in a limited structure size. After inserting all materials and structure components, the total environmental cost will be calculated, keeping in mind the 17 indicators. The program is developed to be user-friendly and does not have a steep learning curve like BIM. They offer training to architects to learn how to use the program in about 3.5 hours. There is also an active helpdesk helping architects and engineers to understand the program.

However, the program is still in development so naturally there are still some operating points. The EPD's were adopted in October 2020 but are still evolving. In 2021, TOTEM will switch to a newer version of the European standard (being EN15804+A2), leading to a newer version of the EPD's. Next, they try to improve the calculations by improving the approximation of the impact of energy consumption. The team is also focussing on how to implement circular elements in the tool, like reversibility of connections. The TOTEM-team will also expand the library and try to add new building parts like stairs and foundations. They aim to improve the link with BIM-software in the far future, at the moment there is a size limit of 20 Mb on IFC-files. The team is considering developing TOTEM into a BIM-plug in, leading to the loss of the server issues. The team also aims to add a benchmark in the future. However, this is still in its initial phase.

3.3 Barriers construction companies

Researchers of the VITO, WTCB and UHasselt performed a study regarding the current deficiencies and bottlenecks in the system and the biggest barriers in the construction sector regarding the adoption of the circular economy. The following list gives an overview of the results of this study.

- Lifecycle costs

  The AEC-sector is an industry where the product has a bigger lifespan than in other industries. These structures are often built to operate over a period of more than 20 years and are even designed to last over 50 years. This extensive lifespan leads to not keeping the future value of the project in mind. This means only the costs of constructing the building are taken into account. There is no consideration of the full lifecycle cost of the project. Buildings should be seen as a material bank containing resources that can be reused.

- Risk-averse
  The risk aversity is embedded in the construction sector due to the different accountabilities. The architect, the engineering company and the building contractor have a 10-year responsibility regarding the stability of the building. This accountability leads to fewer innovations and experimenting in construction.
- Limited reliance on partners
  Within the value chains, there is a limited trust between the different stakeholders. There is limited cooperation, but it seems like this trust needs to be reinitiated with every new project. there should be a contractual commitment in order to obtain a shared commitment
- Limited sense of urgency
  The general problem of construction and demolition waste is not yet publicly accepted/known. Citizens are aware of the pollution of the oceans, the water deficit but they are not yet aware of the finiteness of materials. They do start to get aware of the framework regarding energy and energy-efficiency, but the material footprint is still rather unknown.
- Scale
  Nowadays, the early adopter of the circular economy principle are companies that work in certain niches. These stakeholders come up with great ideas, but they don’t possess the scale to generate an advantage. A great number of platforms should be developed to sell deconstructed elements. There is still a need for a logistics chain to scale up these activities.

According to 'Vlaanderen Circulair', their biggest barrier is the sense of urgency. The main focus still lies on the energetic aspect of construction. Companies try to optimise their property by focussing on energy efficiency and trying to lower energy consumption. However, this is not the only part that needs focussing, there is a need to focus on material usage since you need to demolish a building at its end-of-life. This demolishing also generates a lot of CO_2. The energetic aspect of a building is already a lot to take for engineers and architects although this is not the full story of sustainability. The government policies need to raise awareness about the material impact while battling the political issues regarding this subject. 'Vlaanderen Circulair' also states that civilians don't yet realise that a building and every aspect of it has its footprint.

According to 'Vlaanderen Circulair', there should be a shift in the decision process of the building contractor at a public tender. At the moment, the most crucial factor is the price. It happens often that the main reason a project is allocated to a certain contractor is its low price. However, the entire lifecycle cost should be taken into account instead of the building cost.

3.4 BIM

'Vlaanderen Circulair' states that the implementation of BIM could facilitate the circular transition in the construction sector. They think that having a digital twin simplifies the transition due to the variety of information. Since this information is digital, everyone (who is granted access) can address the information. They state that this information, regarding what happened during its Lifecycle, is crucial to deconstruct/reuse the materials due to the long lifespan of a building. The material passport could also be integrated into the BIM-model, linking this passport to a 3D data model. This could help indicate the location and quantities of different materials.

3.5 GRO

Gro is a manual developed in 2017 to help implement sustainability into the building projects. The ambition is to develop sustainable, futureproof buildings through an integrated design process. It is a sustainability monitoring system of the Flemish Government. This manual is obligated to use when participating in public tenders and has several (material) criteria which demand the use of the TOTEM-tool. In this manner, the Flemish Government operates as an early adopter of the TOTEM tool. Since there are not yet benchmarks set in TOTEM, the building contractors need to focus on the improvement of the 4 elements which have the greatest impact on the environmental cost in TOTEM. The company then needs to optimise these 4 elements to create a more sustainable building. (Vlaamse overheid, 2020)

CHAPTER 4: DISCUSSION

In this chapter, the results of the research are discussed and the link between the three groups, Early Adopters, Laggards and Governmental Institutions, and the literature review is made. The conclusion of the previous chapters will be made in three main parts, being BIM adoption, Circular Economy and Governmental Institutions.

1 Literature implications

1.1 BIM adoption

In order to form a conclusion of the acceptance of BIM in the construction sector, an adapted form of UTAUT fitting the research was made, as can be seen in Figure 13. It is important to mention that the UTAUT framework is adapted to the findings on a company level instead of the level of an individual. Therefore, the influence of gender, age, the voluntariness of use and experience are not relevant. Based on the interviews, it was concluded that the factors influencing both the Performance Expectancy and the Effort Expectancy are the Company Size, Project Complexity and Company Type. In addition, it was found that Company Type also has an impact on Social Influence.

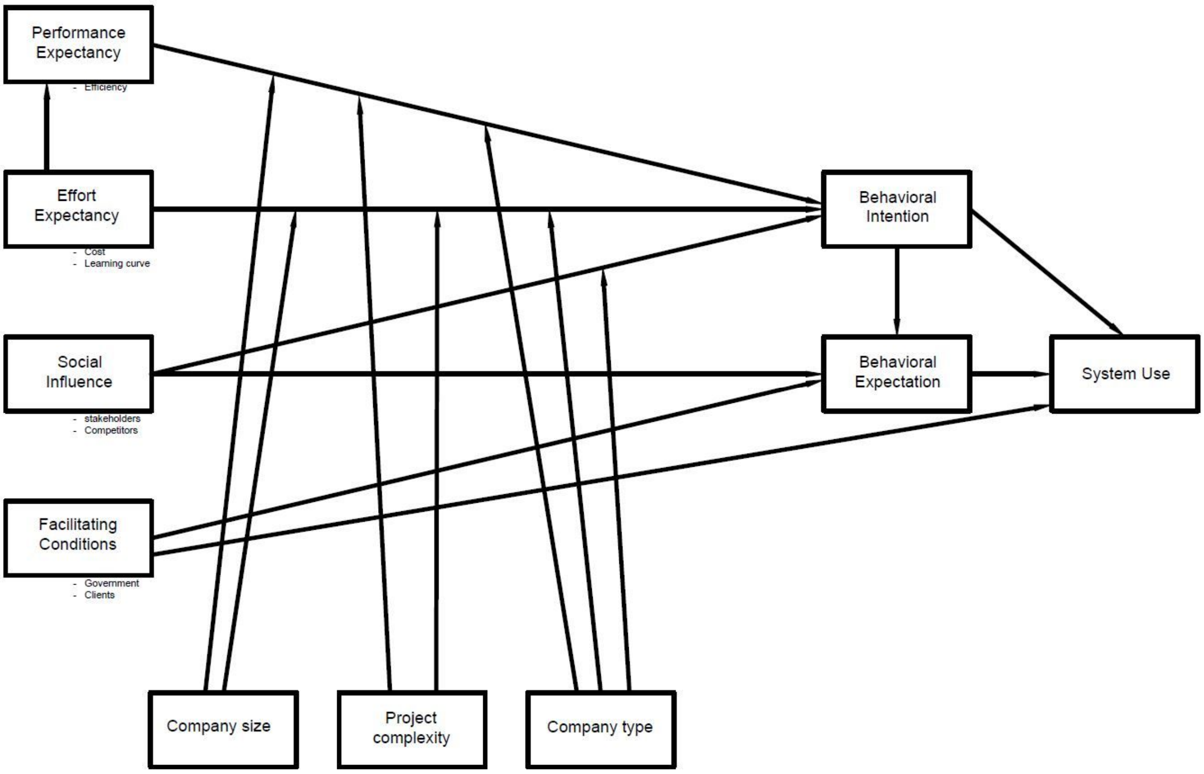


Figure 13: Adapted UTAUT-framework of BIM-adoption

In Table 13 the predictors are presented with the associated factors mentioned in the interviews.

Table 13: Predictors BIM-adoption

Predictors	Factors
Performance Expectancy	Efficiency
Effort Expectancy	Cost
	Learning-Curve
Social Influence	Stakeholders
	Competitors
Facilitating Conditions	Client
	Government

Both the Early Adopters as the Laggards stated that the use of BIM could enhance the company's efficiency, thus indicating that the use of BIM has a positive **Performance Expectancy**. However, both groups also indicated that companies who have not yet implemented BIM face a high **Effort Expectancy**. These efforts are the high cost and steep learning curve. Companies state that not only do they have to invest in expensive BIM-software packages, they also have to invest a lot of time and money in training employees. This as a result of the perceived steep learning-curve of BIM. Here, a difference can be seen between the statements of the Early Adopters and the Laggards. The Laggards state that BIM is not yet broadly implemented because the Clients do not yet request the use of BIM and are therefore not willing to pay extra for the use of BIM. However, the Early Adopters see the investment in BIM as a cost for the company itself rather than a cost attributable to the Client. As one of these companies stated, Laggards are probably less able to recognize the return on investment BIM brings, as they can't charge the Client for the use of BIM. On the contrary, the return on investment recognized by Early Adopters lies in the indirect cost savings resulting from the increase of efficiency.

It is important to look into the influence of the **company size and project complexity** on the Performance Expectancy and the Effort Expectancy. Large companies will have a larger budget and knowledge, significantly lowering the Effort Expectancy. However, they will be less flexible to changes in their infrastructure, being an advantage to lower the Effort Expectancy of smaller companies. Larger Companies often will have more projects, and will often need more internal collaboration, leading to a larger magnification of the performance gains relative to the effort. Furthermore, efficiency gains will be most significant for complex projects as mistakes can be eliminated e.g. by visualization and clash detections, leading to a positive influence of higher complexity on the Performance Expectancy.

The **Social Influencing** factors concluded from the interviews are the influence of the other stakeholders involved in the construction projects and the competitors. Both the Early Adopters as the Laggards indicated that the construction sector is very conservative and people like to "do things as they always have done it". Because of the fragmentation of the construction sector, construction projects need the involvement of a lot of different stakeholders, each specialised in their part of the chain. In order to implement the use of BIM throughout the project life-cycle, collaboration is needed. Because partners, competitors and other stakeholders do not use BIM or do not support the use of BIM for their trade, there is a lack of incentive to use BIM.

As a final predictor, the **Facilitating Conditions** identified are governmental stimulation and client request. Although both the Early Adopters as the Laggards recognized governmental stimulation and client request as important factors, this is especially the case for Laggards. One of the Laggards stated that as long as it is not requested by the client, and not mandated by the government, they will not implement BIM in their business processes.

In 2.2 Case selection of Chapter 2: methodology, the companies were listed according to the **Company Type**, being architectural companies, engineering companies and contractors. As the companies have a different role in the construction process, have a different impact during the project phases, have contact with different stakeholders, etc. the Company Type will have an influence on the Performance Expectancy, Effort Expectancy and Social influence. Here, the most important conclusion is that Contractors will experience a lot more Social Influence as they work together with more different stakeholders and are often involved in a later stage of the project, where the working method is often already determined to a certain extent. Therefore, new contract forms like Design & Build where the contractor is involved from the start of the project show a lot of potentials to enhance collaboration and increase the contractor's input.

1.2 Circular Economy

1.2.1 Enablers and Barriers

The implementation of Circular Economy principles in the construction sector is still in an early stage. From the interviews, it can be concluded that for the Early Adopters, the main reason behind the choice to implement the Circular Economy principles was a result of their mission and vision rather than the enablers listed in the literature review. In addition, both Early Adopters as Laggards stated that the customer request and governmental stimulation can be important enablers. Although both the customer request as the governmental stimulation is increasing, it is still insufficient as the Circular Economy in construction finds itself in the early stages of adoption. A difference in enablers was shown compared to the literature review, where the customer request was not listed. However, when analysing the statements covering the need for governmental stimulation, many similarities were seen with some of the key enablers listed in the literature review. Here, enablers from the literature review like the development of design tools and guidance, offering financial incentives, providing clear business cases, raising awareness, etc. are seen as a responsibility mainly from governmental institutions.

Both Early Adopters as Laggards indicated similar barriers to the circular transition, being the lack of knowledge and information, the fragmented nature of the industry, the additional cost and inaccurate value proposition, and the lack of governmental stimulation and customer request. This shows similarities with the barriers listed in the literature review.

1.2.2 BIM as Circular facilitator

From the interviews, it can be concluded that both the Early Adopters as the Laggards recognize the potential in the use of BIM to facilitate the Circular transition. In the literature review, BIM was proposed as a solution to overcome certain barriers impeding the Circular transition. Apart from BIM itself, three key-approaches to the implementation of the Circular Economy principles were presented, and the use of BIM to support these approaches were discussed. In this section, the findings of the literature study, Early Adopters and Laggards related to these approaches are compared and a conclusion is formed.

First, literature proposed **BIM** as a possible approach to eliminating the barrier of the fragmentation and the low consideration of the whole life-cycle. As the literature study showed, BIM could enhance collaboration between the partners throughout the whole life-cycle and thus eliminating mistakes, information losses, etc. However, the research showed that although both groups recognize the potential of BIM to solve these problems, the collaboration between different partners through e.g. IFC is still very difficult, and a change of the conservative mindset is needed to enable trust and transparency. In addition, the use of BIM is still mostly stopped after Design- and Construction-phase, while both groups did state that BIM could have significant advantages during the Operation and Demolition/Deconstruction phase. The main reason given is that the adoption of BIM is still in an early stage, stating that these steps will be made soon.

In the following part, the potential of Design for Deconstruction, Material Passports and BAMB as concluded from literature is compared to the results from the research. It is important to mention that although the Laggards were asked about these approaches, the conclusion from the research will restrict itself to the findings of the Early Adopters, as the Laggards did not implement, or were not familiar with these approaches.

Literature study concluded that **Design for Deconstruction** is a necessary step in the Circular transition. In the literature study, three main principles to implement DfD were discussed. Based on the interviews, it can be concluded that DfD is gaining popularity, and the Early Adopters are starting to implement some of the principles. However, the implementation mainly depends on the customer request. Another conclusion was that new contract forms like Design and Build allow contractors to have an impact on the design, wherein traditional contract forms the contractor is involved in a later stage. This allows contractors to collaborate with architects and engineers and propose methods for DfD. Finally, it was concluded that since there is still a lack of information about existing buildings and infrastructures, demolition is still common practice. Research confirms that because BIM collects data and offers a digital twin for visualisation, it could solve this problem and support DfD.

Following DfD, the production of **Material Passports** was also recognized as very useful. The companies stated that to be able to fully exploit the potential of Material Passports, a uniform framework and definition should be worked out by the government. Secondly, B Architects & Engineers stated that a manufacturer database is needed to be able to work with Material Passports. Therefore, the manufacturers play a key role in exploiting the full potential of Material Passports. It was concluded that, although the companies see Material Passports as separate from BIM, the use of BIM to create Material Passports would have great advantages. This could be done by defining a uniform framework determining the way to connect data concerning Material Passports to the BIM-model. Finally, the Dutch Madaster initiative was discussed which creates Material Passports based on uploaded IFC-models.

As the last approach, **BAMB** was discussed. Although the Early Adopters see BAMB/ Urban Mining as a necessity to realize a Circular Economy in construction, BAMB is still in an early phase and there are still many barriers impeding the implementation. BIM was acknowledged to have the potential to obtain a database of construction products available when the models could be stored in a municipal database.

1.3 Governmental Institutions

A major conclusion from the executed surveys with both the Early Adopters and the Laggards is the **need for a unified framework** and the **need for governmental stimulation**. Both groups state that "it is still groping in the dark". The government agrees, like the companies, that BIM could facilitate the circular transition and the implementation of Material Passports in BIM could be possible. As 'Vlaanderen Circulair' doesn't manage any buildings, they state not having control over the stimulation of BIM. However, the government is trying to implement TOTEM into a sustainable building. As TOTEM offers the possibility to upload IFC-files, this can lead to indirect stimulation to use BIM. In terms of the circular economy, 'Vlaanderen Circulair' is trying to raise awareness among companies. However, they note that it is also groping in the dark due to the lack of concrete information available. They aim to learn about the possibilities through workshops together with the forerunners and acknowledge that more concrete information is necessary before it can be fully implemented. Their main purpose at the moment is to unite the Early Adopters to work together, thinking of new ways to implement the circular economy model.

2 Managerial implications

2.1 Recommendations for BIM-adoption

Performance Expectancy

- Verify whether the implementation of BIM results in efficiency gains. This can be done by consulting experts and contacting software providers.

Effort Expectancy

- Take into account the high cost of software packages.
- Take into account that the implementation of BIM is a gradual process and will require a lot of time and training of employees.

Company Size

- Verify whether the use of BIM would enhance internal collaboration. Research indicates that efficiency gains increase with the need for internal collaboration.
- Verify whether the cost of software packages and training has a large impact on the company's budget.
- Verify the company's flexibility to implement BIM in the business process. Research indicates that smaller companies will have higher flexibility.

Project complexity

- Verify whether the projects are complex enough to gain efficiency. Research indicates that efficiency gains by the implementation of BIM will increase with the project complexity.

Company Type

- Verify whether BIM offers benefits for the specific discipline of the company. This can be done by market research, consulting external BIM-experts, contacting software providers, etc.

Social Influence

- Check whether competitors use BIM and how they use BIM. Avoid lacking behind when competitors are implementing BIM.
- Discuss the implementation of BIM with crucial partners and other stakeholders in construction projects. Try to avoid the need for collaboration through IFC by opting to use the same software vendor for the different BIM applications.
- Try to enable relations with partners based on trust and transparency to enhance information flows.
- Enhance collaboration by opting for new contract forms like Design and Build.

Facilitating Conditions

- Verify whether clients support or request the use of BIM on their projects.
- Try to create client awareness.
- Follow new developments of governmental institutions in relation to BIM.

Finally, research suggests that the best way to implement BIM is by starting a pilot project.

2.2 Recommendations for Circular Economy implementation

Research indicates that most companies choose to implement Circular Economy principles based on their own mission and vision. It was stated that implementing Circular Economy principles would contribute to the sustainable image of the company. In addition, a business opportunity was recognized because of the rising price of raw materials. Managerial recommendations are:

- Try to understand the Circular Economy principles by following webinars provided by governmental institutions like 'Vlaanderen Circulair' or by consulting Circular Economy experts.
- Participate in the Flemish Green Deal initiative. This initiative is a voluntary agreement between companies and the government to work together and initiate green projects.
- Start up a pilot project.
- Try to increase client awareness.
- Try to work together with stakeholders to come up with possible solutions.
- Try to use new contract forms that enhance collaboration.
- Try to implement Design for Deconstruction by considering adaptable designing, by taking evaluating component options related to the possibility of repair, recycling, re-use and disassembly.
- Try to preserve as much data as possible regarding the materials and their location and follow new developments of Material Passports.
- Try to follow new developments related to BAMB in the future.

CHAPTER 5: LIMITATIONS AND FURTHER RESEARCH

This master dissertation explored the topic of BIM and Circular Economy. However, there are some limitations to the scope of this report. This section focusses on addressing the limitations and proposes possibilities for future research. As a first limitation, it can be noted that it was chosen to interview Early Adopters and Laggards to conduct this research. It is important to mention that other groups like the Early Majority, the Innovators and the Late Majority were not included in this research. In order to fully understand the barriers and enablers of both BIM and Circular Economy, it is necessary to obtain their statements as well.

As the time range to execute this master dissertation was limited, a limited number of cases were addressed during the execution of this research. To get a broad view of the findings of different companies spread over the whole of Europe, it is necessary to obtain more data by interviewing more companies. Since the limitation of time, only a selection of people of the company was interviewed to obtain a global point of view of their company. However, the companies involved can be further examined by performing interviews with several employees and partners. It can also be of great value to follow up a project of the Early Adopters to fully understand their working method to implement the circular model.

A strong emphasis on BIM can be noted. However, it is also possible to engage in the circular economy without applying BIM. It is, therefore, necessary that research is performed regarding other methods to make the circular transition.

During this thesis, the emphasis lied on the existing stakeholders that are connected to the construction industry. However, the literature mentioned that clients have the most important role of all stakeholders. Therefore, research regarding the awareness and willingness to pay of customers could provide greater insight.

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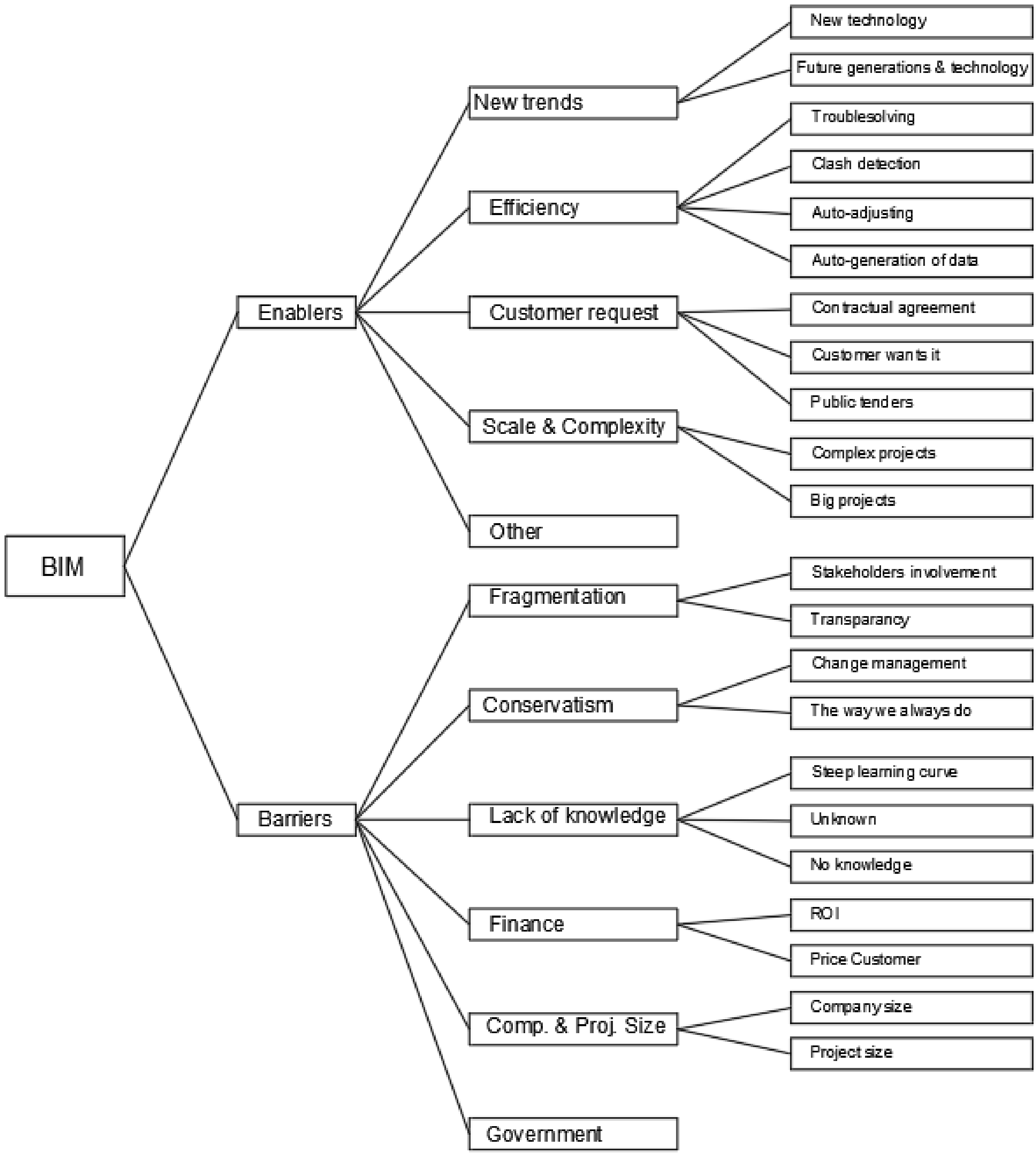
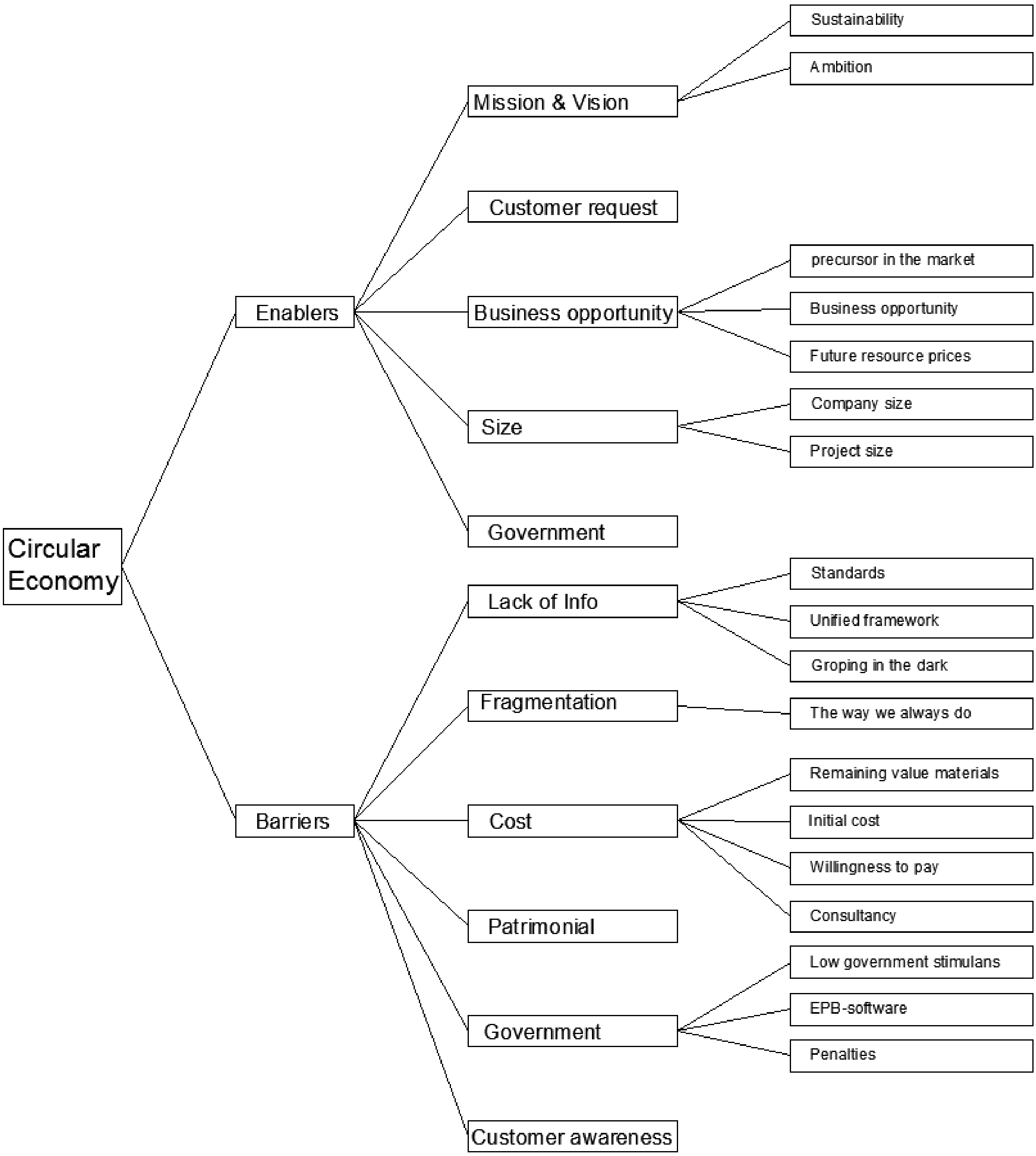
APPENDICES

1 Results Enablers and Barriers BIM



2 Results Enablers and Barriers Circular Economy



3 Questionary

3.1 Companies

1. Maakt jullie bedrijf reeds gebruik van BIM?

INDIEN BEDRIJF GEBRUIK MAAKT VAN BIM

2. Waarom kozen jullie ervoor om BIM te gebruiken?
3. Voor welke doeleinden wordt BIM momenteel ingezet?
4. In welke fases van het bouwproces wordt het BIM model gebruikt?
5. Wat zijn eventuele barrières om BIM te gebruiken voor bedrijven?
6. Bent u van mening dat BIM de transitie naar een circulaire economie mogelijk kan maken?

Indien Ja

Hoe?

- Denkt u dat BIM Design for Deconstruction kan helpen en hoe?
- Denkt u dat het gebruik van Material Passports hierbij een grote rol kan spelen? (ZIE BIJVRAGEN)
- Heeft u reeds gehoord van BAMB? (Zo ja) Ziet u dit haalbaar in de toekomst?

Zet uw bedrijf reeds in op circulaire economie?

- Redenen en barrieres

Indien Nee

Waarom denkt u dat?

Zet uw bedrijf reeds in op circulaire economie?

Denkt u dat CE haalbaar is zonder BIM en hoe?

INDIEN BEDRIJF GEBRUIK MAAKT VAN BIM

1. Wat zijn de redenen waarom het bedrijf nog geen gebruik maakt van BIM?
2. Wat zou het gebruik van BIM binnen het bedrijf eventueel kunnen aanmoedigen?
3. Bent u van mening dat BIM de transitie naar een circulaire economie mogelijk kan maken?
4. Zet uw bedrijf reeds in op circulaire economie?
   - Redenen en barrieres

5. Denkt u dat CE haalbaar is zonder BIM en hoe?

Bijvragen indien gebruik van Material Passports

1. Welke informatie moet de MP's bevatten?
2. Wat zijn de redenen die het bedrijf gestimuleerd hebben om MP's te gebruiken?
3. Wat zijn eventuele de barrieres die bedrijven hinderen om MP's te gebruiken?
4. Is BIM noodzakelijk om met het systeem van MP's te kunnen werken of kan het het gebruik vergemakkelijken? Waarom wel/niet?

3.2 Government instances

- Vlaanderen Circulair en OVAM

1. Wat is Vlaanderen Circulair?
2. Wat doet OVAM?
3. Wat houdt de Green Deal circulair bouwen in?
4. Wat is Open Call en zijn doel?

BIM

1. Wordt er bij overheidsprojecten reeds gebruik gemaakt van BIM?
2. Denkt u dat de overheid een belangrijke rol speelt in de stimulatie van het BIM-gebruik voor bedrijven?

Hoe stimuleert de overheid bedrijven om in te zetten op circulaire economie?

1. Wat is het beleid in Vlaanderen omtrent circulair economie?
2. Wat is TOTEM en zijn doel?
3. Wat zijn de barrières die volgens u bedrijven ondervinden bij het maken van deze transitie en hoe pakt de overheid deze aan?

Bent u van mening dat BIM de transitie naar een circulaire economie mogelijk kan maken?

INDIEN WEL

1. Denkt u dat BIM Design for Deconstruction kan helpen en hoe?
2. Denkt u dat het gebruik van Material Passports hierbij een grote rol kan spelen? (Zie bijvragen)
3. Zet de overheid reeds in op het stimuleren van BAMB/Urban Mining? Is dit iets die nu al haalbaar is of is dit nog toekomstmuziek?
4. Merkt u dat BIM ook reeds gebruikt wordt voor facility management en afbraak van gebouwen?

INDIEN NIET

1. Waarom denkt u dat?
2. Zet de overheid reeds in op het stimuleren van BAMB/Urban Mining? Is dit iets die nu al haalbaar is of is dit nog toekomstmuziek?

Bijvragen Material Passports

1. Welke informatie moet de MP’s bevatten?
2. Hoe stimuleert u bedrijven om MP’s te gebruiken?
3. Wat zijn volgens u eventuele de barrières die bedrijven hinderen om MP te gebruiken?
4. Is BIM noodzakelijk om met het systeem van MP’s te kunnen werken? Waarom wel/niet?
5. In welke mate kan het gebruik van MP de transitie naar een circulaire economie faciliteren?
6. Wordt het gebruik van Madaster ook hier in België gestimuleerd?